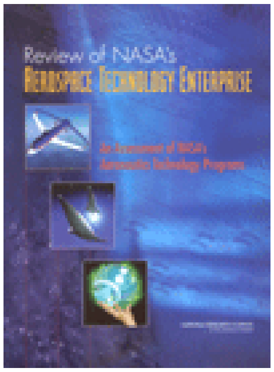

Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Aeronautics Technology Programs

Committee for the Review of NASA's Revolutionize Aviation Program, National Research Council

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Review of NASA's
AEROSPACE TECHNOLOGY ENTERPRISE

An Assessment of NASA's Aeronautics Technology Programs

Committee for the Review of NASA's
Revolutionize Aviation Program

Aeronautics and Space Engineering Board

Division on Engineering and Physical Sciences

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Preface

The National Research Council (NRC) of the National Academies was asked by NASA and the Office of Management and Budget to perform an assessment of NASA's Aerospace Technology Enterprise. The first such review, which began in early 2002, examined Pioneering Revolutionary Technology (now known as Mission and Science Measurement Technology). The assessment presented here, of the Aeronautics Technology Programs, began in early 2003 and is the second in the review series.

NASA's Aeronautics Technology Programs has five primary objectives:

1. Protect air travelers and the public.
2. Protect the environment.
3. Increase mobility.
4. Support national security.
5. Explore new aerospace missions.

The Aeronautics Technology Programs has three components: the Vehicle Systems Program, the Airspace Systems Program, and the Aviation Safety Program. To conduct this review, the NRC established three panels, one for each of the component programs. The NRC also established a parent committee, consisting of the chairman and a subset of members from each panel. The committee and panels comprised a cross-section of experts from industry, academia, and government and included senior-level managers and researchers in the aeronautics field. Biographical information on the committee and panel members is found in Appendix A.

The committee and panels were tasked to conduct a detailed, independent review of the technical quality of the work conducted in the Aeronautics Technology Programs. The detailed statement of task is given in Appendix B. In addition, in a meeting with the chairs of the study, the then Associate Administrator for NASA's Aerospace Technology Enterprise, Jeremiah Creedon, asked the committee to answer the following four questions:

1. Is the array of activities about right?
2. Is there a good plan to carry out the program?
3. Is the program doing what it set out to do?
4. Is the entire effort connected to the users?

The committee and panels agreed to use these four questions as the framework for conducting the review and writing the final report. These questions are addressed in this report at the program, project, subproject, and task level for the constituent programs—the Vehicle Systems Program, the Airspace Systems Program, and the Aviation Safety Program.

The NRC also asked the principal investigator of each task within the Aeronautics Technology Programs to complete a questionnaire on the task goals, progress, funding, and outcomes. The questionnaires were distributed to the panel members before the first meetings. Each panel met separately in Washington, D.C., during February and March 2003 to obtain overviews of the NASA programs. The panel members spent March, April, and May 2003 gathering additional information through site visits to the relevant NASA facilities, e-mail exchanges with personnel, and teleconferences. The panels then convened in April or May to share information obtained during the site visits, to achieve consensus on findings and recommendations, and to meet again with NASA personnel to obtain additional program information. Each panel was composed of many of the top experts in their fields. They produced a working report and submitted it to the parent committee. The committee met in July 2003 to evaluate the panel reports, develop a set of top-level, programwide observations, and arrive at consensus on final findings and recommendations. The panels and the committee based their evaluations on information provided by NASA and on the committee and panel members' expertise, experience, and knowledge of the technologies and comparable work performed around the world in specific disciplines. A detailed schedule of committee and panel activities is given in Appendix C.

This report contains the committee's assessment of the Aeronautics Technology Programs. Chapter 1 presents a top-level assessment, and Chapters 2 through 4 provide the assessments of the Vehicle Systems Program, the Airspace Systems Program, and the Aviation Safety Program, respectively.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Norman Abramson (NAE), Southwest Research Institute, retired,
Meyer Benzakein (NAE), GE Aircraft Engines,
Susan Coughlin, Aviation Safety Alliance,
Earl Dowell (NAE), Duke University,
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Dennis Muilenburg, The Boeing Company,
Richard Petersen, NASA, retired,
Robert Ravera, RJR Aviation, LLC, and
John Sullivan, Purdue University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Louis Lanzerotti, Lucent Technologies. Appointed by the NRC's Report Review Committee, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Executive Summary

The National Research Council (NRC) of the National Academies was asked by NASA and the Office of Management and Budget to perform a detailed, independent assessment of NASA's Aeronautics Technology Programs. To conduct this review, the NRC established three panels, one for each of the component programs within the Aeronautics Technology Programs. The NRC also established a parent committee consisting of the chairman and a subset of members from each panel. The committee and panels began their activities in early 2003.

The NRC committee and its three subordinate panels conducted an independent peer assessment of the Vehicle Systems Program (VSP), the Airspace Systems Program (ASP), and the Aviation Safety Program (AvSP), the three elements of NASA's Aeronautics Technology Programs. NASA specifically asked the committee and panels to address four questions:

1. Is the array of activities about right?
2. Is there a good plan to carry out the program?
3. Is the program doing what it set out to do?
4. Is the entire effort connected to the users?

The committee developed findings and recommendations at three different levels. At the top level, it created a list of 12 key crosscutting recommendations for the overall Aeronautics Technology Programs on issues that span the entire set of programs. These recommendations are appropriate for guiding Congress, NASA Headquarters, and the White House in prioritizing NASA's aeronautics research and development programs. At the second level of detail, the committee provided program-level recommendations appropriate for the NASA Research Centers' program and project managers. Finally, the committee developed findings and recommendations at the task level that are designed to assist the individual principal investigators in improving the quality of their research. These third-level recommendations are numerous and detailed and are not included in the Executive Summary.

OVERALL ASSESSMENT

The committee's simple answer to the four questions posed by NASA is that, in general, the Aeronautics Technology Programs are very good but could be greatly improved by following the committee's 12 top-level recommendations. The array of research activities is about right, although a few additions and deletions are recommended in various areas. There are good plans to carry out the programs and they are accomplishing much of what they were established to do, but some changes in the plans for execution could improve results significantly. In addition, the programs are reasonably well connected to the users, but here again the committee recommends some improvements. These issues—scope, planning, achievement, and ties to users—are addressed more completely in the specific recommendations themselves:

Top-Level Recommendation 1. The government should continue to support air transportation, which is vital to the U.S. economy and the well-being of its citizens.

Top-Level Recommendation 2. NASA should provide world leadership in aeronautics research and development.

Top-Level Recommendation 3. NASA has many excellent technical personnel and facilities to achieve its aeronautics technology objectives but should improve its processes for program management.

Top-Level Recommendation 4. NASA should eliminate arbitrary time constraints on program completion and schedule key milestones based on task complexity and technology maturity.

Top-Level Recommendation 5. NASA should reduce the number of tasks in its aeronautics technology portfolio.

Top-Level Recommendation 6. NASA should pursue more high-risk, high-payoff technologies.

Top-Level Recommendation 7. NASA should reconstitute a long-term base research program, separate from the other aeronautics technology programs and projects.

Top-Level Recommendation 8. NASA's aeronautics technology infrastructure exceeds its current needs, and the agency should continue to dispose of underutilized assets and facilities.

Top-Level Recommendation 9. NASA should implement full-cost accounting in a way that avoids unintended consequences harmful to the long-term health of the aeronautics program.

Top-Level Recommendation 10. NASA should develop a common understanding with the Federal Aviation Administration (FAA) of their respective roles and relationship.

Top-Level Recommendation 11. NASA should seek better feedback from senior management in industry and other government organizations.

Top-Level Recommendation 12. NASA should conduct research in selective areas relevant to rotorcraft.

ASSESSMENT OF THE VEHICLE SYSTEMS PROGRAM

The Vehicle Systems Program contains seven projects:

- *Breakthrough Vehicle Technologies*. Develops high-risk, high-payoff technologies to dramatically and substantially improve vehicle efficiency and emissions.
- *Quiet Aircraft Technology*. Discovers, develops, and verifies, in the laboratory, technologies that improve quality of life by reducing society's exposure to aircraft noise.
- *Twenty-first Century Aircraft Technology Project*. Develops and validates, through ground-based experiments, the aerodynamic, structural, and electric power technologies that will reduce by 20 percent the fuel burn and carbon dioxide emissions from future subsonic transport aircraft.
- *Advanced Vehicle Concepts*. Develops advanced vehicle concepts and configurations to reduce travel time, expand commerce, and open new markets.
- *Flight Research*. Tests and validates technologies and tools developed by NASA in a realistic flight environment.
- *Ultra-Efficient Engine Technology*. Identifies, develops, and validates high-payoff turbine engine technologies that would reduce emissions.
- *Propulsion and Power*. Researches revolutionary turbine engine technologies, propulsion concepts, and fundamental propulsion and power technologies that would decrease emissions and increase mobility.

The committee noted that VSP has a clear mission statement with a set of fully linked goals and products, but it believes that NASA needs a better understanding of the core competencies required to meet these goals. The committee also believes that the current investment strategy of VSP appears to be ad hoc, with too many unprioritized projects and tasks and no apparent methodology to determine which areas will provide the greatest benefit. The committee recommends that NASA identify and prioritize technologies with respect to their potential benefit to aviation.

The committee was concerned that the recent transition to full-cost accounting will have an unintended effect on certain facilities and infrastructure that are national assets and will compromise the research program by reducing the number of full-scale tests for concept validation.

The committee was also concerned that NASA does not always get the benefit of industry involvement at the appropriate management level and suggests that NASA reexamine the composition of its advisory groups.

The committee evaluated a total of 172 tasks in the VSP portfolio. The committee determined that more than 80 percent were of good quality or better, with 30 percent (51 tasks) rated as world-class. The committee identified 91 tasks that were good quality, 6 that were marginal, and 24 that were poor and should be redirected.

ASSESSMENT OF THE AIRSPACE SYSTEMS PROGRAM

The ASP is organized into four projects:

- *Advanced Air Transportation Technologies.* Develops air traffic management tools to improve the capacity of transport aircraft operations at and between major airports.
- *Small Aircraft Transportation System.* Develops and demonstrates technologies to improve public mobility through increased use of local and regional airports.
- *Virtual Airspace Modeling and Simulation.* Develops models and simulations to conduct trade-off analyses of concepts and technologies for future air transportation systems.
- *Airspace Operations Systems.* Develops better understanding, models, and tools to enhance the efficient and safe operation of aviation systems by human operators.

The committee was concerned that NASA's ASP research was generally too focused on short-term, incremental payoff work. NASA should plan ASP research based on a top-down understanding of the air transportation system. Research should focus on areas of greatest payoff—that is, areas that relieve choke points and other constraints to a more efficient air transportation system.

The committee noted that many existing airspace research tasks will not be completed before the expiration of the projects under which they are currently funded. NASA is establishing a new project, NASA Exploratory Technologies for the National Airspace System (NAS)—NExTNAS—to continue some ongoing research tasks and start some new tasks. The committee recommends that NASA incorporate many ongoing tasks in the NExTNAS project so they can be completed.

The committee determined that the ASP also should support basic research relevant to long-term objectives and other research with a farsighted vision. More specifically, the committee observed that the portfolio was primarily directed at improving ground-based air traffic management. The committee recommends that NASA continue distributed air-ground research for autonomous separation, with increased effort on the airborne side.

The committee developed a series of findings and recommendations regarding the FAA-NASA relationship. First, the committee noted that two different tools, Research Management Plans and Research Transition Plans, were being used to facilitate the transition of technology from NASA to the FAA.[1] The committee believes that there are worthwhile elements in the Research Transition Plans that could be included in Research Management Plans. In addition, NASA and FAA program directors should vigorously adhere to the Research Management Plan process, with reviews and updates at regular intervals. If either agency determines that the research results will not be implemented, the Research Management Plans should be cancelled and NASA should formally reassess the merits of continuing to develop a product that will not improve the operation of the NAS.

The committee also had recommendations about how NASA should measure the success of its research. Currently, it tends to view success in terms of the ability to mature technology and get the FAA to implement it for operational use. Some FAA users, however, believe this view of success leads NASA to focus too

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[1] The FAA's Free Flight Phase II Office uses Research Transition Plans, which are similar to the Research Management Plans used by other FAA offices.

much on implementation issues, which NASA may not be qualified to address given its limited operational experience. The committee recommends that NASA and the FAA develop a common definition of what constitutes the successful completion of an applied ASP research task. Success of NASA applied research tasks should not be defined solely in terms of implementation.

ASSESSMENT OF THE AVIATION SAFETY PROGRAM

The AvSP consists of three projects:

- *Vehicle Safety Technology*. Strengthens aircraft to mitigate vehicle system and component failures, loss of control, loss of situational awareness, and postcrash or in-flight fires.
- *Weather Safety Technology*. Researches and develops technologies to reduce the frequency and severity of weather-related accidents and injuries.
- *System Safety Technology*. Reduces the frequency and severity of aviation accidents and incidents by proactively managing risk in a systemwide approach.

The committee found several examples of work of outstanding quality in AvSP, notably the Aircraft Icing subproject (Weather Safety), the Crew Training task (System Safety), the structures health management subtask (Vehicle Safety), the mode confusion subtask (Vehicle Safety), and scale-model development and testing work (Vehicle Safety).

The committee was concerned about recent changes it observed in the quality of the human factors research in AvSP, partly because the number of in-house human factors personnel was decreasing and those who remained were primarily managing the work of contractors. In addition, the committee noted that human factors work did not appear to be well-integrated across the program. The committee recommends that AvSP strengthen in-house human factors research with federal employees who have outstanding human factors expertise. In addition, NASA should consider human factors requirements early in the design phase of all aeronautics technology research projects.

The committee believes AvSP health would be improved if 5-year lifetimes were not imposed on every project. Instead, a project should endure for the natural lifetime of the research activity, which would allow basic research efforts to extend beyond 5 years. In addition, the committee found the AvSP research portfolio to be too product-oriented and recommended that it include more basic research.

The committee also found that NASA's existing management structure obscures the lines of responsibility and accountability within the program, to the point that it is difficult to trace project, subproject, and task goals to the vision and goals of the program as a whole. The committee recommends that AvSP develop a hierarchy of goals and improve its management processes to create clearer accountability.

The committee believes that several products under development in AvSP duplicate similar products being developed in industry. The committee recommends that AvSP improve its user connections and benchmark its products against similar work performed elsewhere. NASA should not be working in a specific technical area unless it is leading the field. An outside advisory committee structure of some sort could assist AvSP in determining which technical areas it should address.

Finally, the committee noted a large gap in the program portfolio in the area of rotorcraft. NASA could significantly contribute to improving rotorcraft safety without substantial additional investment, particularly in the areas of decision aids, synthetic vision, pilot training, workload reduction, and situational awareness.

1

Top-Level Assessment

The committee developed 12 recommendations that pertain to all three Aeronautics Technology Programs. These recommendations are presented in this chapter as the top-level assessment. Specific findings that led to these recommendations are presented as part of the detailed descriptions of the three programs in Chapters 2, 3, and 4 of this report.

Top-Level Recommendation 1. The government should continue to support air transportation, which is vital to the U.S. economy and the well-being of its citizens.

A strong national program of aeronautics research and technology directly contributes to the vitality of the U.S. aeronautics industry, the efficiency of the U.S. air transportation system, and the economic well-being and quality of life of people in the United States. The government has an important role in assuring the best possible air transportation system and the development of related technologies that enable products and services to compete effectively in the global marketplace. This is consistent with the legislative charter for NASA, the National Aeronautics and Space Act of 1958, as amended. The Act specifies that NASA's aeronautics research and technology development should "contribute to a national technology base that will enhance United States preeminence in civil and aeronautical aviation and improve the safety and efficiency of the United States air transportation system."

Top-Level Recommendation 2. NASA should provide world leadership in aeronautics research and development.

To provide leadership, NASA should develop consistent strategic and long-range plans that focus the aeronautics program in areas of national importance. NASA should have well-formulated, measurable, attainable goals at all program levels. To be meaningful, the goals should be based on a sound evaluation of future needs, of technological feasibility, and of relevant economic and other nontechnical factors.[1]

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[1] Another recent NRC report, *Securing the Future of U.S. Air Transportation: A System in Peril*, addresses in more detail the need for strong interagency leadership in overcoming future technical and nontechnical challenges to the success of the U.S. air transportation system. That report also identifies specific long-term research needs related to modeling and simulation and the performance of aircraft and the air transportation system. (National Research Council. 2003. Securing the Future of U.S. Air Transportation: A System in Peril. Washington, D.C.: The National Academies Press. Available online at <www.nap.edu/catalog/10815.html>.)

Top-Level Recommendation 3. NASA has many excellent technical personnel and facilities to achieve its aeronautics technology objectives, but NASA should improve its processes for program management.

Many NASA facilities are world-class national assets. In addition, the committee was impressed with the technical expertise of many program personnel. To maximize these assets, NASA needs to improve its program management and systems integration processes, including integration across programs. NASA should also assure clear lines of responsibility and accountability. The use of matrix and line management reporting structures sometimes obscures lines of accountability, and subproject and task-level plans, funding, goals, metrics, staffing, and responsibility are often difficult to define or cannot be clearly traced back to a plan or vision for the program as a whole. Further, NASA should use independent quality assurance processes for program evaluation, and all projects should be evaluated regularly to determine whether continued investment is warranted.

Top-Level Recommendation 4. NASA should eliminate arbitrary time constraints on program completion and schedule key milestones based on task complexity and technology maturity.

Research priorities, funding, and organizational structure change during the course of any research and development effort. However, NASA should resist constant changes and realignments designed to meet artificial 5-year sunset requirements. Several long-term research efforts have been disguised as a series of 5-year projects with different names so that it is not easy to trace the real progress of the research. In addition, the continuous reorganization and restructuring that occur in response to the 5-year sunset rule create an unstable atmosphere that does not permit NASA researchers to pursue the best path to technology maturation. NASA programs need clear exit criteria at the task level that specify when research is complete or ready for transition to industry or other agencies.

Top-Level Recommendation 5. NASA should reduce the number of tasks in its aeronautics technology portfolio.

NASA is trying to do too much within the available budget and resists eliminating programs in the face of budget reductions. Often there are too many tasks to achieve research objectives in key areas. This overload may be partly the result of including various basic research tasks within more focused efforts. The committee is concerned that breadth of activities is coming at the expense of depth.

Top-Level Recommendation 6. NASA should pursue more high-risk, high-payoff technologies.

Many innovative concepts that are critical to meeting aviation needs in the next decades will not be pursued by industry or the Federal Aviation Administration (FAA). NASA should fill this void. The committee applauds the inclusion of high-risk, revolutionary subprojects in many areas and believes the program portfolio could benefit from additional far-reaching efforts with the potential for high payoff. This type of research is critical to investigating the feasibility of innovative concepts and reducing risk to the point where the concepts are suitable for advanced development and transfer to industry or the FAA.

Top-Level Recommendation 7. NASA should reconstitute a long-term base research program separate from the other aeronautics technology programs and projects.

The current research is mostly product-driven, with not enough fundamental work. Fundamental research is crucial for the development of future products. NASA needs to provide researchers the opportunity to conduct forward-looking, basic research that is unencumbered by short-term, highly specified goals and milestones. Historically, NASA has been a world leader in its core research areas; however, that base has eroded in recent years as the amount of in-house basic research diminishes. NASA needs to reassess its core competencies and assure their support through a base research program.

Top-Level Recommendation 8. NASA's aeronautics technology infrastructure exceeds its current needs, and the agency should continue to dispose of underutilized assets and facilities.

NASA test facilities incur large fixed costs. Some of these facilities are not unique, and long-term fixed costs could be reduced through consolidation and deactivation. This should be an ongoing effort as the needs of the industry change and as validated computational tools reduce or eliminate the need for some experimental facilities.

Top-Level Recommendation 9. NASA should implement full-cost accounting in a way that avoids unintended consequences harmful to the long-term health of the aeronautics program.

NASA is in the process of transitioning from a net accounting system to a system that uses full-cost accounting. Under the former scheme, researchers managed only costs directly related to research and development. In full-cost accounting, all project costs are included in the project budget, including institutional infrastructure costs such as research operations support; direct procurement; direct civil service workforce, benefits, and travel; service pools; center general and administrative; and corporate general and administrative. The committee is concerned that, if not carefully managed, full-cost accounting could result in (1) the closure of critical infrastructure and special-purpose facilities that will be needed for future program execution and (2) a disincentive to use large-scale facilities and flight tests to fully demonstrate technology readiness. This can easily occur if the responsibility for preserving institutional capabilities is delegated to lower level project managers. These project managers will also tend to avoid full-scale flight tests or wind tunnel tests in order to conserve their project budgets, since under full-cost accounting much of the cost of the testing infrastructure will be billed directly to their projects if they perform such tests. The testing infrastructure will be underutilized and will not generate the resources needed to sustain it. The committee recommends that basic research costs should be carried as a line item and not hidden in larger projects and that large infrastructure costs, such as wind tunnels and full-scale flight testing, should be attributed to the total program and accounted for accordingly.

Top-Level Recommendation 10. NASA should develop a common understanding with the FAA of their respective roles and relationship.

NASA's airspace research ultimately benefits many government, industry, and private organizations with an interest in aviation, including the Department of Defense (DoD), airlines, manufacturers, system operators (air traffic controllers, managers, flight dispatchers, and pilots), and the flying public. Practically speaking, however, the most important customers are the senior managers at the FAA who decide whether they will take applied research products from NASA and continue their development to the point of incorporating them in operational systems. Although much of NASA's airspace research is applicable to systems acquired and operated by DoD, other government agencies, and industry, most of it is intended for application to civil aviation systems acquired, operated, and/or certified by the FAA. In this sense, customers also include the many other organizations and officials who influence decisions by the government and industry regarding the advanced development of new systems for civil application.

NASA and the FAA often collaborate at the technical level, but there is a real need for more effective management coordination**.** The need for continued improvement in NASA's interactions with its customers is indicated, in part, by the committee's observation that NASA managers seem to perceive interactions with the FAA as more effective than do FAA managers. NASA officials need to recognize that implementation decisions rest with FAA management (for systems to be implemented by the FAA), and advocacy by NASA, when it runs counter to FAA implementation plans, is not helpful. Problems in this area are exacerbated by (1) the view of many at NASA that the success of applied research is measured only in terms of the extent to which customers incorporate NASA technology in their operational systems and (2) competition that may arise between NASA and other organizations that conduct research on behalf of the FAA or other key customers. As a particular NASA research effort approaches the point where the value of continued development is contingent on operational implementation, the prospective user may decide that implementation is not feasible. NASA should then be willing to close out the project that has no future and use the resources to support other research.

Top-Level Recommendation 11. NASA should seek better feedback from senior management in industry and other government organizations.

NASA's customers include aircraft manufacturers, operators, airlines, and the FAA. NASA already involves customers in almost all of its research—for example, in the form of joint efforts with the FAA to take research products into the field for testing. Some projects, such as Small Aircraft Transportation Systems (SATS), also sponsor wide-ranging outreach efforts. Usually, however, customer involvement earlier in the process would be beneficial. Early involvement would (1) ensure that researchers understand and are able to respond to user requirements and concerns as early as possible and (2) probably increase customer buy-in. Customers need not and should not be given veto authority over NASA research, but researchers should be aware of—and research plans should account for—objections or concerns that customers raise. This is especially important for research intended to provide operationally useful products capable of meeting specific functional requirements, but early consultations with users would also be beneficial in a base research program. NASA should improve its relationships with the FAA and other customers by involving them from the early stages of the research and development process through field implementation. One method for improving interaction would be for NASA to convene a yearly meeting, co-chaired by the FAA and NASA Administrators, with participation by industry executives at the chief operating officer level and senior managers from other federal agencies (e.g., Department of Transportation, Department of Homeland Security, and DoD). Topics should be limited to near-term issues and implementation plans, and such a meeting should not be held unless the NASA and FAA Administrators and industry chief operating officers will commit to personally attending the meeting.

Top-Level Recommendation 12. NASA should conduct research in selective areas relevant to rotorcraft.

Rotorcraft are an important constituency of air transportation. Many of the research projects currently under way in the Aeronautics Technology Programs, such as synthetic vision and human factors, would be directly relevant to rotorcraft with only minimal additional investment. NASA could make a significant impact in underresearched areas of rotorcraft such as decision aids, synthetic vision, pilot workload, and situational awareness. Further, the existing U.S. Army programs in rotorcraft technologies and industry research and development in rotorcraft could be leveraged by NASA to meet civilian needs in this area. The committee believes that research in civil applications of rotorcraft will not be conducted elsewhere in government or industry and that NASA's decision to discontinue rotorcraft research has left critical civilian needs unaddressed. Therefore, NASA should consider potential applications to rotorcraft in its research programs in general aviation and transport aircraft.

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The first two top-level recommendations reiterate the importance of air transportation and of NASA's role in the research and development process. Top-Level Recommendations 3-7 suggest ways the content and/or structure of the programs could be improved. Top-Level Recommendations 8 and 9 identify near-term, important concerns. The final three top-level recommendations address the relationships between NASA and its customers. The committee believes that NASA can improve and strengthen its Aeronautics Technology Programs by following this advice.

2

Assessment of the Vehicle Systems Program

BACKGROUND

Program Information

The Vehicle Systems Program (VSP) is divided into seven projects that contain 172 tasks. Table 2-1 lists the VSP budget for FY03 and FY04. The values are listed in full-cost accounting, where the cost of civil servant salaries and all support infrastructure is included in the budgets of individual projects, as discussed below. Figure 2-1 shows a program organization chart for the VSP.

The VSP contains seven projects:

- *Breakthrough Vehicle Technologies.* Develops high-risk, high-payoff technologies that will dramatically and substantially improve vehicle efficiency and emissions.
- *Quiet Aircraft Technology.* Discovers, develops, and verifies, in the laboratory, technologies that improve the quality of life by reducing society's exposure to aircraft noise.
- *Twenty-first Century Aircraft Technology.* Develops and validates, through ground-

TABLE 2-1 Net Budget for the Vehicle Systems Program

	Budget (million $)	
NASA No. and Project Name	FY03	FY04
Vehicle Systems	604.6	573.5
1.0 Breakthrough Vehicle Technologies	124.2	115.3
2.0 Quiet Aircraft Technology	41.4	60.2
3.0 Twenty-first Century Aircraft Technology	46.0	42.0
4.0 Advanced Vehicle Concepts	72.5	41.0
5.0 Flight Research	91.4	85.4
6.0 Ultra-Efficient Engine Technology	87.8	90.0
7.0 Propulsion and Power	141.3	139.6

SOURCE: Information provided by R. Wlezien, VSP Project Manager, NASA Headquarters.

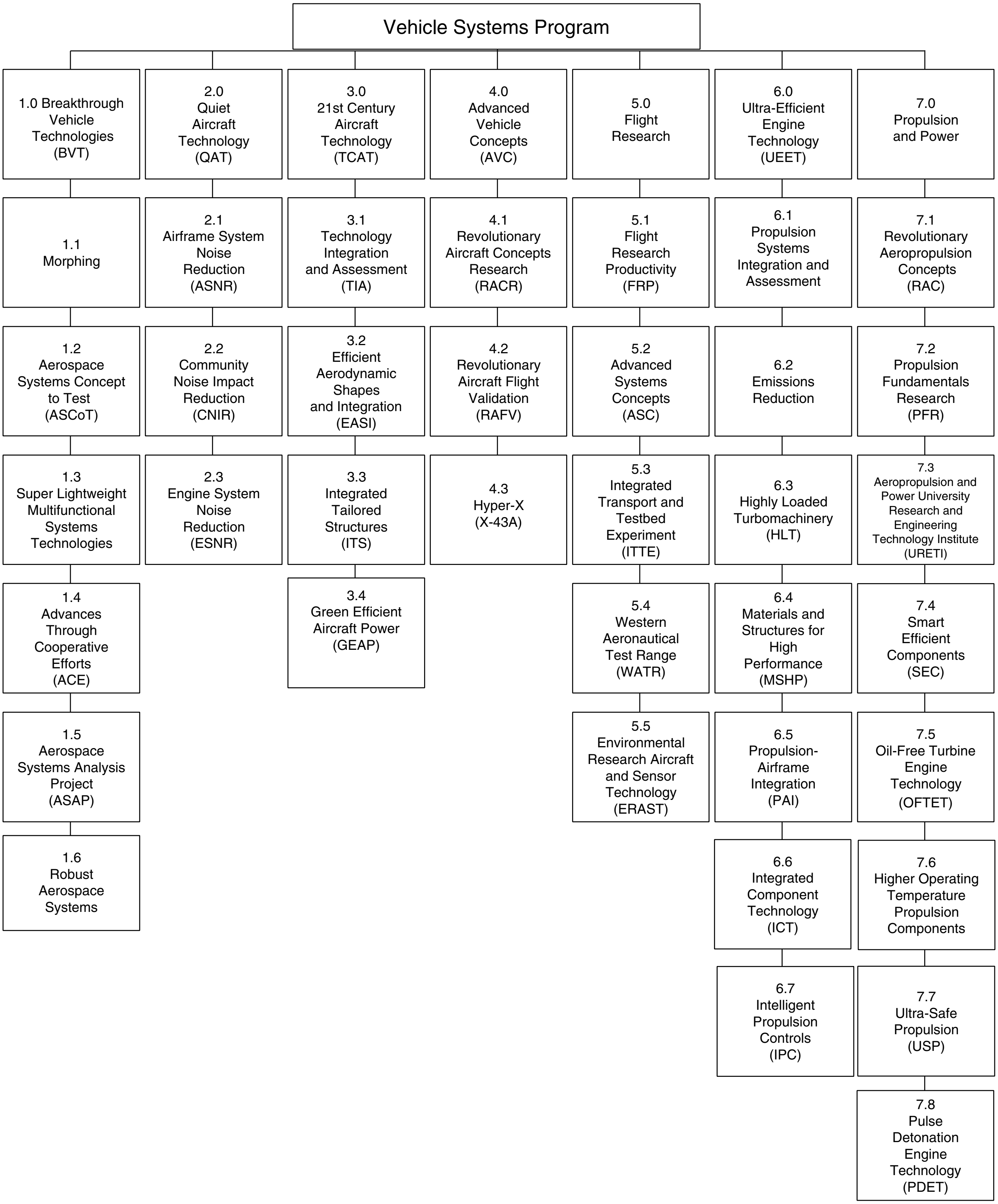

FIGURE 2-1 Vehicle Systems Program organization chart showing VSP projects and subprojects as of March 2003. At the completion of the study, major reorganizations by product family (commercial, unmanned air vehicles, etc.) were under way but had not been finalized.

based experiments, the aerodynamic, structural, and electric power technologies that will reduce by 20 percent the fuel burn and carbon dioxide emissions from future subsonic transport aircraft.

- *Advanced Vehicle Concepts*. Develops advanced vehicle concepts and configurations to reduce travel time, expand commerce, and open new markets.
- *Flight Research*. Focuses primarily on testing and validating, in a realistic flight environment, technologies and tools developed by NASA.
- *Ultra-Efficient Engine Technology*. Focuses on identifying, developing, and validating high-payoff turbine engine technologies to reduce emissions.
- *Propulsion and Power*. Researches revolutionary turbine engine technologies, propulsion concepts, and fundamental propulsion and power technologies to decrease emissions and increase mobility.

Review Process

The panel on the Vehicle Systems Program conducted a series of reviews over a 3-month period to assess the quality and relevancy of the research and technology development efforts being conducted across NASA's VSP. The panel surveyed 172 tasks organized within the seven projects and 36 subprojects that made up the VSP at the start of this review. As NASA already had efforts under way to reorganize the VSP before the start of this review, the program and supporting task structure in place at that time was used as the baseline for all evaluations in this report.

To help focus the VSP panel's review, the broad guidelines contained in the statement of task in Appendix B were reformulated into a set of concise questions:

- Is NASA conducting research and development in appropriate areas that are clearly aligned with its vision and mission?
- Are there projects that should be discontinued because they have completed their work or are not performing well?
- Is the mix of research about right?
- Is the balance of near-term and far-term technology development tasks about right?
- Does the program have a balanced portfolio of near-term and far-term projects, along with fundamental and more mature research and development?
- Does NASA have a good research plan that sets forth specific goals, identifies the right people/skill sets, and specifies an appropriate level of funding to achieve the goals as outlined?
- Is the work done poorly or well? Is it world-class?
- Is the research making good progress?
- Is NASA successfully transitioning the technologies being developed to the user community and the technical community at large?

Prior to the first meeting of the VSP panel, the NRC asked each principal investigator at NASA to complete a short questionnaire with 12 questions about the research and development goals, products, roadblocks, user connectivity, and technical outcomes of their work. A blank questionnaire is shown in Appendix D. The completed questionnaires were distributed to the VSP panel. Reviewing the questionnaires allowed panel members to become familiar with the program and individual projects. The questionnaire proved to be a valuable tool for the panel's use in assessing the program. It allowed each panel member to assign an initial ranking of the perceived quality of each project and task.

At the first meeting of the VSP panel on March 17-19, 2003, in Washington, D.C., VSP managers gave technical briefings on the overall program to the 16-member panel. Technical briefings were also given for the specific projects and the individual tasks in the VSP. The panel updated the initial ratings of all projects and tasks at the meeting using a weighted evaluation matrix. They then agreed on the assessments. The review process is shown in Figure 2-2.

After the first meeting, panel members and a consultant participated in site visits to each of the relevant NASA facilities (Langley Research Center, Glenn Research Center, and Dryden Flight Research Center). The purpose of these visits was to clarify the goals, methods, and performance of specific projects and tasks; to speak directly with the principal investigators of some of the projects; and to inspect the products, facilities, and operations in the program firsthand.

Because of the large number of VSP tasks, the panel prioritized how to spend its time investigating the different projects. The panel used its initial assessment of the responses to the task questionnaires and the briefings received at the March 2003 meeting as its start-

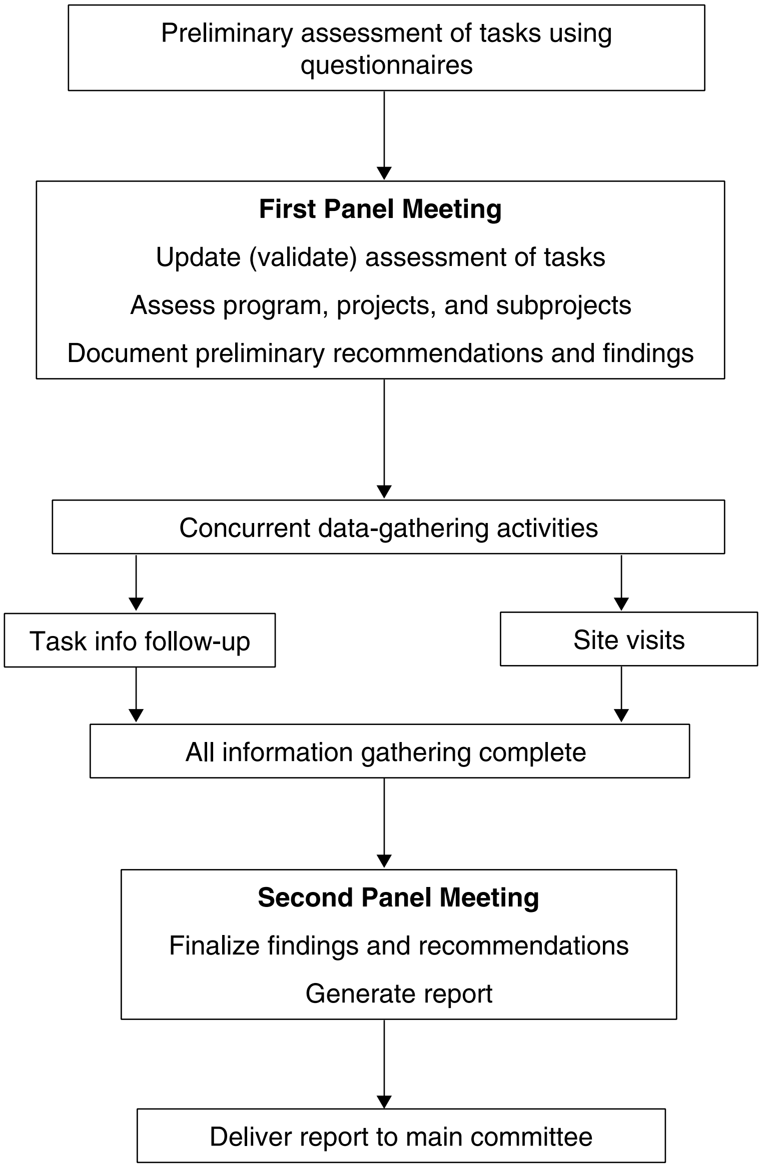

FIGURE 2-2 VSP panel review process.

ing point. Using that information, combined with their own expertise, panel members divided the tasks into two groups: those that were adequately understood and for which additional information was not necessary, and those about which the panel was concerned or for which the panel did not have enough information. For the latter category, the panel determined what additional information it needed (site visits, answers to written questions, or some other communication with NASA) and proceeded accordingly. A detailed list of all the panel site visits can be found in Appendix C. As a necessary consequence of this approach, some tasks received more attention from the panel and committee than others, and some tasks have a more detailed assessment of their strengths and weaknesses than others.

At the conclusion of the site surveys, the VSP panel was reconvened in Los Angeles on May 27-29, 2003. The goal of the meeting was to finalize the panel's earlier findings and generate a set of consolidated recommendations. Using the criteria established by the panel and the weighted evaluation matrix, the 172 tasks in the VSP were placed in four categories:

- *World-class*. Outstanding work that is on a par with the best work anywhere in the world.
- *Good*. Solid, meaningful tasks that should be continued but that have some opportunity for improvement.
- *Marginal*. Solid, meaningful tasks that have substantial room for improvement.
- *Poor*. Tasks that have systemic issues requiring major reevaluation or restructuring, or even cancellation.

KEY FINDINGS AND RECOMMENDATIONS

The committee generated numerous findings and recommendations for the VSP, which can be found throughout this chapter. It then identified three key areas of concern and made a number of general observations about the VSP.

Key Issue 1: Core Competencies

The competencies developed by NASA during the 1960s, 1970s, and 1980s enabled the U.S. aerospace industry to take a dominant position in both the military and commercial marketplaces worldwide. NASA has not reduced the scope of those core competencies or research focus areas even in the face of changing market needs and reduced budgets for vehicle systems throughout the 1990s and early 2000s. Rather, NASA has left the same broad set of capabilities in place, with each portion of VSP research forced to operate on ever smaller budgets. As a consequence, some (not all) of the current VSP projects and tasks find themselves on budgetary "life support." These projects are unable to produce technologies that transition to, and significantly impact, the aeronautics marketplace. In other areas of the VSP, industry state of the art has overtaken NASA capabilities, which raises the question of whether NASA should continue to pursue those competencies.

NASA's Office of Aerospace Technology and the VSP have a top-level aeronautics vision that was being finalized at the time of this review. The committee has confidence that this vision will be realized and yield positive results, because the program has already demonstrated that it has clearly defined product areas. However, the committee is concerned that NASA has not defined the core competency areas that it will need to support those product areas. While NASA's core competencies were clearly defined in the 1960s, 1970s, and 1980s, NASA no longer has a clear set of core competencies and technologies. VSP should create a rank-ordered set of core competency areas to help guide investment decisions. It will then be able to leverage those core competencies to ensure that proposed projects cultivate new opportunities rather than just competing with what is already being pursued by others. It will also be able to ensure that, for the highest-ranked priorities, NASA is recognized as a world leader and has the potential to revolutionize aviation in these areas.

The committee assumes that the technologies chosen as core competencies will have a higher risk of unsuccessful completion (high risk/high payoff) than the technologies industry would be willing to accept. This philosophy is in alignment with NASA's vision of "doing what only NASA can." The future VSP investment portfolio should also take into account and look to rectify the problem that over the past two decades industry has reduced its investment in basic research, which serves as the seed corn for future technology opportunities.

Finding: Core Competencies. NASA and the Vehicle Systems Program have a clear mission statement with a set of fully linked goals and products; however, NASA lacks a good understanding of the core competencies (in order of importance) required to meet these goals.

Finding: Investment Strategy for the Vehicle Systems Program. The VSP appears to have an ad hoc investment strategy, with too many unprioritized projects and tasks and no apparent methodology to determine which research areas will provide the greatest benefit to the U.S. gross domestic product and do the most public good, satisfying the needs of industry, the user marketplace, and other government agencies. This situation is compounded by ever-decreasing budgets.

Program Recommendation: Investment Strategy for the Vehicle Systems Program. The VSP should identify and prioritize technologies (core competency areas) that have the greatest potential to revolutionize the future of aviation and impact the gross domestic product of the United States.

Key Issue 2: Full-Cost Accounting

Before FY03, NASA's program budgets reflected only the cost of the actual hands-on development of the particular technology. All civil servant salaries and infrastructure costs were allocated separately. This accounting practice allowed researchers at NASA to have access to fairly expensive test facilities, which their small research budgets would not have been able to support. The advantage of this system is that it allows individuals to innovate without having to justify the need for large capital investments. The drawback of this system, however, is that the real costs of research are not always apparent, and there is the potential for financial waste.

In FY03 NASA introduced full-cost accounting, which requires each budget line and task to account for all civil servant salaries as well as the infrastructure that it uses. The advantage of this system is that it will give NASA improved insight into the cost and utilization of its facilities and infrastructure and make the true cost of research readily apparent.

The committee's concern, based on the past experience of some members in transitioning to full-cost budgets, is that researchers may no longer take technologies to large- or full-scale testing. Researchers faced with using available dollars to pay for both human capital and costly full-scale testing may elect to significantly reduce their level of concept validation testing. Although this testing is expensive, it has historically been the benchmark by which industry and the user community determine if technologies are mature enough to transition to a marketplace, public or private.

If concept validation testing is reduced, NASA could be faced with little justification for certain test facilities and infrastructure that are critical national assets. The committee encourages the VSP to learn from industry experience when moving to full-cost accounting. It is vital for NASA to avoid the unintended atrophy of NASA's validation and verification test capabilities, because without sufficient final testing, transitioning research and development to practice is nearly impossible.

NASA may need to have an overhead charge applied to all tasks to cover the core costs for certain test facilities. A core cost overhead budget should be used to retain and maintain a test facility or asset when it is not in use. These budgets should include labor associated with basic maintenance of a facility or test asset. Labor and operating costs above the core maintenance level should be charged directly to the project or task that requests the test service.

Finding: Full-Cost Accounting. NASA's transition to full-cost accounting will present challenges to preserving the ability to conduct final, full-scale validation and verification tests.

Program Recommendation: Full-Cost Accounting. The Vehicle Systems Program should create an overhead charge to cover the core cost of test facilities and assets. Core costs are the costs of retaining a test facility or asset when not in use, including the cost of labor for basic maintenance.

Key Issue 3: External Advisory Groups

The committee noted that the VSP has various approaches to the staffing and use of advisory groups. In some cases the committee found these advisory groups (as NASA assets) are not as effective as they could be because industry was not involved at the appropriate level—namely, chief operating officers.

Finding: Advisory Groups. NASA's industry advisory panels do not seem to have sufficient participation from top-level industry management to assure buy-in to projects.

Program Recommendation: Advisory Groups. The Vehicle Systems Program should reevaluate the composition of its industry advisory panels to ensure that the appropriate participants are involved—namely, those who are responsible for turning technologies into marketable products in their respective companies and those who can implement recommended changes.

Other General Observations

The committee encourages NASA to take a close look at the fixed costs incurred by the VSP, such as the cost of the facilities that NASA now supports. The committee believes that NASA should work to identify those test facilities that are truly unique, while looking for opportunities to cut costs through consolidation. Such consolidations might require one-time investments, but over the long term, fixed costs would be reduced.

For example, significant resources have been invested in computational fluid dynamics (CFD) modeling to reduce the need for extensive physical modeling and wind tunnel testing required in the past and to make better use of current laboratory experiments. As validated computational tools reduce or even eliminate the need for particular experimental facilities, some of these costly units should be consolidated or deactivated.

The committee also found that the sunset provision mandated by the Office of Management and Budget (OMB) forcing all projects to end in 5 years regardless of status or progress of the technology made its assessment difficult. Such a provision means that projects must be reorganized periodically so that they appear to be newly formulated, making their history and progress difficult to assess. The committee believes that the sunset provision is appropriate for some technology projects, but not all. It urges OMB and NASA to devise a new method for ensuring that the nation's funds are spent efficiently.

Finding: Office of Management and Budget Sunset Requirements. The OMB sunset provision, which requires all projects to end in 5 years regardless of status or progress, often necessitates reorganization and can damage the continuity of legacy programs. Although such a provision may be appropriate for some projects, many research projects have a time horizon from basic research to mature technology of more than 5 years.

Program Recommendation: Sunset Requirements. Managers of the Vehicle Systems Program should actively work to remove the sunset requirement for research programs as necessary.

PORTFOLIO

The VSP research portfolio ranges from projects and tasks that are pursuing long-term high-risk/high-payoff technologies to near-term initiatives that are closely aligned with industry and that will come to market over the next 5 to 10 years. One of NASA's strengths has always been its ability to work on high-risk concepts with long-term payoffs, which industry often cannot do. The committee found, however, that NASA is not always taking advantage of its ability to do this high-risk work. This may be partly due to the sunset requirements noted above, which cause NASA to focus on 5-year horizons.

Finding: Program Balance. The Vehicle Systems Program appears to have become involved in many near-term activities, sometimes at the expense of the revolutionary high-risk/high-payoff activities that are needed to keep NASA's core competencies and leadership role alive.

Program Recommendation: Program Balance. The Vehicle Systems Program should increase its proportion of revolutionary projects and tasks relative to projects and tasks with near-term results in order to keep NASA's core competencies alive and preserve NASA's leadership role in aeronautics research and development.

The committee also found that VSP is simply conducting too many tasks for the amount of funding available. Since it is unlikely in the current fiscal climate that additional funds will become available, the committee believes that NASA should look for ways to reduce costs by eliminating tasks or projects, as needed, as well as by creatively seeking to leverage money from industry and other government agencies. For instance, a small number of the tasks identified in this report are catching up or competing with industry. These tasks are not providing any skills or technologies that are NASA-unique and are good candidates for cancellation.

Finding: Portfolio Breadth. The Vehicle Systems Program is pursuing too many tasks for the funds available.

Program Recommendation: Portfolio Breadth. The Vehicle Systems Program should try to reduce its overall research portfolio in order to concentrate on projects that make use of capabilities unique to NASA and that strengthen NASA's core competency in aeronautics.

NASA requested that the panel identify any critical missing technologies or technology areas that the Office of Aerospace Technology should be pursuing. The committee identified two such areas that fell into this category: (1) technologies for the advancement of rotorcraft and (2) research in flight controls and handling qualities. Although there are technology elements applicable to both areas, there is no focused program or project set that advances them. NASA led many of the revolutions in rotorcraft design that we now find in the commercial and military sectors. Unfortunately, however, the NASA plans reviewed by the panel had no focused rotorcraft activities. If the U.S. rotorcraft industry is to remain competitive in the international marketplace, NASA leadership and innovation will be required to respond to the European and Asian products now entering the market.

NASA's past work in flight controls and handling qualities provided the reference standard for today's system designs. However, as we move toward unmanned systems, the existing standards, which are for manned systems, may be too restrictive. Further evolution of the base work done by NASA to include unmanned systems is essential to creating a competitive advantage for U.S. products as this market becomes more price-driven.

Finding: Flight Controls and Handling Qualities and Rotorcraft. The committee identified two technology areas missing from the Vehicle Systems Program research portfolio: (1) flight controls and handling qualities and (2) rotorcraft research.

Program Recommendation: Flight Controls and Handling Qualities and Rotorcraft. NASA should pursue additional efforts in (1) flight controls and handling qualities and (2) rotorcraft.

PROGRAM PLAN

The committee found that research plans were good, and managers and researchers were making good progress on projects that were appropriately funded. This solid progress was especially true for projects or tasks with a long, clearly defined history—another argument for removing or revising the OMB sunset requirement discussed above. The exemplary Hyper-X subproject is discussed below. The committee believes that the VSP would improve overall if other projects were to model their management activities on the Hyper-X.

Many of the projects had gateway milestones (measures of technical success). It was not clear to the committee, however, what happened to a task or project when it failed to meet those milestones. NASA seldom used linkage to other tasks (where one technology development project is critical for another task's completion) or task or project interdependency as a factor in establishing decision gateways for project or task continuation.

Finding: Use of Milestones by the Vehicle Systems Program. NASA does not always use milestones as decision points for continuing a project or task, reevaluating a project/task plan or test procedures, or canceling a project or task outright.

Program Recommendation: Use of Milestones by the Vehicle Systems Program. VSP should make effective use of milestone gateways for program management decisions and to guide program exit strategies and cancellation decisions.

Finally, the committee initially had difficulty logically grouping the projects placed under the VSP. The committee believes that this is due to a lack of defined, prioritized core competencies, as discussed earlier. NASA is aware of this problem and appears to be taking appropriate steps to remedy the situation.

TECHNICAL PERFORMANCE

The committee found that 51 of the tasks reviewed were world-class, 91 were good, and 6 were marginal. Finally, 24 of the 172 tasks were found to be poor.

Table 2-2 summarizes all of the tasks that were viewed as world-class. These tasks were well aligned with the visions and goals of NASA and VSP, well organized and managed, and performing cutting-edge research. Tasks categorized as good are not discussed in detail in this report as they are not in urgent need of attention.

Twenty-four tasks were at the other end of the performance spectrum. These tasks were in need of either major restructuring or realignment or they were candidates for cancellation. Table 2-3 lists the six tasks that are marginal and need improvement. Table 2-4 lists tasks that are recommended for reevaluation to determine if they should be restructured or canceled. Table 2-5 identifies tasks that the committee believes should be canceled.

During the consensus meeting in Los Angeles, the VSP panel developed observations that cut across different projects and tasks within VSP. The panel reached consensus on the findings and recommendations and submitted them to the full review committee for its consideration.

The great majority of VSP tasks were either exceptional or good. The committee found that overall the VSP employs an extremely qualified and capable staff

TABLE 2-2 Fifty-one VSP Tasks That Are World-Class

Task No.	Task Name	Task No.	Task Name
1.1.1	Micro-Adaptive Control	6.2.17	Lean Direct-Injection, Low-NO_x Combustor Concepts
1.1.3	Adaptive Structural Morphing		
1.2.1	Physics-Based Flow Modeling	6.3.6	Average Passage Modeling
1.2.2	Fast, Adaptive Aerospace Tools	6.3.7	Dual Spool Turbine Facility
1.2.5	Computational Aeroelasticity, Modeling, and Scaling	6.4.1a	Materials and Structures Turbine Airfoil System/ Low Conductivity
1.3.1	Biomimetics/Nanotechnology	6.4.1b	Materials and Structures Turbine Airfoil System/ Advanced Airfoil Alloy Development
1.4.3	Tire Mechanics/Dynamics		
1.4.4	NASA/DoD Collaborative Activities	6.4.3b	Computational Materials Science—Ceramic
1.6.2	Robust Avionic Architectures	6.5.1	Active Flow Control
1.6.3	Control of Complex Air Vehicles	6.7.1	Rotating Machinery Clearance Management
1.6.6	Ageless Structural Systems Technology	7.1.2	Hot/Smart Materials for Aeropropulsion
2.2.1	Impact Modeling	7.1.3	Morphing Structures for Self-adaptive Aeropropulsion
2.2.3	Low Noise Flight Procedures		
2.3.5	Engine Systems and Advanced Concepts	7.1.5	Miniature Autonomous Sensors and Actuators for Smart Propulsion Systems
3.2.1	High-Speed Slotted Wing		
3.2.3	Ground-to-Flight Scaling	7.1.7	High Power Motor Control Inverter for Aeropropulsion
3.3.1	Tailored Structures		
4.1.4	Active Vibration Suppression	7.1.13	Interstage Turbine Burner
4.2.1	Intelligent Flight Control System: C-17	7.2.2	Nanotechnology
4.2.2	Intelligent Flight Control System: NF-15	7.4.1	Aspirating Flow Control
4.3.1	Flight 2/Return to Flight	7.4.2	Compressor Flow Control
5.1.1	Flight Research Productivity	7.4.3	Intelligent Flutter Control
5.2.1	Active Aeroelastic Wing	7.4.5	Combustor Technologies
5.2.2	Autonomous Aerial Refueling	7.4.9	Active Combustion Control
5.5.1	Helios	7.5.1	Foil Bearing Development/Testing/Analysis
6.2.14	Benchmark Test with Liquid Spray Injector	7.6.3	Metallics
6.2.15	Combustor Code	7.6.4	Instrumentation
6.2.16	Large Eddy Simulation of a Gas-Turbine Model Combustor	7.7.2	Crack-Resistant Materials

TABLE 2-3 VSP Marginal Tasks That Need Improvement

Task No.	Task Name	Task No.	Task Name
1.1.4	Biologically Inspired Flight and Control Systems	2.3.1	Fan Noise Reduction
2.1.2	Propulsion Airframe Aeroacoustics	2.3.4	Liner Technologies
2.1.3	Passenger/Crew Environment	3.4.3	Configuration and Performance Evaluation

TABLE 2-4 VSP Tasks That Should Be Reevaluated for Restructuring or Cancellation

Task No.	Task Name	Task No.	Task Name
1.5.1	Aviation Assessments	6.4.3a	Computational Materials Science—Metallic
3.1.1	Technology Benefits Assessments	6.4.4a	3000°F Ceramic Matrix Composite System
3.3.2	Tailored Materials/Processing Technology	6.4.5	Ultra-High-Temperature Ceramics
4.1.5	Vehicle Concept Teams	7.3.3	Intelligent Engine Systems
6.3.1	Fan Trailing Edge Ejection		

TABLE 2-5 VSP Tasks Recommended for Cancellation

Task No.	Task Name	Task No.	Task Name
1.3.2	Revolutionary Metallic Materials and Structures	7.8.3	Instrumentation and Control
1.3.3	Lightweight Multifunctional Structures	7.8.4	Combustion/Pulse Detonation Engine Testbed
3.4.1	Hydrocarbon Fuels Processing and Fuel Characterization	7.8.5	Inlets
		7.8.6	Nozzles
3.4.2	Power Management and Distribution Testbed	7.8.7	Combined Cycles/Ejectors
6.6.4	Mechanical Components	7.8.8	Hybrids
7.8.1	Cycle Analysis	7.8.9	Acoustics
7.8.2	Materials and Structures		

and that the program has more than adequate infrastructure to support the initiatives being pursued.

USER CONNECTIONS

The committee believes it is essential to have strong connectivity to the user community and the technical community at large to ensure that the technology being developed by NASA is being used for the public good. The committee found that many projects very successfully leveraged industry participation, small business innovation research awards, and academic research to achieve many objectives. However, at the user buy-in level, the committee did not see evidence of top-level industry connections. The committee emphasizes that there is a difference between industry advice and industry buy-in. It would like NASA to review not only the composition of its industry advisory committees, but also the positions the advisory committee members hold within their respective companies. Although the committee understands that industry advisory committees depend on voluntary participation, NASA should seek to reconfigure projects if necessary to ensure participation from the appropriate top-level industry people who can take action within their companies, including cost sharing and commitment to the process. The committee found this to be a critical issue in the VSP (see Key Issue 3: External Advisory Groups earlier in this chapter).

ASSESSMENT BY PROJECT

Breakthrough Vehicle Technologies Project (1.0)

Background

The goal of the Breakthrough Vehicle Technologies (BVT) project is to enable a more efficient and environmentally friendly air transportation system. The project plan is to achieve this goal through the discovery and creation of technological breakthroughs. It is divided into five subprojects with specific technologies (morphing, lightweight technologies) and high-level concepts (systems analysis, systems testing, and cooperative efforts). This is a high-risk, high-payoff, exploratory endeavor designed to create “disruptive” technologies that will dramatically and substantially improve vehicle performance. This effort was funded at $41.4 million in FY03 and is budgeted at $60.2 million in FY04, under the full-cost accounting scheme.

Portfolio

The portfolio of the Breakthrough Vehicle Technologies project (1.0) represents a good mix of technologies programs that address both near- and far-term needs. Activities of two subprojects—the nanotechnology work in Super Lightweight Multifunctional Systems Technology (SLMFST) (1.3) and the robust avionics work in Robust Aerospace Systems (1.6)—are developing revolutionary technologies and have the potential to significantly impact future aerospace products. The tools work being done in the Computational Aeroelasticity, Modeling, and Scaling task (1.2.5) and the Robust Aerospace Systems subproject (1.6) are linked to the successful development of many of these revolutionary technologies.

The Advances Through Cooperative Efforts subproject (1.4) is effectively developing near-term products such as runway friction parameters and tire mechanics, while leveraging the unique NASA facilities and skills to support key DoD program initiatives.

The committee had difficulty understanding the rationale for the logical grouping of these efforts under the Breakthrough Vehicle Technologies project head-ing. In some areas, the committee had difficulty finding program decision linkages among subprojects 1.1 through 1.6. For example, the Control of Complex Air Vehicles task (1.6.3) has a lengthy development program that assumes there will be no hardware execution obstacles in implementing the control concepts. Instead, there should be some cross-task interdependency so that the control theories can be initially validated when the hardware is being validated. The final development of the control algorithms should only occur after both the control theories and the hardware have been validated.

Several elements of the portfolio are poorly linked to NASA goals and objectives and warrant reexamination. These include the Aerospace Systems Analysis subproject (1.5) and two of the three tasks under SLMFST (1.3). Also, the Biologically Inspired Flight and Controls task (1.1.4) is considered marginal. Details of these items are provided below.

Program Plan

The Breakthrough Vehicle Technologies project, like many research projects, is dependent on the successful demonstration of core technologies under development. The technology demonstrations often depend on research outcomes from other projects. For this reason, the Breakthrough Vehicle Technologies project gateways (technical goals that indicate success) and off-ramps (the transition of successful tasks or the cancellation of unsuccessful tasks) should include decision points from related projects, as discussed previously in this chapter. Such improved integration of gateways and off-ramps will strengthen the project.

Technical Performance

The committee notes that excellent work is being done in many locations within this project, particularly in the work on intelligent controls and methods. This work is just what NASA should be doing and does well. The project staff recently demonstrated high-quality work in the Abrupt Wing Stall Research task (1.2.4), in which NASA successfully resolved the F/A-18E/F abrupt wing stall problem.

User Connections

There is good collaboration with government, industry, and academia across the Breakthrough Vehicle Technologies project portfolio. This collaboration is evidenced in the NASA/DoD Cooperative Programs task (1.4.4), where the name of the task shows that NASA's work is closely tied to DoD's work. This task leverages NASA resources to service DoD and industry needs.

While the committee commends NASA for its cooperative efforts with the DoD, it cautions NASA not to use its expectation of future work with the DoD to determine the number of facilities to be retained or how often those facilities will be used. Specifically, the committee urges NASA to maintain only those facilities that are needed to meet NASA-specific needs at NASA Langley.

Assessment by Subproject

Although the overall portfolio of the Breakthrough Vehicle Technologies project was strong, some refocusing of subprojects and tasks would strengthen the project. Specifically, the committee identified tasks within the Morphing (1.1), SLMFST (1.3), and Aerospace Systems Analysis (1.5) subprojects that should be reexamined in order to strengthen the overall project.

The committee believes the Aerospace Systems Analysis subproject (1.5) is an essential tool for selecting, evaluating, and tracking the value of technologies in the research portfolio. However, the committee believes that the efficiency of this initiative can be improved by reexamining staffing and cost. Even though this effort is essential, NASA should keep the operating costs to a minimum since the effort yields no technology product.

The committee offers the following comments on specific subprojects and tasks within the Breakthrough Vehicle Technologies project for NASA's consideration.

Morphing Subproject (1.1)

Micro-Adaptive Control Task (1.1.1)

This technology-oriented task has developed strong collaborations with a diverse range of academia and industry players. It has shown some gains that can be leveraged in the Twenty-first Century Aircraft Technology project. The work is strongly linked with that of the Smart Technologies task (1.1.2), where NASA first tests a concept and then transitions it to flight testing.

Smart Technologies Task (1.1.2)

This task was assessed to be adequate by the committee.

Adaptive Structural Morphing Task (1.1.3)

Industry is well connected to the Adaptive Structural Morphing task (1.1.3), and the committee applauds such collaboration. However, the committee is also concerned that the technologies being pursued will not easily scale to a full-sized aircraft. It encourages NASA to make certain that the technologies it is pursuing will be widely applicable to a range of aircraft.

Biologically Inspired Flight and Control Systems Task (1.1.4)

This task comprises a host of diverse programs, some of which are doing groundbreaking work and others of which, while interesting, are not aligned with NASA's objectives of bringing unique capabilities to the aeronautics field. The committee notes that there is some very positive work being conducted. For instance, the piezoelectric pumped jets for control subtask is an example of good, cutting-edge wing technology that has the potential to significantly influence how future low-observable and non-low-observable vehicles are designed.

The hyperbolic wing designs inspired by nature clearly offer advantages over planar elliptical wings, but the basis of comparison should not be planar elliptical wings but, rather, optimized winglets. The committee is concerned that although this work will yield results comparable to winglets, manufacturing a hyperbolic wing poses significant cost and design issues that may discourage its production. Unless it can be proven that hyperbolic wing designs are significantly better than optimized winglets, the committee recommends that this work be terminated.

The micro air vehicles and control algorithms subtask is very interesting. However, the committee believes that this niche market segment is not one that NASA should try to influence. The commercial arena is already competing for this market. This activity seems poorly aligned with NASA's top-level goals of impacting large markets and ultimately benefiting the gross domestic product of the United States. Furthermore, the committee could not identify anything unique that NASA is contributing that could not be done by others. Work currently being conducted or planned in this area, which includes low-cost autonomy (hardware and software) and flexible structure/wing warping technology, does offer potential advantages to larger classes of vehicles.

Finding: Wing Design. The Vehicle System Program uses planar elliptical wings as the baseline against which to evaluate the advantages of hyperbolic wing designs inspired by nature. However, a more valid comparison would be with optimized winglets.

Recommendation: Wing Design. The hyperbolic wing design work in the Biologically Inspired Flight and Control Systems task (1.1.4) should demonstrate a major improvement over optimized winglets to justify continuation.

Finding: Micro Air Vehicles. The Vehicle System Program's work on micro air vehicles and control algorithms is quite interesting but seems to cater to a niche market already captured by competitive market forces.

Recommendation: Micro Air Vehicles. For the micro air vehicle subtask to have a broader impact it should focus on low-cost autonomy (hardware and software) and flexible structure/wing warping technology; otherwise, the effort should be discontinued.

Also, within the Biologically Inspired Flight and Control Systems task (1.1.4), NASA has also demonstrated that fuel savings can be realized by flying in the wake of an adjacent aircraft in formation flying. Additional research activities proposed to optimize this approach and further develop the control algorithms that would be used by formation aircraft appear premature, however. NASA must discuss this research with the military services, the FAA, and/or other government agencies to determine a concept of operations. This concept of operations should rely on formation flown aircraft and must be accepted by a user community (or, at a minimum, be within the realm of acceptability). Without advance involvement of a potential user community, NASA will have difficulty transitioning the formation flying work to the user community. The committee therefore recommends that activities associated with formation flying focus on gaining user acceptance.

Finding: Formation Flying. At present, NASA's work in formation flying and associated control algorithms does not adequately involve the military services or the FAA.

Recommendation: Formation Flying. The research on formation flying under the Biologically Inspired Flight and Control Systems task (1.1.4) should continue only if the FAA, the military services, or some other government agency outside NASA agrees to a concept of operations that calls for formation flying.

Aerospace Systems Concept to Test Subproject (1.2)

This subproject (tasks 1.2.1 to 1.2.6) as a whole has excellent integration of advanced concepts into practical applications. The NASA staff are working well with a diverse range of industry, academic, and government staff. The committee encourages the researchers to expand their scope by including a central effort to integrate CFD experiments and the work by industry into their research. The European researchers have been successful in integrating CFD experiments into their designs, and the committee strongly believes that NASA could become the agency that coordinates CFD integration.

Super Lightweight Multifunctional Systems Technologies Subproject (1.3)

Biomimetics and Nanotechnology Task (1.3.1)

NASA is conducting world-class nanotechnology research under this task and the technology being produced, if successful, could be a significant enabler of future technological progress. However, because a number of other agencies have made large investments in nanotechnology initiatives, the committee is concerned about the potential impact of NASA's efforts in the Biomimetics and Nanotechnology task.

Revolutionary Metallic Materials and Structures Task (1.3.2) and Lightweight Multifunctional Structures Task (1.3.3)

The committee is concerned that the friction stirring work conducted under the Lightweight Multifunctional Structures task (1.3.3) is simply repeating what is already being done by industry. The committee does not believe that this is an area to which NASA brings unique value. Additionally, the parts being developed in the electron beam initiative under the Revolutionary Metallic Materials and Structures task (1.3.2) may yield only very small weight reductions that do not justify the effort.

Finding: Task Relevance. The committee is concerned that friction stirring work in the Lightweight Multifunctional Structures task (1.3.3) is already being done by industry, while the electron beam welding work in the Revolutionary Metallic Materials and Structures task (1.3.2) produces parts not leading to recognizable weight reductions. Thus, these tasks do not have clear relevance to the program-level goals of enhancing aircraft performance.

Recommendation: Task Relevance. Due to the advanced state of industry practice in the same areas, the committee recommends that NASA discontinue the Revolutionary Metallic Materials and Structures task (1.3.2) and the Lightweight Multifunctional Structures task (1.3.3).

Advances Through Cooperative Efforts Subproject (1.4)

This subproject was assessed to be adequate by the committee.

Aerospace Systems Analysis Subproject (1.5)

Aviation Assessments Task (1.5.1)

This task provides overall analyses activity within the program mainly as a service for project managers, allowing them to assess technical progress and the relevance of various programs to the objectives of NASA's Aeronautics Technology Theme—Protect the Environment, Increase Mobility, Explore New Aerospace Missions, and Support National Security.

The team has a large staff (28 technical members), who should be able to perform the complex system analyses using a variety of specialized tool sets. However, the committee found that the analysts were not using the best planning and analysis tools currently on the market and some of their results were difficult to interpret. Specifically, the team should help the end users interpret and understand the results, not simply present results and assume the end users will understand them.

Also, specific metrics are used and applied via platform models in numerous categories to assess the viability of a given technology development program. The technique tends to be very accurate in the higher technology readiness levels (TRLs) but falls off as smaller, lower TRL tasks are introduced (see Figure 2-3). Given the number of lower TRL programs in VSP, the need for this technique is still very great as it provides a tool to prioritize programs in a resource-limited environment.

The committee understands that coordination with the project and subproject management teams is required to perform this task. However, the team should report directly to the Vehicle Systems Program manager without oversight from the project managers, as this could pose a conflict of interest. Reporting directly to the program manager will assure proper reporting of progress.

Finding: Assessment Reporting Structure. The Aviation Assessments task (1.5.1) team currently reports to a project manager, which could mean a potential conflict of interest.

Recommendation: Assessment Reporting Structure. In order to improve efficiency and effectiveness in the Aviation Assessments task (1.5.1), the team should be set up as an independent, project-level entity (or its equivalent) so that it reports directly to the Vehicle Systems Program manager.

In addition, the team needs to be in close touch with actual platforms through the airframe community in order to assure that metrics and benefits assessments are realistic. The committee noted that there was a lack of coordination between team members and their aviation peers in spite of the efforts of the Aerospace Technology Advisory Committee (ATAC). This situation could be resolved by using actual platforms in some instances and working with industry benefits analyses teams. Industry acceptance of the goals, objectives, technical challenges, and approaches roadmaps—its buy-in—is needed to succeed in technology transition.

Robust Aerospace Systems Subproject (1.6)

The tasks in this subproject were assessed to be adequate by the committee.

Quiet Aircraft Technology Project (2.0)

Background

The Quiet Aircraft Technology (QAT) project seeks to discover, develop, and verify, in the laboratory, technologies that improve quality of life by reducing society's exposure to aircraft noise. The adverse environmental by-products of aviation—primarily noise and emissions—are major constraints on the growth of the aviation industry. Public concerns over the environmental effects of aircraft and airport operations, as well as the increasingly stricter requirements embodied in laws and regulations, can severely constrain the ability of the aviation system to meet the world's future needs for mobility, increased trade/market access, and sustained economic growth. In 1995, the National Science Technology Council said that "environmental issues are likely to impose the fundamental limitation on air transportation growth in the 21st century."[1]

Portfolio

At the project level, the committee found the QAT portfolio to be well balanced. The portfolio addresses major concerns, with the notable exception of sonic booms. The QAT project comprises three subprojects: Airframe System Noise Reduction (2.1); Community Noise Impact Reduction (2.2); and Engine System Noise Reduction (2.3). The distribution of funding between the engine and airframe subprojects appears commensurate with their relative contribution to noise. The committee commends NASA for also addressing community noise impact through operational procedures, as endorsed by the International Civil Aviation Organization. Successfully mitigating the impacts of aircraft noise is dependent on a balanced approach that considers advanced technology, operational procedures, controls, and land use practices. The committee found a gap in the portfolio in the area of sonic boom mitigation. The Defense Advanced Research Project Agency (DARPA) recently conducted a very successful test of technology for reducing sonic boom. NASA

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[1] National Science Technology Council. 1995. Goals for a National Partnership in Aeronautics Research and Technology. Washington, D.C.: White House Office of Science and Technology Policy. Available online at <http://www.ostp.gov/html/aero/cv-ind.html>.

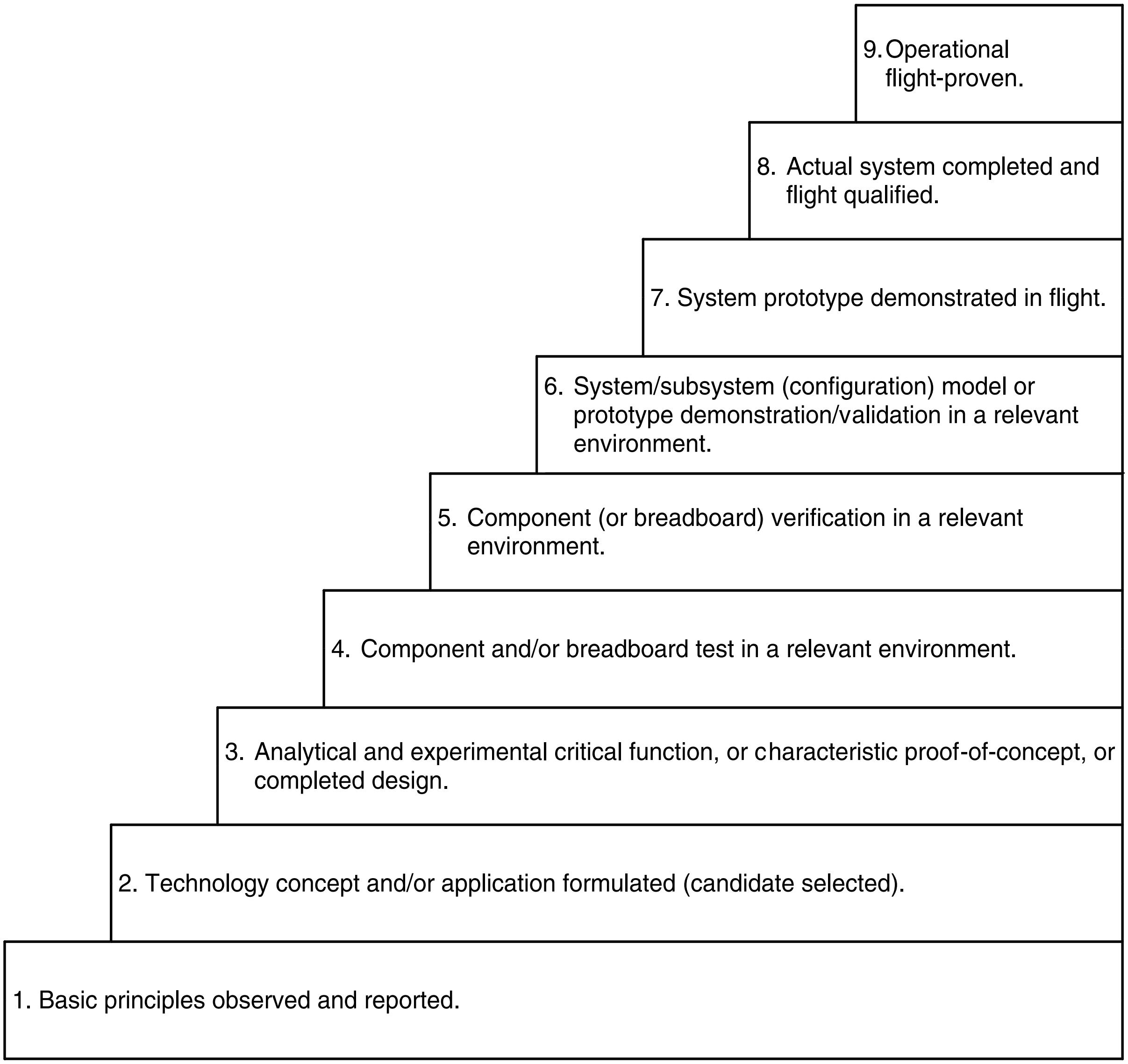

FIGURE 2-3 NASA technology readiness levels. The TRL of a NASA research product is specified according to the above criteria. SOURCE: NASA (2000).

is mentioned as a supporter of this program, but the committee saw no research activity in this area during its review. The committee believes NASA should consider following the DARPA success with a project in this area.

Noise concerns include takeoff and landing noise, taxi and engine run-up noise, noise from flyovers at cruise altitude over areas of low ambient noise, and sonic booms associated with supersonic flight. The committee believes that noise source abatement technologies are an important area for NASA investment. This is consistent with a study by the National Academies Transportation Research Board, which noted that the great advances made in the 20th century to reduce the impact of aircraft noise were due primarily to advanced technology.

Finding: Noise Source Abatement. Developing noise source abatement technology is a critical area for the air transport system and is consistent with NASA's mission.

Recommendation: Noise Source Abatement. NASA must continue to identify tasks and conduct

research to advance technology for noise source abatement.

The committee specifically commends the Community Noise Impact Reduction subproject (2.2). It commends the excellent linkage between modeling and full-scale data acquisition/flight procedure verification programs, such as the Low-Noise Flight Procedures task (2.2.3). The committee also commends the excellent use of teaming, including a relevant airport (Louisville), a manufacturer (Boeing), academia (Massachusetts Institute of Technology), NASA (both Langley and Ames), an operator (United Parcel Service), and both controllers and policy makers at the FAA. In this case, NASA took the technology to a TRL 6 by doing a real-life demonstration. Although it is arguably not a model that should be followed by all NASA programs, it is very appropriate for some technologies that require a full community demonstration.

The committee did have some concerns about the portfolio content of the other subprojects. For example, the committee questioned NASA research in cabin noise abatement given manufacturers' ongoing investments in this area and the limited resources NASA has to pursue the very ambitious goals of the task.

Program Plan

At the project level, Quiet Aircraft Technology (2.0) has clearly defined goals. These goals include reducing the perceived noise levels of future aircraft by one half (10 dB) from 1997 subsonic aircraft within 10 years and by three quarters (20 dB) within 25 years. The NASA presenters understood and articulated the user benefits well. The 10-year goal enables containing 65 Day-Night Level (DNL) noise within an airport's physical boundary. The 25-year goal ambitiously seeks to contain noise within airport boundaries at 55 DNL. Manufacturers, operators of the airlines and airports, and the FAA endorse these goals, as does this committee.

The committee believes that the program plan for the Community Noise Impact Reduction subproject (2.2) is exemplary. The plan has an excellent mix of modeling, simulation, flight validation, and laboratory experimentation. The NASA project team showed excellent qualifications, and the NASA Ames simulation facilities are world-class. NASA also does an excellent job of getting relevant stakeholders to participate on the team.

The committee had concerns about the program plans for the Airframe System Noise Reduction (2.1) and Engine System Noise Reduction (2.3) subprojects. Although the committee believes the work is important, it noted weaknesses in that the subprojects did not always focus on key areas with the highest payoff. The committee recommends that NASA select the highest-priority research through consultation with relevant stakeholders. Before initiating tasks, managers should clearly define goals and the milestones along the way that signal research success, redirection, or failure. For example, the committee believes that NASA should examine the process for measuring success and for creating appropriate technology off-ramps in the Revolutionary Aeropropulsion Concepts subproject (7.1) and use it as a model.

Finding: Focusing on High-Payoff Research. The work in the Airframe Systems Noise Reduction (2.1) and Engine Systems Noise Reduction (2.3) subprojects is critical to the air transport system. However, NASA has not identified key areas with the highest payoffs in these subprojects and focused resources accordingly.

Recommendation: Focusing on High-Payoff Research. The Vehicle Systems Program should examine the use of goals and milestones in the Revolutionary Aeropropulsion Concepts subproject (7.1) and use similar methodology in the Airframe Systems Noise Reduction (2.1) and Engine Systems Noise Reduction (2.3) subprojects to focus resources on key areas that offer the highest payoffs.

Finding: Assessing System Penalties. In some instances, NASA is developing noise abatement technology that has an unacceptable overall system penalty (weight, performance).

Recommendation: Assessing System Penalties. NASA should use its systems analysis capabilities to assess tasks from a system impact standpoint and not continue to pursue those tasks that are not justified when overall system penalties exceed expected gains.

The committee commends NASA for seeking to discern the physics governing aircraft noise. However, the committee is concerned about the transitioning of models to manufacturers. The committee did not see evidence of this transition and believes NASA must generalize its models for them to become useful prediction tools.

Finding: Transitioning to Industry. The committee did not see evidence of transitioning NASA models of the physics of noise in aircraft to industry.

Recommendation: Transitioning to Industry. NASA should work with industry to identify requirements and produce generalized fundamental physics models to make useful noise prediction tools.

Finally, the committee commends NASA's plan to leverage QAT funding by seeking greater industry contributions in future plans to take selected technologies to TRL 6. However, the committee is concerned with the quality of industry's contribution. In the Advanced Subsonic Technology Noise Reduction Program (the QAT predecessor), industry's contributions were generally in-kind, which is acknowledged to be less satisfactory. NASA should seek to enhance both the amount and quality of the industry contribution.

Technical Performance

The QAT project has shown evidence of good performance and achievements. It builds on a strong base from past national noise reduction efforts. The project generally has a solid, successful technical team in place and very good industry, university, and FAA participation. Examples of exemplary recent achievements include the development of chevrons and swept stators along with the identification and verification of continuous descent approach procedures in the Community Noise Impact Reduction subproject (2.2). In all cases, the recipe for success included having teams made up of the relevant stakeholders and advancing the technologies to TRL 6.

The committee believes that technical challenges get more difficult with each decibel of reduction and believes that future performance and achievements may be hindered by resource limitations. In the past, items taken to TRL 6 had clear payoffs. The committee urges NASA to continue to advance QAT technologies to TRL 6. The committee commends NASA's recent augmentation of QAT funding and believes NASA should focus these funds in advancing technologies.

Finding: Industry Cost Share. Industry cost share in some Quiet Aircraft Technology tasks was minimal, and when industry did provide cost share, the quality of the cost share tended to be low (i.e., it offered in-kind support). In cases where there was good collaboration with relevant stakeholders in a task and the technology was taken to technology readiness level 6, there was significant payoff.

Recommendation: Industry Cost Share. NASA should work with the industry advisory groups to enhance both the amount and quality of the industry contribution through direct and innovative cost sharing practices and to assure that promising technologies are carried to the appropriate technology readiness level.

User Connections

The QAT project does exhibit good user connectivity at the technical level. As already stated, the goals are relevant and endorsed by the community at large. The committee particularly commends QAT on including airlines and airport personnel on its advisory board and encourages other projects to follow suit. The Community Noise Impact Reduction subproject (2.2) is an excellent example of integrating stakeholders' interests and capabilities to produce positive results. Although the other subprojects benefit from the same group of advisors, the committee believes that more of their tasks should have the involvement of industry.

At the policy and user buy-in level, the committee did not see evidence of top-level industry connections. The committee emphasizes that there is a difference between industry advice and industry buy-in. The committee believes that NASA should review not only the composition of its industry advisory committees, but also the positions advisory committee members hold in their respective companies. Although the committee understands that industry advisory committees depend on voluntary participation, NASA should seek to reconfigure projects if necessary to ensure participation from the right people—that is, the people who can take action on cost sharing and commit their company to the process.

Finding: Outside Stakeholders. Outside stakeholders are not adequately involved in all Quiet Aircraft Technology tasks. In particular, NASA does not sufficiently use contracts, grants, or SBIR partnerships to leverage outside expertise.

Recommendation: Outside Stakeholders. NASA should involve outside stakeholders while maintaining in-house expertise. Innovation through the involvement of small businesses and universities is encouraged. The committee highlights, as an example, the Propulsion and Power project (7.0), which innovatively funded some high-risk subprojects and used technology incubation in its Revolutionary Aeropropulsion Concepts subproject (7.1).

Finding: Prioritizing Quiet Aircraft Technology Research. Funding constraints appear to be limiting the program content in QAT, confining the work to low technology readiness levels and thereby inhibiting technology transition.

Recommendation: Prioritizing Quiet Aircraft Technology Research. NASA should work with its advisory committee to focus its limited QAT resources. NASA should also carefully consider mitigating the risk of task failure by carrying technologies to a higher technology readiness level before down-selecting to a single technology or contractor.

Recommendation: Use of Milestones and Reviews. The committee encourages NASA to put in place milestones and review processes involving senior management or outside advisory groups in the assessment of progress and the decision to continue, redirect, or cancel a task.

Assessment by Subproject

Airframe System Noise Reduction Subproject (2.1)

The Airframe System Noise Reduction subproject has a sound goal, and the industry steering committee appears to represent the stakeholders well. The committee also notes that large-scale demonstrations are planned to advance technologies to a higher TRL. To meet the subproject's very ambitious goals, NASA has explored high-risk concepts.

The committee found that the subproject lacked focus and was too broad in its scope. This weakness, coupled with limited resources, results in an inability to ensure industry involvement and commitment.

The committee felt, for instance, that although the quality of the efforts in the Passenger/Crew Environment task (2.1.3), which concentrates on cabin noise reduction, was excellent, it was unconnected to the overall QAT goal of reducing community noise exposure. Furthermore, the committee questioned the necessity of NASA investment in cabin noise abatement efforts given similar work in industry.

The committee believes that the Airframe Noise Reduction task (2.1.1) needs to be more tightly coupled with full-scale experiments to provide guidelines for model development. Specifically, in the Propulsion Airframe Aeroacoustics task (2.1.2), the work in predictive tools for installation effects appears to overlap with work under the Airframe Noise Reduction task (2.1.1). NASA should integrate or merge these tasks.

Finding: Airframe Noise. The committee found that the Airframe System Noise Reduction subproject has sound, critical goals. However, some of the subprojects lack focus and their scope was too broad for the available resources.

Recommendation: Airframe Noise. NASA should assess whether the Passenger/Crew Environment task (2.1.3) cabin noise reduction research is consistent with overall goals of the Quiet Aircraft Technology project and evaluate the potential payoff of this NASA investment given similar efforts by industry.

Recommendation: Landing Gear Noise. The Airframe Noise Reduction task (2.1.1) needs to be linked to activities with full-scale experiments to provide guidelines for model development.

Recommendation: Landing Gear Noise. The predictive tools for installation effects in the Propulsion Airframe Aeroacoustics task (2.1.2) appear to overlap with the Airframe Noise Reduction task (2.1.1). NASA should explore integrating or merging these tasks.

Community Noise Impact Reduction Subproject (2.2)

Subproject 2.2 is the strongest one in the Quiet Aircraft Technology project. It demonstrates excellent connectivity to major constituents, which is leading to near-term return on investment. The work with Boeing has produced useful applied models, and the industry steering committee represents all the stakeholders well.

The committee urges NASA to develop innovative ways of expanding the project, even in the face of funding limitations.

Finding: Community Noise. Research by the Community Noise Impact Reduction subproject (2.2) on continuous descent approach noise abatement procedures was exemplary and offered excellent opportunity for near-term return on investment.

Recommendation: Community Noise. NASA should develop innovative ways of expanding continuous descent approach research to other geographic areas.

Engine System Noise Reduction Subproject (2.3)

The goals of this subproject are also sound, and the 9 ft × 15 ft wind tunnel test facility is a significant national asset. The subproject is looking at some innovative concepts, such as microelectromechanical systems (MEMS), and the industry steering committee appears to represent stakeholders well.

In view of the limited resources available for the subproject, NASA should refocus it by giving it fewer tasks in order to achieve realistic goals. The rescoping of the subproject should be done with industry involvement so as to leverage industry funds.

While there is evidence of good-quality work in this subproject, the committee encourages NASA to reexamine some of the tasks in light of top-level design concept issues that may be insurmountable. For instance, in the Fan Noise Reduction task (2.3.1), the committee believes that any technology developed under this task might result in unacceptable system penalties owing to weight penalties and the need for high-speed airflow. NASA should assess this and all other technology development tasks by taking into account their impact on overall system performance.

For example, in the Liner Technologies task (2.3.4), it is not evident that the potential benefits of integrating piezoelectric devices in liners for jet engines outweigh the negatives of their complex operational requirements. Further, the committee did not see evidence that the scaling limitations of such devices have been adequately addressed at the system level.

Finding: Engine Noise. The Engine System Noise Reduction subproject has sound, critical goals. However, in some instances the subproject lacks focus and the scope is too broad for the available resources.

Recommendation: Engine Noise. NASA should engage relevant stakeholders to help focus the project on fewer tasks in order to achieve realistic goals.

Finding: Assessing System Penalties. In some instances, NASA did not consider whether the potential benefits would outweigh the penalties resulting from various engine noise abatement approaches.

Recommendation: Assessing System Penalties. NASA should assess the benefits and penalties of noise abatement technology development for the Fan Noise Reduction (2.3.1) and Liner Technologies (2.3.4) tasks and terminate or refocus them if there is low payoff.

Twenty-first Century Aircraft Technology Project (3.0)

Background

The Twenty-first Century Aircraft Technology (TCAT) project intends to develop and validate, through ground-based experiments, the aerodynamic, structural, and electric power technologies that will reduce by 20 percent the fuel burn and carbon dioxide emissions from future subsonic transport aircraft. The project is motivated by a desire to reduce the impact of aircraft on global climate change and to reduce smog surrounding airports. The project combines research in aerodynamics, structures, and electric power to achieve its objectives. The effort was funded at $46 million in FY03 and $42 million in FY04.[2]

Portfolio

The Twenty-first Century Aircraft Technology project plans to accomplish its goal through the development of the following:

- Aerodynamic technologies to reduce drag,
- Structures and materials technologies to reduce weight, and

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[2] J.L. Pittman and D. Hahne, NASA Langley, "Twenty-first Century Aircraft Technology Project," presentation to the Vehicle Systems Panel on March 18, 2003.

- Secondary electric power for zero CO_2 and NO_x emissions.

The committee believes that the project has a good portfolio and that NASA has properly assembled the right mix of aerodynamic and structural design technology tasks to target drag and weight reduction, which will result in reduced CO_2 emissions.

Program Plan

The program plans of the project presented by NASA support development of the key technologies required to meet the program-level goals of the Vehicle Systems Program. The program plan presented for the Efficient Aerodynamic Shapes and Integration subproject (3.2) was exemplary, with well-defined milestones and a good mix of mature and developing technologies. It was clear to the committee how these technologies produced direct benefits that will enable NASA to meet the stated goals.

The program plan for the Integrated Tailored Structures subproject (3.3) was not as well defined. The subproject would specifically benefit from the creation of interim milestones. It was also not clear why industry and university involvement in these tasks had not been integrated earlier in the task life cycle. While aeroelastic tailoring clearly benefits the project goals, the weight benefits derived from the structures and materials technologies were not as evident.

Technical Performance

The committee found performance across the project to be good, with some excellent derived benefits in the High-Speed Slotted Wing (3.2.1) and Simplified High-Lift Systems (3.2.2) tasks. The experimental data presented in the latter showed a clear improvement in vehicle performance using high-lift technologies. These tasks make excellent use of the wind tunnel resources at NASA to validate the computational predictive methods with experimental data. The Integrated Tailored Structures subproject (3.3), in its buckling stability and damage tolerance tasks, also validates its predictive models using NASA test resources.

User Connections

The Twenty-first Century Aircraft Technology project has made good progress toward the goal of maximizing cost sharing with public and private funds, as well as making use of interagency partnerships. The project has also been effective at incorporating university researchers, although (as mentioned above) the committee believes NASA should include university researchers earlier in the development of the subprojects. NASA has been able to increase the TRL of technologies and enhance technology transfer because of its cost-sharing with public and private partners in the Efficient Aerodynamic Shapes and Integration subproject (3.2).

Although these partnerships provide large benefits, they are not without risks. Reliance on partner assets creates resource uncertainties and may jeopardize project commitments. The committee encourages NASA to broaden its scope of involvement as much as possible. For instance, in the Integrated Tailored Structures subproject (3.3), the wing structural design activities for both aeroelastic tailoring and structural concept development should be more closely tied to commercial transport industry teams.

Finding: Ties to Industry. For certain advanced wing development activities, ties to the current commercial end user were not readily apparent.

Recommendation: Ties to Industry. In order to broaden the scope of the work and to ensure long-term viability, both the aeroelastic tailoring and structural concept development tasks in the Integrated Tailored Structures subproject (3.3) should work more closely with the nation's commercial transport manufacturers.

Assessment by Subproject

While many of the tasks in the Twenty-first Century Aircraft Technology project are solid and the committee does not have recommendations for change, several others could benefit from redirection. For example, NASA should acquire better tools and develop appropriate metrics in the Technology Integration and Assessment subproject (3.1) and evaluate alternative production processes in the Tailored Materials and Processing Technologies task (3.3.2). The committee presents details of subprojects and tasks below.

Technology Integration and Assessment Subproject (3.1)

The purpose of this subproject is to quantitatively measure the impact of TCAT on the emission reduction goal of NASA's Aeronautics Technology Programs. The subproject attempts to identify unfunded, high-payoff technologies. In this sense, the subproject is not actually a research and development effort, but a management tool. The committee acknowledges that there is certainly a benefit to having the capability to assess technology payoff.

Finding: Technology Assessment Tools. The tools being used by the subproject appear to be insufficient to perform the detailed systems analyses and assessments required to measure the results of research by the Twenty-first Century Aircraft Technology project against the goal of 20 percent CO_2 reduction. In the write-ups provided to the committee, NASA does recognize this shortfall, but no plan or investment to resolve these deficiencies was apparent.

Finding: Technology Assessment Metrics. The potential benefits of certain technologies are not easily quantifiable (e.g., new computational tools) and measuring them may require either a detailed systems analysis or the development of an unconventional baseline aircraft (e.g., a blended wing body). Metrics for establishing priorities within the subproject do not exist.

Recommendation: Technology Assessment Tools and Metrics. In order to project the technology payoff for the Technology Integration and Assessment subproject (3.1), NASA should establish an assessment plan with appropriate resources and clear metrics.

Efficient Aerodynamic Shapes and Integration Subproject (3.2)

Efforts in the Efficient Aerodynamic Shapes and Integration subproject (3.2) are exemplary. The goals of the subproject are to develop and demonstrate a suite of innovative, vehicle-integrated aerodynamic technologies. These technologies would reduce vehicle drag, increase transonic speed, or allow for extremely short takeoff and landing distances for subsonic transport (commercial, business jet) and tanker missions.

Finding: Aerodynamic Shapes and Integration. The project plans and milestones for the Efficient Aerodynamic Shapes and Integration subproject (3.2) clearly support the project goals, and NASA has established solid relationships with both industry and universities. The computational fluid dynamics methods and experiments, with emphasis on the transonic regime, have been well linked.

Integrated Tailored Structures Subproject (3.3)

This subproject contains a good mix of the basic technology development required to meet subproject goals. The goals of a 35 percent weight reduction and a 25 percent increase in aspect ratio strongly support the overall VSP goals. To achieve these goals, however, NASA must aggressively pursue highly efficient aircraft structures and materials to meet strength and stiffness requirements. Specifically, in order to meet the aggressive vehicle weight goals, NASA must expand its portfolio to include highly efficient structural concepts.

The methods development work in the various tasks is excellent. The hardware development activities are appropriate for the higher TRL tasks and they also serve to validate the analytical methods using empirical methods. The structural development tasks should expand the scope of stiffening approaches to include sandwich structures.

While it is clear that progress is being made in the Tailored Materials/Processing Technology task (3.3.2) with vacuum-assisted resin transfer molding (VARTM) processing, this production method is already very mature in the industrial sector and it is questionable whether this approach has any performance benefits. NASA should be the leader in technology development efforts and should not be playing catch-up with industry.

Tailored Structures Task (3.3.1)

NASA may realize its project weight and aspect ratio goals if it succeeds in developing the aeroelastic tailoring of a wing. NASA is taking full advantage of the capabilities for composite materials by building in a bend-twist coupling for the wing structure. The NASA team appears to be competent in use of the tools required to perform this task. However, the team should utilize multidisciplinary optimization techniques that couple the unsteady aerodynamics (flutter) response of the wing to the more basic structural optimization.

Finding: Resin-Film-Infused Wing Baseline. NASA appears to have selected a stitched resin-film-infused wing baseline because of funding limitations for executing the research program.

Recommendation: Resin-Film-Infused Wing Baseline. NASA should reevaluate this baseline structural concept, developed for low-cost manufacturing in the Advanced Composites Technology program, which is not likely to produce the highest performance wing structure.

- **Unitape preimpregnated composite sandwich wing skin concepts should be included in the initial trade study candidates for the aeroelastically tailored wing.**
- **Strong ties to the Boeing commercial wing development program in Seattle should be established to attract the interest of an external customer who might make use of the wing box.**

Tailored Materials and Processing Technology Task (3.3.2)

The relevance of this task to VSP goals is minimal. While the VARTM process has the potential to reduce cost, the structural properties of VARTM-produced composites are typically poorer than those of standard unitape preimpregnated laminates. The VARTM process described by NASA is mature in the aerospace industry and available from several subcontractors. Tailored laminates with tight process control are available from the industry using standard unitape preimpregnated materials with custom fiber orientations.

Finding: High-Performance Laminates. The vacuum-assisted resin transfer molding process is mature and used by industry.

Recommendation: High-Performance Laminates. NASA should continue to investigate high-performance laminates; however, current funds should be redirected to address emerging, nonautoclave curing methods, such as ultrasonic tape lamination or e-beam cure, to achieve program goals.

Design Technology for Tailored Structures Task (3.3.3)

The current work in this task supports project goals, and the technologies have the potential to reduce airframe weight. NASA should expand the methods for evaluating the buckling stability of stiffened shells, including skin-stringer stiffened shells, syntactic sandwich shells, and honeycomb sandwich stiffened shells, to capture emerging and highly efficient structural shell concepts. These concepts are consistent with industry recommendations for both the NASA Advanced Composites Technology and NASA High Speed Research fuselage structures.

Finding: Design Technology. The validation of analysis methods using structural test shell elements is well done.

Recommendation: Design Technology. The validation of analysis methods using structural test shell elements should be continued in a modular test plan. NASA should establish closer ties to the end users that might eventually use this technology for their commercial fuselage structures.

Residual Strength/Damage Tolerance Task (3.3.4)

Like the preceding task, this task supports project goals by developing technologies that have the potential to reduce airframe weight. The methods presented for high-fidelity residual strength analysis of composites also improve future airframe reliability. The analysis method validation using structural test elements was well done and should be continued. The activity was well planned. The committee believes that this task should continue per the current task plan.

Green Efficient Aircraft Power Subproject (3.4)

The long-range objective of the Green Efficient Aircraft Power subproject (3.4) is to use fuel cells to create an all-electric, zero-emission aviation propulsion system. This objective requires a paradigm-shifting approach consistent with NASA's role as a high-risk, high-payoff technology incubator, and the committee applauds NASA for having this vision.

Since the initial review, NASA has decided to terminate the subproject as it was originally constructed. The committee agrees with this action, because the subproject is no longer focused on its long-term objective of creating a zero-emission propulsion system and will not bring about the paradigm shift to all-electric aircraft. Most of the ongoing projects did not logically support the technologies that will be required for the long-term vision. Specifically, much of the effort was directed toward the development of a Jet-A reformer/solid oxide fuel cell auxiliary power unit that would be used at airports.

Neither of the two most directly relevant tasks, Hydrocarbon Fuels Processing and Fuel Characterization (3.4.1) and Configuration and Performance Evaluation (3.4.3), were developing technologies relevant to the long-term all-electric vision. Furthermore, much of the content of these two tasks and the content in the Power Management and Testbed task (3.4.2) is redundant with work being done elsewhere.

On a positive note, NASA directed a small element of the Configuration and Performance Evaluation task (3.4.3) toward a fuel-cell-powered small plane. This element was well leveraged, cost effective, and in sync with the long-range goals.

In summary, the committee applauds the vision behind the Green Efficient Aircraft Power subproject (3.4) and encourages future endeavors in this area. NASA is to be commended for recognizing the issues with the current formulation of the subproject and making the appropriate decision to cancel the effort.

Finding: Fuel Cells. The use of fuel cell technology to create an all-electric, zero-emission aviation propulsion system is a paradigm-shifting approach consistent with NASA's mission. However, much of the ongoing work in Green Efficient Aircraft Power (3.4) did not support this vision, and the committee was informed that NASA is canceling this subproject.

Recommendation: Fuel Cells. The committee endorses the decision to cancel the Green Efficient Aircraft Power subproject (3.4) as previously constituted but urges NASA to pursue future work in this area, which leads to the long-range goal of a zero-emissions propulsion system.

Advanced Vehicle Concepts Project (4.0)

Background

The Advanced Vehicle Concepts project (4.0) is charged with developing advanced vehicle concepts and configurations to reduce travel time, expand commerce, and open new markets. This is accomplished by examining a variety of systems to identify new high-payoff aircraft design configurations, performing ground-based tests, and conducting analyses and flight validation.

This project will be complete and no longer exist after FY 2004. It has had some successes, discussed below, that will be transitioned to other, higher-TRL programs for continued development.

Portfolio

The committee found the portfolio of the Advanced Vehicle Concepts project (4.0) to be comprehensive and appropriate to NASA's and the program's missions. The technology being developed is state of the art, and the work is relevant and aligned with top-level goals. The committee believes this project should be continued.

As a whole, it should be noted that the Advanced Vehicle Concepts project (4.0) represents a well-managed and well-conducted mixture of technologies and applications.

Program Plan

In general, the plans for most programs are adequate. The Hyper-X subproject (4.3) is extremely well managed and stands out as exceptional. This project was logically derived from it research predecessors and has a clear path forward with appropriate planning off-ramps; the committee believes these factors contribute significantly to the success of this project. NASA personnel account for the fact that the project is high risk and manage the project accordingly. The committee encourages NASA to look closely at this project and use the management practices developed to serve as an example for other projects.

In the Vehicle Concept Teams task (4.1.5), however, only preliminary plans appear to be in place. Although the task aims are commendable, the committee believes that baseline data for other than the subsonic transport will be needed (e.g., for the joined and strut-braced wing) in order to meet the subproject goals.

Technical Performance

The committee believes the overall project is well run and contains much merit. As an example, it finds the controls work in the Revolutionary Aircraft Flight Validation subproject (4.2) outstanding.

Finding: Project Quality. The subprojects within the Advanced Vehicle Concepts project (4.0) are appropriate, and NASA should pursue them aggressively.

Recommendation: Project Continuation. As the Advanced Vehicle Concepts project (4.0) nears completion, NASA must continue to build on the progress made by it, since it is essential that acquired core competencies be preserved as projects are discontinued.

User Connections

This project's tasks have been very responsive to the Aeronautics Technology Advisory Committee, the VSP Red Team, and the joint workshops with industry, academia, and other U.S. government and nongovernment agencies. For example, the Hyper-X subproject (4.3) leveraged the vibration suppression work done in Australia as well as other work related to the intelligent flight control systems. This is commendable and can serve as an example not only in the VSP but also across all of the Office of Aerospace Technology.

Assessment by Subproject

Revolutionary Airframe Concepts Research Subproject (4.1)

Blended Wing Body Task (4.1.1)

The committee believes that, using a modular approach, NASA should compare the derived benefits for the blended wing body configuration with those of other advancements, such as a composite, conventional configuration, to provide an accurate estimate of the improvements attributable only to the configuration. In this manner, NASA could obtain a more accurate assessment of the advantages, or lack thereof, of the blended wing body configuration.

The committee believes that NASA can realize additional improvements to the design concept by taking advantage of modern controls technology to fly the aircraft in a highly unstable configuration, such as trimming elevon down, with stability augmentation redressing the dynamic deficiencies.

Aeronautical Vehicle Technologies Demonstrator Task (4.1.2)

This task was assessed to be adequate by the committee.

Personal Air Vehicle Task (4.1.3)

This task was assessed to be adequate by the committee.

Active Vibration Suppression Task (4.1.4)

The committee agrees with NASA's assessment that this technology has long-term applications in the structurally embedded vibration suppression of civil and military aircraft. The committee has determined that the work is very good and should continue.

The current focus of the task is an F-18 platform with future application to the Joint Strike Fighter and F-22 aircraft. The committee has a concern that the scant resources being applied to this task will not yield significant results. An active search for additional end uses on the part of NASA should yield many other aircraft and structural applications. The committee encourages NASA to search for these other uses as they could bring in additional funding.

Vehicle Concept Teams Task (4.1.5)

This task develops vehicle concepts to allow an evaluation of technologies and their benefits. The work has been distributed among the key project areas: personal air vehicles; high-altitude, long-endurance vehicles; joined and strut-braced wings; and blended wing body. The task is ongoing and long term.

This task represents a long-needed function within NASA, and the committee is encouraged that the task is in place. However, although objectives for vehicle concepts are a good idea, NASA should include baselines for vehicles other than the subsonic transport (e.g., joined and strut-braced wing). To accomplish this, the committee believes that the project team should interact with the appropriate centers and NASA headquarters programs. This interaction would improve the visibility of the task as well as provide a useful tool for headquarters' management to prioritize projects and for centers to run similar projects.

Revolutionary Aircraft Flight Validation Subproject (4.2)

This subproject is very relevant to both the military and commercial sectors, and customers are clearly defined. Military applications include the UCAV, C-17, and F-15 testbeds. Future applications will almost certainly be much wider and will one day be integrated into civilian transport because this technology has great promise for flight controls transparency in the presence of system component failures.

This subproject represents the type of work NASA should be doing—that is, bringing technologies to a higher TRL. It has taken many interdisciplinary components and has properly applied NASA resources to the problem. The subproject draws upon the superior expertise in flight systems, controls, and simulation of researchers at Ames, Langley, Dryden, and the academic community.

The subproject has evolved from academic work to piloted simulation. Ultimately, NASA will perform flight testing, which nicely fits NASA capabilities. The subproject is well planned and takes technologies that can be demonstrated with real hardware in a multistage process. This is a clear-cut example of what NASA is uniquely qualified to do in a step-by-step process that ends in flight test. The committee commends NASA for its innovation in acquiring assets to conduct the testing. The combination of these entities under the NASA rubric is world-class.

Hyper-X Subproject (4.3)

The Hyper-X subproject shows some of the best planning seen across all the programs reviewed by the committee. The NASA planning reflects the high-risk aspect of this task by providing for three vehicles and anticipating possible loss. The first flight test was not successful because a rocket booster failed, demonstrating the wisdom of the contingency aspects of this plan.

The subproject is well connected programmatically to its antecedents, another of its notable features. Indeed, many of the detailed aspects to be investigated are directed at answering key questions surrounding hypersonic flight. By virtue of careful consideration of this background and good planning, the goals of the subproject are realistic and the risk associated with it has been mitigated. The ultimate goal is to demonstrate positive net thrust of the scramjet; this is a laudable, though difficult, goal that the committee hopes can be achieved.

Flight Research Project (5.0)

Background

The VSP Flight Research project (5.0) is conducted at NASA Dryden. The project is focused primarily on testing and validating, in a realistic flight environment, technologies and tools developed at NASA's other research centers. Consequently, the committee focused its review of the project not on technologies but on the people, assets, and infrastructure in place at NASA Dryden to support these test requirements. The 5.0 project activities are broken into five subprojects:

- Flight Research Productivity (5.1),
- Advanced Systems Concepts (5.2),
- Integrated Transport and Testbed Experiments (5.3),
- Western Aeronautical Test Range (5.4), and
- Environmental Research Aircraft and Sensor Technology (5.5).

Each subproject was reviewed in detail, culminating in an on-site review at NASA Dryden. Overall, the facilities, people, and resources at Dryden are outstanding. Dryden plays a key role in providing the user and aeronautics market with the confidence that technologies are indeed ready for transition.

Because the content of this project does not fit the template for the other Vehicle System Project areas, the committee provides its summary in a slightly different format.

Portfolio

Simulator facilities, laboratories, aircraft hangar, and storage space have been consciously pared down over time to be in alignment with projected future testing levels. Facilities such as the flight simulation center are limited in scope but allow for ground mission rehearsals and preflight validation of operating flight program software for piloted and nonpiloted test programs. This simulation capability is vital to reducing flight test costs.

Appreciating that the NASA Dryden and its assets represent a large fixed cost for the VSP, the committee attempted to identify where NASA could reduce costs. Overall, the committee found little opportunity to reduce infrastructure or test-related assets, with two possible exceptions. The first opportunity is with the F/A-18 fleet and the second in the electronics prototyping laboratory.

The committee believes it may be feasible to reduce the number of F/A-18 test aircraft. There are relatively few programs that utilize these aircraft, and NASA has been allowing the Air Force to use its aircraft on occasion, a sign that the F/A-18 test fleet is not used to its fullest capacity by NASA.

Finding: Fleet Size. The total number of F/A-18 test aircraft appears to be greater than NASA requires.

Recommendation: Fleet Reduction. The Vehicle Systems Program should examine the future needs of the F/A-18 aircraft test fleet at NASA Dryden as a possible way of reducing fixed costs. The committee estimates that four or five flyable F/A-18 aircraft will be required to meet future needs.

In the prototype electronics lab, which supports unique and short-turnaround circuit board manufacture, the manufacturing assets in place are being used, by NASA's estimate, at 20 percent of capacity to populate boards. The committee recommends that standing contractual arrangements for populating printed circuit boards be pursued with outside contractors as a means to eliminate the cost of maintaining and housing these assets. The committee expects that if the above arrangements are made, the support infrastructure associated with these assets would also be reduced. The electronics packaging and design capability should, however, be retained in-house.

Finding: Circuit Board Manufacturing. A portion of the current practice of internal circuit board manufacture at NASA Dryden appears to be inefficient and costly.

Recommendation: Circuit Board Manufacturing. To save costs, NASA Dryden should establish external contract agreements to provide printed circuit board assembly services (circuit board population) as it currently does with circuit board manufacturing.

Technical Performance

NASA Dryden provides NASA with the unique ability to conduct research from concept to full validation in a realistic flight environment.

An on-site review of the facilities, control rooms, labs, and hangars showed that the center has assets and skills in place to meet the broad range of test needs brought to it by other NASA research centers. Safety practices, operational procedures, and facility maintenance practices are of the highest quality.

Similarly, the talents at NASA Dryden—pilots, maintainers, laboratory technicians, engineering staff—are also commendable in quality, experience, and breadth of knowledge. As with most flight test organizations, Dryden has become skilled in adapting to the constantly changing support needs and priorities of different customers. For the level of testing currently being done there and planned through FY05, the facility is the right size.

One concern the committee has is that as NASA implements its full-cost accounting system, many researchers might elect to stop their technology development at TRL 5 or 6, because pushing their technologies forward to full-scale test might become prohibitively expensive. NASA should take positive steps to ensure that full-cost accounting is implemented in a manner that does not unintentionally reduce the willingness of developers to conduct full-scale testing and, consequently, the willingness of the user community and market to adopt these technologies.

Finding: Full-Scale Flight Testing. Full-scale flight test capability at NASA Dryden is an important catalyst in getting industry to embrace new technologies and to move technologies into the marketplace. If this last step in the test and validation process becomes unaffordable, industry will be unwilling to take new technologies beyond technology readiness level 5 or 6.

Recommendation: Full-Scale Flight Testing. NASA should work diligently to ensure that full-cost accounting is implemented in a manner that does not reduce the effectiveness of research by inhibiting the use of full-scale flight testing at NASA Dryden.

User Connections

By their very nature, all activities conducted at NASA Dryden have strong involvement from a user community. The committee noted one aspect of the Helios task (5.5.1) that requires special consideration.

The technical results of this task have been outstanding, as demonstrated by overnight flights of this all-electric, high-altitude vehicle. The committee fully expects that the Helios vehicle will yield significant results for the earth sciences portion of NASA, its primary customer. The committee further applauds NASA for innovative thinking in identifying other possible uses and other possible markets for the aircraft, such as serving as a low-cost, high-altitude (relatively) stationary telecommunications platform. Despite the best efforts of the partner company and aircraft manufacturer, AeroVironment, to attract interest from the U.S. industry, only Japanese telecommunications researchers have tested their equipment on the Helios platform. The committee acknowledges that if this telecommunications strategy pays off, NASA will have helped establish a small overseas niche market for future Helios aircraft.

Ultra-Efficient Engine Technology Project (6.0)

Background

The combination of the Ultra-Efficient Engine Technology project (6.0), the Propulsion and Power project (7.0), and the Green Efficient Aircraft Power subproject (3.4) incorporates most of the engine and propulsion elements of the aeronautical program at NASA. The range of projects extends from low TRL—very high-risk, high-payoff tasks—to projects with relatively high TRL values that in some cases have appeared in flight vehicles. Because the Ultra-Efficient Engine Technology (6.0) and Propulsion and Power (7.0) projects are so intertwined, their background, portfolio, program plans, technical performance, and user connections are discussed together here. The Propulsion and Power tasks are discussed in the next section.

The Propulsion and Power project (7.0) discovers, develops, and verifies in the laboratory advanced technologies that improve the quality of life by reducing exposure to aircraft emissions and increasing mobility. NASA accomplishes this by investing in new turbine engine technologies, new propulsion concepts, and foundational propulsion and power technologies emphasizing high-risk, high-payoff concepts and technologies.

Portfolio

The Ultra-Efficient Engine Technology (UEET) project (6.0) is a relatively tightly structured array of subprojects and tasks clearly aimed at improving engine performance, using either efficiency or emissions as the metric of success. Much of the work is at a relatively high TRL level and is done jointly with industry. Consequently, the paths forward and the placement and interrelationships of the various tasks and subprojects within the project are straightforward.

The Integrated Component Technology subproject (6.6) contains a notable array of tasks. It consists of a series of "other transaction" agreements, which permit NASA to have creative partnerships with industry and advance technology readiness. However, NASA should not use these agreements exclusively, as the committee was concerned about overinvesting in technologies that would not contribute to the general knowledge base and overall public good because of intellectual property restrictions.

The other project, Propulsion and Power (7.0), has a much more diverse mix of subprojects and tasks. It tends to emphasize the research and low-TRL side of the technology maturation process more than does the 6.0 project. The two projects are complementary in this regard.

Of particular note in the 7.0 portfolio is the Revolutionary Aeropropulsion Concepts subproject (7.1). This is a commendable subproject as it offers an excellent approach for achieving a key portion of NASA's mission: the pursuit of high-risk, high-payoff work that otherwise would not be performed by the community. Another commendable subproject is Oil-Free Turbine Engine Technology (7.5). This subproject targets an area that could be a significant gain for small gas turbine engines and that might have long-term applicability to large commercial engines as well. The Propulsion and Power (7.0) portfolio contains a good balance of modeling and experimental tasks. One of the elements involved a resourceful approach to obtaining long-term engine data by using a commercial turbogenerator system.

The committee was concerned about some tasks in the general engine and propulsion portfolio—mainly in the Green Efficient Aircraft Power (3.4) and Pulse Detonation Engine Technology (7.8) subprojects.

The committee notes that the Green Efficient Aircraft Power subproject has been canceled and agrees with this decision. However, it also believes strongly that the vision and goals of the subproject offer a paradigm-shifting approach that is clearly consistent with NASA's role as a high-risk, high-payoff technology incubator and that NASA should pursue these visions and goals. This subproject is discussed in more detail above.

The committee believes NASA should also closely reexamine the need for the Pulse Detonation Engine Technology subproject (7.8), because much of the effort directed at military objectives is redundant and that directed at civil aviation is unlikely to be useful.

There are other areas within the propulsion area that NASA should reexamine and possibly reconfigure, refocusing the work to reflect available resources. In the Materials and Structures for High Performance subproject (6.4), some milestones are too ambitious and there are no realistic plans to satisfy them. This is the case in the 3000°F Ceramic Matrix Composite System (6.4.4) and Ultra-High-Temperature Ceramics (6.4.5) tasks.

Furthermore, the goals of the Computational Materials Science-Metallic task (6.4.3) do not appear to be realizable with the time and funds available. The contractors are working at temperatures where microstructure is not stable with time and plastic deformation is continuously occurring. This set of conditions presents a considerable challenge, although ultimately significant progress could be made. However, the task currently lacks sufficient progress metrics, decision points, and off-ramps. It should be reconsidered and refocused, with reasonable milestones against which its progress can be compared.

Program Plan

Plans for the majority of projects and subprojects are appropriate, with meaningful milestones and reviews. The Materials and Structures Turbine Airfoil System task (6.4.1) is an example of excellent planning. The Revolutionary Aeropropulsion Concepts subproject (7.1) also had an excellent approach for assessing progress at the appropriate milestone and for managing off-ramps if needed.

The committee did have some concerns. For instance, the process used by NASA to formulate emissions goals was unclear to the committee: it appears to link the goals to regulatory processes, which may not be appropriate. Aviation regulatory emissions goals are not generally designed to push technology, and the goals could become subject to political issues unrelated to technology. The committee strongly believes that NASA should be at the forefront of setting emissions reduction goals that look beyond what regulators are doing today, leading the way in addressing new issues that push the boundaries of current technology.

The committee believes that it is imperative for NASA to address the interrelationships between noise and emissions. NASA should leverage the work traditionally being done in UEET and QAT, using common demonstrators where appropriate.

The high cost associated with the large number of technicians involved in facilities such as the combustor facility is problematic. This burden should be shared among a broader segment of the related projects; otherwise a facility could unintentionally become unaffordable for all projects. An example of this is the Emissions Reduction subproject (6.2). NASA should review this situation carefully so it does not negatively impact other projects.

Technical Performance

Many of these subprojects are extensions of previous work and they have recently been replanned. Since many are still in the early stages of development, the technical accomplishments are limited at this juncture.

The committee believes that a strong example of achievement is the Compressor Flow Control task (7.4.2), which was able to transition from a fundamental research idea at the Massachusetts Institute of Technology to a proposed test in an Army engine (T-700) in 2004.

Performance and achievement of many tasks are hindered by resource limitations and concern about technology downselection, as happened to combustor contractors in the Emissions Reduction subproject (6.2). Premature downselection in this subproject may limit the degree of technology exploration, and if there is a single failure, the overall subproject might fail.

The committee had several areas of concern. For instance, in the Fan Trailing Edge Ejection task (6.3.1), despite additional dialogue with NASA, the committee questions the connection between the benefits assessment and the overall vehicle systems benefit. Specifically, NASA should consider trade-offs between noise reduction and system penalties such as weight, specific fuel consumption, and emissions.

User Connections

Owing to the large number and varied types of subprojects and tasks within the projects, there is naturally a wide range of user involvement. Particular examples of excellent user connectivity include the Ultra-Safe Propulsion subproject (7.7). This is a user-driven research project addressing real-world problems with close industrial collaborations.

The University Research and Engineering Technology Institute (URETI) subproject (7.3) is another example of very good user connectivity. The URETI advisory board enables connections with many entities, which ensures good leveraging of resources. However, the URETI directorate needs to empower the advisory board to terminate and redirect tasks as appropriate to ensure progress toward project goals. The committee is also concerned that, while the URETI involves multiple universities, it excludes many others, with substantial investment going to a small subset of potential participants. Hence by default some potentially useful contributors are not engaged, possibly limiting opportunities and reducing the diversity of views. This is offset by the worthy objective of attaining critical mass by involving the URETI centers.

Another noteworthy example of user connectivity is the Highly Loaded Turbomachinery subproject (6.3). This subproject has extensive involvement with engine companies and DoD in various tasks, as well as involvement with the Integrated Component Technology subproject (6.6). This latter array of tasks uses flexible contracting mechanisms to provide industry with a stakeholder role in the efforts, which further enhances technology acceleration and transitions. As with URETI, though, there could be a weakness if this tool is overused, as the focus on a single contractor could diminish the overall benefit to the community.

The committee believes that extensive interaction with industry review panels is essential to ensure that NASA is effectively using its limited resources. Accordingly, it believes that NASA should critically evaluate the current composition of its industry review panels. For example, the inclusion of the airline and airport industry is highly recommended.

Assessment by Subproject

Propulsion Systems Integration and Assessment Subproject (6.1)

The strengths of this subproject include stakeholder interest in high-fidelity system simulations. The NASA research team and available facilities are of high quality and are appropriate for the stated tasks. The overall subproject is well structured and has well-defined milestones.

The committee found weaknesses in this subproject in that the work relies heavily on the team at the Georgia Institute of Technology and its probabilistic metric assessment. The committee notes that this work is generally sound but also believes that NASA should consider additional and alternative methods of evaluation. Another concern the committee had is the apparent lack of NASA participation in projects related to international atmospheric environmental data.

As a general observation, the committee had concerns that NASA's approach to integrating discrete technologies is not consistent with accepted industry practice for systems integration.

Emissions Reduction Subproject (6.2)

The strengths of this subtask include unique facilities such as high-pressure combustor rigs at NASA Glenn. The committee believes that the goal of reducing emissions is sound and that NASA uses good milestones for advancing the TRL of the technologies in the subproject. Industry partnership agreements also enhance connectivity with the stakeholders. The modeling in the subproject is predicated on industry-accepted codes such as large eddy simulation and national combustion codes. This work is considered world-class. The committee considered the transfer of more basic work from the Smart Efficient Components subproject (7.4) to this subproject to be a positive, evolutionary move.

The committee believes that this subproject should separate its goals from regulatory processes, which are generally conservative and potentially fraught with political issues. These regulatory processes do not always consider technological implications nor do they address new environmental issues such as the reduction of particulate matter and air toxins, which NASA should rightly address.

NASA should also consider trade-offs. NASA may be inhibited by resource limitations from working with the broad industry base required for transition, which might result in missed opportunities.

The high cost associated with the large number of technicians involved in the combustor facility is another weakness, mentioned above. A broader segment of related subprojects should share this burden. NASA should review facility burden carefully so it does not negatively impact the subprojects.

The current plan to downselect to a single contractor for each of two engine types concerns the committee because it might limit the degree of technology exploration. Moreover, should the one selected option fail, the overall project would also fail. The committee recommends that NASA carefully consider mitigating this risk of project failure by carrying the projects to a higher TRL before downselecting. The committee acknowledges the reality of funding constraints. NASA should seek innovative ways to maintain the project, perhaps through industry cost-sharing.

Finding: Downselecting. As a consequence of funding limits, NASA's current plan for the Emissions Reduction subproject (6.2) is to downselect to a single contractor for emission reduction technology work at a relatively low technology readiness level.

Recommendation: Downselecting and Contractors. NASA should replan the Emissions Reduction subproject (6.2) and plan future projects to carry activities to an appropriate technology readiness level before downselecting to a single concept or contractor. This process will mitigate the risk of losing valuable technology.

Recommendation: Downselecting and Technology Readiness Level. NASA should carefully consider what technology readiness level is appropriate for use in downselect decisions points in future program planning to avoid the loss of valuable concepts and technology.

Highly Loaded Turbomachinery Subproject (6.3)

The strengths of this subproject include high-risk, high-payoff tasks that take technology from TRL 1 to 4. This is a sound plan and one that NASA should continue. The goal of reducing carbon dioxide by 8 to 15 percent through a reduction in fuel burn is a valid one. There is also good involvement from engine manufacturers and DoD components in the subproject. The Dual Spool Turbine Facility task (6.3.7) is a valuable resource and a national asset.

The committee had concerns about the Fan Trailing Edge Ejection task (6.3.1). Despite additional dialogue with NASA, the committee questions the connectivity of the benefits assessment to the overall vehicle systems benefit. Specifically, the task should consider trade-offs between noise reduction and emissions reductions and the impact on overall system performance. The committee questions the justification for the activities taking place under this task in light of the system-level trade-offs. As a general rule, if a task cannot be justified in terms of system-level gains (noise gains versus weight and fuel burn penalties), then it should be replanned or canceled. The committee recommends that NASA reexamine task 6.3.1 in that light.

Finding: Assessing System Penalties. The Fan Trailing Edge Ejection task (6.3.1) is an innovative concept with the potential to significantly reduce fan noise. This task, however, is also currently projected to incur significant performance and weight penalties.

Recommendation: Assessing System Penalties. NASA should review projects and subprojects on a timely basis, including the Fan Trailing Edge Ejection task (6.3.1), and cancel tasks and/or subprojects when gains do not outweigh overall system penalties.

Materials and Structures for High Performance Subproject (6.4)

The strengths of this subproject include well-conceived and -defined tasks and realistic goals. The Materials and Structures Turbine Airfoil System (6.4.1) is an excellent example and has a good chance to achieve those goals. The subproject goals meet the needs of both commercial and military engines and include a major engine company in the fabrication process.

Weaknesses include testing that was using unrealistic test conditions. The committee notes NASA is correcting this situation.

In some cases, the committee found that milestones in some tasks were too ambitious and there was no realistic plan to reach those milestones. This situation occurs in the 3000°F Ceramic Matrix Composite System task (6.4.4, part a) and the Ultra-High-Temperature Ceramics task (6.4.5).

In the Materials and Structures Turbine Airfoil System task (6.4.1), the fourth-generation turbine blade alloy may not be acceptable to airlines owing to a lack of oxidation resistance in the base metal under the coating. Also, the task is using only a single mechanical property, stress-rupture, as an exploratory metric, which the committee feels is not sufficient. The committee believes that NASA's choice of a civilian customer may be inappropriate because of the problems stated above. It encourages NASA to define and identify military customers, or to consider blade oxidation resistance in the task work. Since the United States is currently conducting little or no nickel-based research, the committee believes this task is important and should continue.

The Computational Materials Science-Metallic task (6.4.3, part a) appears to lack sufficient internal capabilities in this technical area, and the contract goals appear to not be realistic or realizable. Overall, the committee questions the unique value of this particular work and suggests that NASA reassess the task.

There are two tasks working toward 3000°F ceramic matrix composites: the 3000°F Ceramic Matrix Composites System task (6.4.4, part a), and the Ultra-High-Temperature Ceramics task (6.4.5). The committee did not observe innovation in task 6.4.4 part a. The committee also had concerns about task 6.4.5 since it has been in place for 10 years but has made little progress. NASA should address the necessity of having two programs with nearly identical goals. In addition, the goal temperature of these programs may not be realizable. NASA should reassess the subproject goals and, if they cannot be justified, cancel the effort.

Finding: Use of Milestones and Reviews. Goals for some of the tasks (6.4.3, 6.4.4, and 6.4.5) in the Materials and Structures for High Performance subproject were set extremely high, and the plans for achievement are overoptimistic.

Recommendation: Use of Milestones and Reviews. NASA should structure projects and subprojects with milestones and review processes using senior management or outside advisory groups to assess progress and determine if NASA should continue, redirect, or cancel tasks or subprojects on a timely basis.

Propulsion-Airframe Integration Subproject (6.5)

The strengths of this subproject are that it uses an appropriate mix of system studies, aerodynamic modeling, and wind tunnel tests to identify and evaluate advanced integrated systems. The subproject involves relevant industry team members and universities. It has strong researchers and facilities, such as the Langley National Transonic Facility, that are essential for these types of tasks. In addition, the management of the subproject had the courage to make the tough decision to cancel a task when industry interest was no longer there.

The Active Flow Control task (6.5.1) is an example of a strong performer. This is needed, innovative research for low-observable aircraft and S-shaped ducts in inlets.

One area of weakness the committee identified is in the Advanced Configurations task (6.5.3). This task focuses on limited airframe concepts, placing all emphasis on the blended wing body concept. While this effort has merit, the committee believes there are too few milestones for a 4-year effort and that NASA should learn from past industry work and from ongoing activities in similar configurations. The committee saw no indication that NASA had consulted with industry on similar configurations.

There was another area of concern in the Propulsion-Airframe Integration subproject (6.5). NASA said that owing to limited funding, it is not looking at issues such as crosswind and angle-of-attack factors (distorted inlet flow) in the inlet testing and analysis. The committee believes that if NASA does not examine these issues, which it can do even in the face of a limited budget, it may never find a practical solution.

Integrated Component Technology Subproject (6.6)

This subproject benefits from having manufacturers with a stake in the process through the use of flexible contracting mechanisms. This situation shortens the time for technology development and transition. However, there is an accompanying weakness if flexible contracting mechanisms are used too extensively. Flexible contracting mechanisms focus on one contractor, so the technology does not always benefit the community as a whole and may not meet the goal of greater public good.

Given these criteria, the Aspirating Seal Demonstration task (6.6.3) was well regarded by the committee as having possible application to multiple engine types. The committee has also determined that the supersonic 10 ft × 10 ft wind tunnel used in the Nozzle/Inlet Components for High Speed Flight task (6.6.5) is a national asset. The inlet work is critical for continuing advancement. This task is well integrated and leverages Versatile Affordable Advanced Turbine Engine (VAATE) and Long Range Strike work conducted with the military. It also benefits supersonic business jet programs.

One overall weakness of the subproject is that it does not appear to be well constructed and does not have a clear focus and prioritization of goals. The committee was also concerned that the Mechanical Components task (6.6.4) is aimed at developing geared fan systems, which are supported by only one contractor in the user community.

Finding: Supporting the User Community. Task 6.6.4 does not appear to support the engine commu-

nity at large, nor does it appear to have broad support from the airline community.

Recommendation: Supporting the User Community. Since the Mechanical Components task (6.6.4) does not support a broad range of community users, the committee recommends that NASA replan or cancel this task.

Intelligent Propulsion Controls Subproject (6.7)

A strength of this subproject is the NASA Glenn Class-100 silicon carbide work, particularly the clean room at NASA Glenn, which is a unique facility. A number of programs rely heavily on this facility, which the committee believes shows its uniqueness.

Another strength is the high-temperature semiconductor work, which has the potential for developing wireless sensors that would reduce weight, fuel flow, and emissions. Such sensors would also enhance affordability by requiring less maintenance. This work is applicable to supersonic technology and low observables and might be exploited for high-temperature power electronic-based drive systems. The committee identified one weakness: The linkage between this work and that of the Higher Operating Temperature Propulsion Components subproject (7.6) is not clear.

Finding: In-House Collaboration. There is no clear linkage between the Intelligent Propulsion Controls (6.7) and the Higher Operating Temperature Propulsion Components (7.6) subprojects.

Propulsion and Power Project (7.0)

Revolutionary Aeropropulsion Concepts Subproject (7.1)

The overall strengths of this subproject are these:

- NASA is conducting research in an area it is uniquely qualified to evaluate and execute. The experimental and analytical work is consistent with theme objectives for vehicle systems.
- The long-term vision in task selection adequately balances risk with gain.
- NASA Glenn is making good use of both its own facilities and facilities external to NASA.

The committee is concerned that the number of projects being pursued is too great and inconsistent with current funding levels. Also, the external connectivity is predominantly with universities and small companies. A more appropriate connectivity for this type of work would be with larger manufacturers, which do not currently play a role in the subproject. Concentrating on universities and small companies may be a programmatic necessity, but NASA should give thought to engaging larger groups or corporations.

Propulsion Fundamentals Research Subproject (7.2)

The overall strengths of this subproject are that many of the tasks address very early basic research work that industry would not take on, such as the Fundamental Noise task (7.2.4). The Nanotechnology task (7.2.2), which involves single-crystal silicon carbide nanotube systems, is innovative. NASA is a world-class leader in this work at higher temperatures.

The committee was concerned that some of the facilities appear to duplicate those at the Arnold Engineering Development Center and the Air Force Research Laboratory. Also, connectivity to the national nanotechnology program, the National Nanotechnology Initiative, is unclear. This raises concerns on the part of the committee that perhaps not all of the tasks are firmly integrated into the broader community.

Aeropropulsion and Power University Research and Engineering Technology Institute Subproject (7.3)

The overall strengths of this subproject are the following:

- The URETI concept is creative and provides a critical mass of researchers and facilities.
- The URETI advisory board brings connectivity that ensures resources are well leveraged.
- The URETI principal investigators and director are doing a good job of monitoring relevant international work.

The committee noted that the experimental capability of the compressor research in the Intelligent Engine Systems task (7.3.3) was not clear.

Finding: University Research and Engineering Technology Institute. The Aeropropulsion and

Power URETI subproject (7.3) is innovative but contains some weaknesses, including these:

- **The URETI advisory board does not have the power to terminate or redirect tasks as appropriate, to ensure good progress toward goals.**
- **While the URETI comprises multiple universities, it also excludes many other qualified ones.**
- **NASA does not have a mechanism to ensure continuity of the program in situations where critical principal investigators change universities and where principal investigators at other universities can be a significant asset if added.**
- **There is a conflict of interest in having an advisory board that includes individuals who conduct the research funded under the URETI.**

Recommendation: University Research and Engineering Technology Institute. NASA should review the URETI operating guidelines and make appropriate changes to assure that the goals of the program are achieved.

Smart Efficient Components Subproject (7.4)

The adaptive flow control is a good example of transition from fundamental concepts at the Massachusetts Institute of Technology to full-scale testing of an Army engine (T-700) in 2004. The committee believes the lean direct injection combustion research of this subproject is pioneering. Finally, the facilities such as the large, low-speed, multistage axial compressor and the transonic oscillating cascade facility are unique for flow control and unsteady aerodynamics.

The committee had concerns that the connectivity of the URETI research in the Compressor Flow Control task (7.4.2) with NASA Glenn is not evident. Glenn is conducting solid research in compressor flow control but it is not collaborating with the URETI program. Finally, NASA is accomplishing significant levels of research in-house, but leveraging the university community would also benefit research progress.

Finding: In-House Collaboration. The Compressor Flow Control task (7.4.2) does not appear to be collaborating with the solid research at NASA Glenn in compressor flow control.

Oil-Free Turbine Engine Technology Subproject (7.5)

This subproject targets an area of significant potential gain for small gas turbine engines and has a good balance of modeling and experimental work, including a creative approach for acquiring long-term engine data through a turbogenerator system. There is also good university involvement in developing a structural model for planned verification tests. The success of some of this work is evident from the collaboration between NASA and industry on air bearing designs applied to business jets, such as the Eclipse.

The committee had two concerns about this subproject. First, the committee encourages NASA to address drive issues such as power takeoff requirements for engine accessories and utilities. To help in this, the committee suggests coordination with, and leveraging of, the Air Force Research Laboratory's Versatile Affordable Advanced Turbine Engine (VAATE) program. Secondly, the subproject has not addressed the benefits of reducing drag from standard bearings.

Finding: Oil-Free Turbine Engine Technology. NASA does not address concerns about drive issues such as power takeoff for engine accessories and utilities. NASA also does not currently address the benefits of reducing the drag from standard bearings.

Recommendation: Oil-Free Turbine Engine Technology. To make the subproject more effective, NASA should make contact with the Air Force Research Laboratory's Versatile, Affordable Advanced Turbine Engine program in order to help leverage the Oil-Free Turbine Engine Technology subproject (7.5). In addition, the subproject should address benefits of reducing drag from standard bearings.

Higher Operating Temperature Propulsion Components Subproject (7.6)

In the Ceramics task (7.6.1), the publication of ASTM standards for fracture toughness testing and biaxial strength of ceramics was exemplary, as was the task's involvement with user-driven, high-quality research that addressed real-world problems. Also, the

Metallics task (7.6.3) is an example of scientists operating outside the mainstream community on potentially high-payoff research, such as research methods that are computationally less intensive than classical methods. The present investigators understand that their approach to computational alloy development is somewhat outside the mainstream, but they cite their early successes as sufficient reason to continue their effort. It is impossible to determine at this stage if these investigators have developed a suitable approach that will yield answers of acceptable quality while being much less computationally expensive than the classical methods or if their techniques have limited scope and will not be able to produce acceptable results in a wide range of situations. Sometimes such work leads to breakthroughs and new paths for further development. This work should be continued until these questions can be answered.

NASA Glenn's Class-100 silicon carbide clean room, which is heavily used in the High-Temperature Instrumentation task (7.6.4) and in the Intelligent Propulsion Controls subproject (6.7), is a national research facility with many uses, although it is relatively inexpensive.

The committee had the following concerns for this subproject:

- Traditional ceramics processing methods (hot pressing and slip casting) may be difficult to apply to complex configurations.
- Adherence of environmentally protective (life-extending) coatings on silicon nitride has not been adequately addressed. For instance in the Metallics task (7.6.3), the coating technique may not be adequate for two-phase materials.
- There is a high degree of reliance on computer-based predictions that have not been verified and may not be reliable.

Ultra-Safe Propulsion Subproject (7.7)

An overall strength of the Ultra-Safe Propulsion subproject is its connection with its customers through user-driven research addressing real-world problems, which appropriately involves collaboration with industry. This subproject effectively leverages work of others in the field while achieving significant advances.

The committee urges those in NASA involved in this task to review the recommendations in Chapter 4 of this report related to propulsion safety technology. Specifically, there needs to be more fundamental materials work in this area. Safety considerations should be present in all research related to improving propulsion component performance in terms of higher turbine inlet temperatures, lower emissions, and less noise.

Pulse Detonation Engine Technology Subproject (7.8)

The committee acknowledges that increasing cycle efficiency by 10 to 15 percent is an admirable goal. However, it believes that pulse detonation technology is unlikely to help achieve this goal because of its many drawbacks. There appears to be no appreciation for the concerns of commercial customers (e.g., airlines) about noise. The committee believes there is a pressing need for a system analysis to show the potential for a pulse detonation engine to overcome apparent limitations and achieve the stated goals. Finally, NASA's unique contribution to pulse detonation engines is not apparent. NASA should reevaluate whether it should continue investing in pulse detonation engine research or leverage DoD research for applications in the commercial sector.

Finding: Pulse Detonation Technology. Much of the effort of the Pulse Detonation Engine Technology subproject (7.8), while having potential military application, is unlikely to serve civil aviation needs.

Recommendation: Pulse Detonation Technology. To bring tasks more in line with NASA capabilities and goals, the committee recommends that the Pulse Detonation Engine Technology subproject (7.8) be canceled.

3

Assessment of the Airspace Systems Program

BACKGROUND

The first five sections of this chapter describe and assess the Airspace Systems Program (ASP) and the process used to review research in this area. They also set forth program-level findings and recommendations that are largely based on project-level assessments in the sixth and final section of the chapter. Additional findings and recommendations at the project level and task level appear in the sections focused on project-level detail.

Program Information

The goal of ASP is to enable major increases in the capacity and mobility of the air transportation system through the development of revolutionary concepts for operations and vehicle systems that will do the following:

- Improve throughput, predictability, flexibility, collaboration, efficiency, and access to the National Airspace System (NAS), including the enabling of general aviation and runway-independent aircraft operations,
- Maintain system safety, security, and environmental protection, and
- Enable modeling and simulation of air transportation operations.

ASP research and development are performed at NASA's Ames Research Center, Langley Research Center, and Glenn Research Center. Program management resides at Ames. The program is organized into four projects, as follows:

- The Advanced Air Transportation Technologies (AATT) project focuses on the development of air traffic management (ATM) tools to improve the capacity of transport aircraft operations at and between major airports. This multiyear project was initiated in 1996 with a project life of 8 years. Most of the NASA staff working on AATT reside at Ames; the rest reside at Langley and Glenn.
- The Small Aircraft Transportation Systems (SATS) project focuses on the development and demonstration of technologies to improve public mobility through increased use of local and regional airports. This multiyear project was initiated in 2001 with a project life of 4 years. All of the NASA staff working on SATS reside at Langley.
- The Virtual Airspace Modeling and Simulation (VAMS) project focuses on the development of models and simulations to conduct trade-off analyses among concepts and technologies for

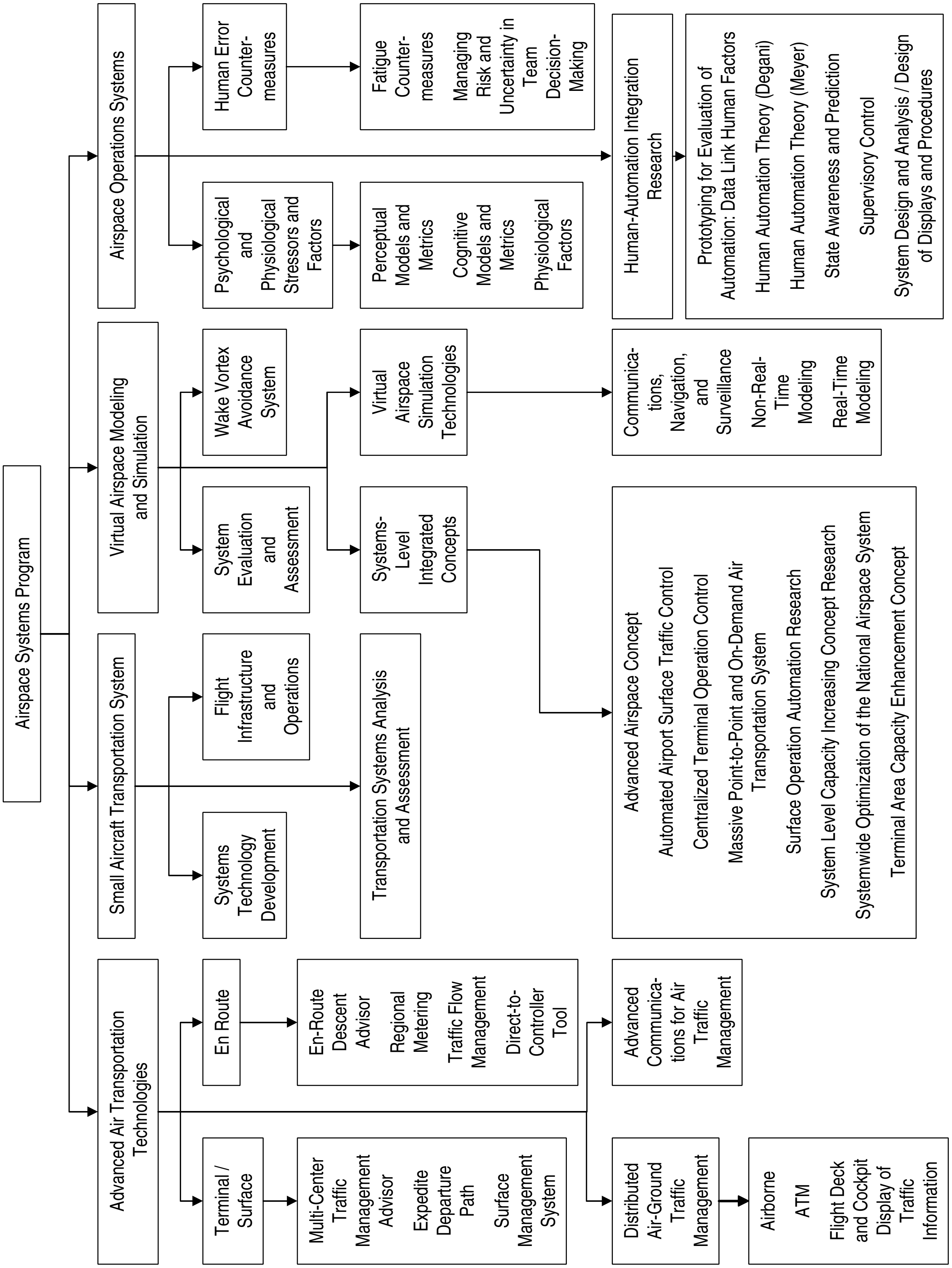

FIGURE 3-1 Airspace Systems Program organization chart.

TABLE 3-1 Net Funding and Direct NASA Staffing Levels for the Airspace Systems Program

		Federal Funding from Project Start Through FY04 (million $)			NASA Staffing Through FY04 (full-time equivalent)		
Project	Duration	Total	Annual Average	FY04[a]	Total	Annual Average	FY04[a]
AATT	FY96-FY04	317	35	41	634	70	69
VAMS	FY02-FY06	46	9	14	65	13	24
AOS	FY00-FY06	96	14	8	515	74	28
SATS	FY01-FY05	49	10	15	105	26	34
Total		508		79	1,319		155

[a] Data for FY04 are planned, as of April 2003.

SOURCE: NASA.

the air transportation system of the future. This multiyear project was initiated in 2002 with a project life of 4 years. Most of the NASA staff working on VAMS reside at Ames; the rest reside at Langley.

- The Airspace Operations Systems (AOS) project focuses on the development of better understanding, models, and tools to enhance the efficient and safe operation of aviation systems by human operators. This multiyear project became part of ASP in 2000 and has a project life of 6 years. All of the NASA staff working on AOS reside at Ames.

The ASP organization is shown in Figure 3-1. Funding and NASA staff levels are summarized in Table 3-1.

Review Process

The Panel on the Airspace Systems Program of the Committee for the Review of NASA's Revolutionize Aviation Programs met for the first time on February 24-26, 2003, in Washington, D.C. Before that first meeting, the 12 panel members had the opportunity to review the brief write-ups provided by the principal investigators of each of the tasks in response to a short questionnaire generated by NRC. The questionnaire asked for a brief description of the task, development of goals, key progress, technical issues, major publications, and roadblocks. It also asked each principal investigator to address the issue of transition, describe the relevancy of the research to NASA missions, and provide a list of internal and external customers. A blank questionnaire is shown in Appendix D.

At the first meeting, panel members received technical briefings in the form of overviews from the ASP program manager and the four project managers. A number of selected tasks were also presented by the principal investigators. The panel subsequently formed four subpanels, one for each of the four projects. Follow-up questions were generated by the panel members and forwarded to the NASA program and project managers. Each subpanel made a site visit to either NASA Langley or Ames. NASA staff from Glenn participated in the Langley site visit. The purpose of these site visits was to review NASA's response to the questions raised by the panel, to speak directly with the researchers working on each task, and to get additional detailed briefings on tasks not reviewed in detail at the first meeting. The site visits also provided an opportunity for the panel members to observe the research facilities and demonstrations of some of the products.

In addition to the site visits, a few panel members met or had telephone conversations with members of the user community, primarily FAA staff. The purpose of these meetings was to understand their views of NASA's ASP research.

The panel then met a second time, in Irvine, California, on April 30 and May 1, 2003, to finalize its results. The panel provided input to the parent committee in the form of a working report. Five members of the panel served as members of the committee.

PORTFOLIO

The Advanced Air Transportation Technologies project is nearing completion and has many near-term, mature tasks that are nearing transition to implementation. The Virtual Airspace Modeling and Simulation project is in an early stage of work and has longer-term tasks that are in the concept development and evaluation phase. The Airspace Operations Systems project supports mostly basic research. Most of the research supported by the Small Aircraft Transportation System project is best described as mid-term. NASA research facilities are world-class, as are many of the researchers. The researchers have a good idea of what they hope to accomplish and how to meet the objectives.

Finding: Support for Basic Research. Although the research portfolio is reasonably balanced, the focus is on the near- and mid-term.

Program Recommendation: Support for Basic Research. The Airspace Systems Program should support basic research relevant to long-term FAA/NASA objectives and other research with a far-sighted vision, even if some present-day users would be reluctant to adopt operational systems arising from the research. Planning for long-term research should take into account user inputs and concerns, but user endorsement of individual long-term research projects should not be viewed as a requirement for starting work.

Finding: Portfolio of the Airspace Systems Program. Most of the decision support tools being developed by NASA are designed to improve ground-based air traffic management. Not enough emphasis is placed on research in support of free flight and the self-separation of aircraft.

Program Recommendation: Portfolio of the Airspace Systems Program. NASA should plan airspace research based on a top-down understanding of the air transportation system. Research should focus on areas of greatest payoff, in terms of their ability to relieve choke points and other constraints to more efficient air transportation.

Program Recommendation: Airborne Research. NASA should continue distributed air-ground airspace research but increase the effort on the airborne side, including research to enable autonomous separation. NASA should explore revolutionary concepts and issues related to distributed air-ground airspace systems, including the distribution of decision making between the cockpit and ground systems, reorganization of how aircraft are routed, and the predicted effect of new concepts on airspace and airport capacity.

PROGRAM PLAN

Advanced Air Transportation Technologies Project

The AATT project is quite mature. It contains many tasks that are at a stage where heavy user involvement is expected. In many cases, they are almost ready for transition to the FAA and are the subject of NASA/FAA transition agreements. The FAA Office of Air Traffic Services instituted a requirement for the FAA's internal research and development organization, NASA, the MITRE Corporation, and other research organizations to use Research Management Plans (RMPs) to identify research tasks and to get assistance from the various FAA organizations that may benefit from the research. The use of RMPs is also intended to prevent unnecessary duplication of efforts among the researchers. The RMP prepared for each task describes the research, research goals, operational uses, linkages to FAA planning documents, roles and responsibilities of participating organizations, plans for resolving specific research issues, and a plan for transitioning research results to the appropriate FAA system development organization. Developing an RMP at the concept development stage of research tasks directed at improving FAA operational capabilities increases the likelihood that NASA research will be responsive to FAA needs, thereby increasing the probability that applied airspace research by NASA will be incorporated in the NAS.

The FAA's Free Flight Phase II Office uses Research Transition Plans (RTPs), which are similar to RMPs in that they outline the roles and responsibilities of NASA and the FAA in the transfer of research results from NASA to the FAA. Once the Free Flight Phase II office is disbanded, the RTP process will cease unless a similar process is established by some other FAA user of NASA research or the unique elements of the RTPs are merged into the broader RMP process.

Neither RMPs nor RTPs commit the FAA to implementing new technology. That responsibility rests with senior FAA acquisition executives and usually requires the appropriation of funds.

Finding: Research Management Plans and Research Transition Plans. RMPs and RTPs are both intended, at least in part, to facilitate transition of technology from NASA and other research organizations to the FAA.

Program Recommendation: Research Transition Plans. The RTP process should be examined to see if it contains worthwhile elements that should be included in the Research Management Plans.

Program Recommendation: Research Management Plans. NASA and FAA program directors and executives should vigorously adhere to a structured interagency approach, such as the RMP process, for coordinated planning, oversight, and periodic review of airspace research that NASA intends to transfer to the FAA for advanced development and implementation. If either party determines that the research results from a particular project will not be implemented, the interagency agreement for that project should be canceled and NASA should formally reassess the merits of continuing to develop a product that is not likely to achieve the intended goal of improving the operation of the National Airspace System.

NASA is establishing a new project, NASA Exploratory Technologies for the NAS (NExTNAS), to continue some ongoing research tasks and start some new tasks. NASA is in the process of defining the research that will be included in NExTNAS, which is expected to run from FY04 to FY08.

Finding: Continuation of Ongoing Tasks. Many existing airspace research tasks will not be completed before the expiration of the projects under which they are currently funded.

Program Recommendation: Continuation of Ongoing Tasks. NASA should include many ongoing tasks in the NExTNAS Project so they can be completed. Areas particularly worthy of continuation include the following:

- **En Route Descent Advisor task,**
- **Surface Management System task,**
- **Distributed Air-Ground Traffic Management subproject,**
- **Traffic Flow Management task, and**
- **The most promising elements of the preferred operational concept coming out of the VAMS project.**

Small Aircraft Transportation System Project

The committee welcomes the initiative taken by NASA over the last few years to redefine the objective of SATS to emphasize mobility rather than capacity. The current focus of SATS—technology development to improve the capabilities and utility of general aviation and business aircraft—is appropriate. More work to understand and mitigate the impact of SATS on the NAS and the environment would be beneficial. Increased use of SATS aircraft could increase total aircraft emissions because small aircraft consume more fuel and produce more emissions per passenger mile than large commercial transports. The demand projections for SATS technologies, however, are generally unconvincing. Projecting air travel demand with enough accuracy is difficult at best—the current state of the aviation industry shows the tremendous impact of unexpected events.

Virtual Airspace Modeling and Simulation Project

The planning of the entire VAMS project seems to have focused initially on a suite of open models and simulation tools that researchers could use to evaluate any new airspace system concept. Development of a core modeling capability for the evaluation of future operational concepts is a challenge that NASA is well suited to meet. However, experience in other fields demonstrates the difficulty of developing generic models; chances for success are improved when models are more specific. Now that new operational concepts are taking shape, the Airspace Systems Program is synchronizing the development of concepts and models. The competence of the model developers and a well-executed systems evaluation and assessment effort has the potential to mitigate much of the risk created by the early development of the models (before future operational concepts have been well defined).

Airspace Operations Systems Project

Most of the human factors research tasks in AOS are basic and should provide useful knowledge and be applicable to concepts of airspace operations that have humans in the loop. The researchers are highly motivated about their work. Many AOS tasks are focused on developing formal methods and tools that can be used to evaluate human interaction with advanced automation. The work can best be characterized as advancing the state of the art in aviation human factors research rather than meeting specific requirements, and some research is driven by the interests of individual researchers. Even so, some of the results have been applied by large airframe manufacturers. AOS research deliverables often take the form of published papers and talks at technical conferences. An integrated plan should be developed to explain how the AOS tasks are organized and work together to support the achievement of ASP objectives.

TECHNICAL PERFORMANCE

The Airspace Systems Program is well executed. The goals and objectives of each project are well defined, and the researchers are very knowledgeable about the NAS. However, some opportunities for improvement exist. Researchers generally lack the implementation experience that comes from working with operational systems. Previous activity has shown that final implementation of new air traffic control (ATC) technologies (such as those developed by NASA) can be exceedingly difficult because of stringent safety and training requirements. The record is mixed. The transition of some tools, such as the Traffic Management Advisor (TMA), to the FAA has been a great success, whereas other tools, such as the passive Final Approach Spacing Tool (pFAST) will not be incorporated into the NAS. Notwithstanding the existence of the RTPs and RMPs, NASA and the FAA have different perceptions of how to move NASA research results into operational FAA concepts.

USER CONNECTIONS

Users (e.g., controllers, pilots, and air traffic managers) are directly involved in much of NASA's airspace systems research, but in some cases user involvement earlier in the process would be beneficial. User involvement throughout the process would ensure that researchers understand and are able to respond to user perspectives.

The panel interviewed many FAA staff to understand their perception of NASA's airspace research. There was general consensus that the relationship between NASA and the FAA has improved significantly over the years. NASA researchers generally are skilled, easy to work with, and dedicated to what they do. In the past, airspace researchers were focused more on advancing the state of the art than on developing operationally useful products capable of meeting specific functional requirements. NASA is now very interested in working with the FAA to take research products into the field for testing. This is a very positive change and should be continued. It is important, however, for NASA researchers to develop a better appreciation of what it takes to transform technology into products that meet all of the safety, reliability, operability, and affordability requirements faced by the FAA and the nonstop operations of the NAS. In particular, systems must be fail-safe, and the overall acceptability of new products may be defined by what happens during abnormal or emergency operating conditions caused by equipment failures, human errors, and/or adverse weather conditions. In addition, more NASA managers than FAA managers see interactions between the two agencies as effective.

NASA should recognize that implementation decisions rest with FAA management and that advocacy by NASA, when it runs counter to FAA implementation plans, is not helpful. In particular, NASA efforts to "sell" the Direct-to-Controller tool, which is under development by the AATT project, to controllers in the field have been viewed with concern by some FAA managers.

Finding: Success Criteria. NASA tends to view success in terms of its ability to mature technology and get the FAA to implement it for operational use. Some FAA users, however, believe this view of success sometimes leads NASA to focus too much on implementation issues, which NASA may not be well qualified to resolve given its limited operational experience.

Program Recommendation: Success Criteria. NASA and the FAA should develop a common definition of what constitutes the successful completion of an applied airspace research task. Success of

NASA applied research tasks should not be measured strictly in terms of implementation.

ASSESSMENT BY PROJECT

Advanced Air Transportation Technologies Project

Background

The AATT research is organized as follows:

- Terminal/Surface subproject
  - —Multi-Center Traffic Management Advisor (McTMA) task
  - —Expedite Departure Path (EDP) task
  - —Surface Management System (SMS) task
- En Route subproject
  - —En Route Descent Advisor (EDA) task
  - —Regional Metering task
  - —Traffic Flow Management (TFM) task
  - —Direct-to-Controller Tool (D2) task
- Distributed Air-Ground Traffic Management (DAG-TM) subproject
  - —DAG-TM Airborne task
  - —DAG-TM ATM task
  - —DAG-TM Flight Deck and Cockpit Display of Traffic Information task
- Advanced Communications for ATM task

Portfolio

AATT research includes a mix of tasks that provide decision support tools for use by air traffic controllers (D2, EDA, EDP); technologies that support the management of air traffic (Regional Metering, TFM, McTMA); and technologies that suggest paradigm shifts from today's ground-based environment to a mix of ground and airborne environments for aircraft control (DAG-TM and Advanced Communications for ATM).

These tasks represent an excellent mix of near- and long-term research and a good array of concepts, especially with regard to improving the ground-based portion of the NAS. However, only a small portion of the tasks (in the AATT project and the other projects) directly support free flight and self-separation of aircraft. Some tasks, such as EDP, reflect a farsighted vision that present-day users may be reluctant to adopt. However, this is the type of project NASA should pursue because it sets the stage for long-term breakthroughs.

The FAA and NASA Administrators have approved establishment of a joint project office to coordinate efforts to develop new aviation systems. This office will report to a newly established interdepartmental policy committee, whose membership will include the Secretary of Transportation, the FAA Administrator, the NASA Administrator, and officials from the Departments of Defense, Homeland Security, and Commerce. The policy committee will be responsible for establishing national goals and objectives, reviewing policies guiding modernization of the NAS, proposing legislation, and supporting budget requests. A key goal is to establish a *transformation* program for the NAS that goes beyond current modernization efforts, which include the FAA's Operational Evolution Plan. The joint project office also has the potential to bring together efforts by RTCA committees,[1] industry, FAA, and NASA to develop future operational concepts. The establishment of a joint project office is an important initiative deserving full support by NASA and the FAA, including assignment of senior personnel from NASA and the FAA, who should be physically located in the same office. It remains to be seen how existing research projects, such as AATT, and existing coordination efforts, such as RMPs, RTPs, and the Interagency Integrated Product Team (IAIPT),[2] will fit into the work of the new joint project office.

McTMA, D2, and SMS have the potential for near-term application. They are part of the FAA's Operational Evolution Plan for Free Flight Phase II, and NASA and the FAA's Free Flight Phase II Office have signed an RTP for each of these tasks.

Other AATT tasks have a longer-term focus. NASA has submitted the Regional Metering and En Route Descent Advisor tasks to the FAA's Air Traffic Services organization with the intent of preparing RMPs for each of these tasks. This would make it more

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[1] RTCA, Inc., is a not-for-profit organization that functions as a Federal Advisory Committee to advise the FAA on issues related to communications, navigation, surveillance, and air traffic management systems.

[2] The IAIPT was established by a memorandum of understanding between the FAA and NASA and includes representatives from the FAA, NASA, MITRE Corporation, the Volpe National Transportation System Center, and the Massachusetts Institute of Technology's Lincoln Laboratory. The mission of the IAIPT is to help coordinate and improve the effectiveness of research related to air-based and ground-based ATC and traffic flow management.

likely that the FAA will make facilities and controllers available to assist in these tasks.

Program Plan

The AATT project has an extensive plan in place to track each task. TRLs are used to quantify the maturity of research (see Figure 2-3). Tasks D2, McTMA, and SMS each have an RTP and are scheduled to go to TRL 6, at which point NASA will transfer the research results to the FAA. Current plans call for the remaining tasks to be matured to TRL 4. There appears to be sufficient funding for all tasks to reach their respective TRLs, and all tasks appear to be progressing on schedule. The AATT project will end in FY04, although some tasks will continue as part of the new NExTNAS project.

Technical Performance

The airspace research facilities at NASA Ames and Langley are world-class. A mix of highly qualified NASA researchers and contractors is assigned to each AATT task. When appropriate, tasks are supported by extensive human-in-the-loop testing using retired and former air traffic controllers and retired and current pilots with various aviation ratings. NASA maintains a field test site at the Fort Worth Air Route Traffic Control Center (ARTCC) to test ATC and ATM tools. Testing of McTMA is being conducted at the New York, Cleveland, Boston, and Washington ARTCCs. A combination of various fidelity simulators at Ames and Langley provides a good balance of capabilities. NASA also uses FAA simulators and facilities throughout the aviation industry.

Moving AATT tasks to TRL 6 sometimes requires flight tests in addition to high-fidelity simulations. NASA flight test capabilities are somewhat limited and expensive to maintain, but few if any alternatives exist (few other organizations maintain flight test capabilities suitable for testing some AATT research, such as the Approach Spacing system, which was recently flight tested as part of DAG-TM at Chicago O'Hare airport).

It is difficult for the FAA to provide active-duty air traffic controllers for human-in-the-loop testing because of cost and availability issues. This may limit the amount of human-in-the-loop testing conducted and, hence, the quality of the overall test program.

Some AATT tasks suggest that current operational procedures, such as "Miles in Trail," should be replaced by a time-based metering concept or a new decision support tool for controllers. However, achieving consensus on the need for—and the nature of—changes to safety-critical controller procedures and systems is difficult for many reasons. ATM decision support tools are more readily accepted because they do not directly affect controllers and are much less critical to flight safety.

Although most AATT tasks are taking advantage of previously completed basic research, the Advanced Communication for ATM and DAG-TM tasks still require some basic research, all of which is well within the capabilities of the teams working on those tasks.

User Connections

The principal user for the AATT research is the FAA. Other elements of the aviation community would use the results of other tasks, such as SMS, TFM, and DAG-TM, although some FAA officials believe that NASA should view the FAA as the only customer for its airspace research because the FAA is the entity that will decide whether the research results will be incorporated in the NAS.

Pilots contacted by the Airspace Systems Panel indicated that pilots are generally satisfied with the involvement of the pilot community with AATT research.

NASA and the FAA signed a memorandum of understanding in September of 1995 essentially making NASA's airspace research one of the FAA's research arms. As a result, NASA participates in meetings of RTCA committees and the IAIPT to discuss NAS issues. The MITRE Corporation is also part of these meetings, where research ideas are discussed with the goal of avoiding unnecessary duplication. New operational concepts developed by NASA are intended to improve the performance of the NAS. NASA typically involves the FAA at TRL 3 or 4, when the concept is judged to be ready for simulation testing. Comments from some FAA officials indicate the desire for closer involvement at earlier stages of NASA research, which would likely increase FAA buy-in to NASA research.

The FAA has adopted TMA and implemented it at several ARTCCs. Some airline operations centers have adopted the Future ATM Concepts Evaluation Tool (FACET), which was developed as part of the TMA task. Of the three tasks with RTPs scheduled to be transferred to the FAA, two—McTMA and SMS, which are ATM tools—will most likely continue once transfer to the FAA has occurred. Comments from the FAA indicate that (1) the FAA may delay or forgo implementation of D2 research in the NAS because D2 is not included in the plan for En Route Automation Modernization (ERAM)[3] and (2) NASA programs that integrate with operational ATC systems are difficult to implement because of cost, timing, and controller acceptance. NASA has transferred to the FAA one other decision support tool (pFAST) that was not implemented, at least in part because of problems integrating pFAST with the current air traffic automation system.

Finding: Early Involvement of Users. Delaying user involvement makes it much more difficult for the concept or system design to accommodate unexpected user concerns.

Recommendation: Early Involvement of Users. NASA should involve the FAA and other users, as appropriate, early in the development of new operational concepts and airspace systems research to properly account for the need to maintain safe, continuous operations in both routine and unexpected situations.

Assessment by Subproject

Terminal/Surface Subproject

Multi-Center Traffic Management Advisor Task

This task is an enhancement to TMA, which has already been delivered to the FAA. Its goals and objectives are clear and concise. The FAA is fully involved, and an RTP between the FAA and NASA is in place. A fully functional laboratory is in place at NASA and a prototype system is in place at several key FAA facilities. Budget and time lines are adequate to fulfill the RTP.

Field testing is under way and TRL 6 should be achieved on time. The task is using proven logic from the TMA project. The concept is supported by users at the field test sites, and there are plans to continue research to expand the concept beyond the current effort involving the Boston, New York, Cleveland, and Washington ARTCCs.

The airline industry is also involved. NASA personnel are on site at the field test sites and interface daily with the FAA and airline users. TMA is already deployed at several ARTCCs, and McTMA is also expected to be accepted by the FAA.

McTMA is an excellent example of user-driven research. Live field testing is ensuring that real-world problems are being addressed.

Finding: Multi-Center Traffic Management Advisor. The McTMA task makes excellent use of field testing. The research team is very knowledgeable and is quite familiar with FAA operations. However, TMA and McTMA use a time-based metering concept that is not fully endorsed by many FAA Air Route Traffic Control Centers, which could limit the actual use of this concept by FAA controllers and traffic management coordinators.

Recommendation: Time and Workload Savings of the Multi-Center Traffic Management Advisor. NASA should thoroughly analyze the time and workload savings created by the TMA time-based metering concept to validate its potential benefits.

Expedite Departure Path Task

EDP goals and objectives are clear and potential user benefits are well understood, although technology off-ramps (i.e., the point at which research results will be incorporated in future research, implemented in operational NAS systems, or terminated) have not been well defined. EDP researchers recognize that controller acceptance of new tools such as EDP and human factors are major concerns. However, to some extent this is an implementation problem that goes beyond technology, meaning that the FAA ultimately will be responsible for solving it.

EDP is being field tested at Dallas-Fort Worth using human-in-the-loop simulations with controllers because TMA and related tools are already implemented there and Dallas-Fort Worth has high-density air traffic. The EDP research team has an excellent mix of academic involvement, drawing on studies of simulation, noise abatement, and trajectory synthesis, among others.

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[3] ERAM has been planned, budgeted, and approved through the FAA's formal decision making process and is *the* program for making improvements to the en route portion of the NAS. Trying to insert D2 in ERAM now would increase cost, delay the schedule, and perhaps increase the risk of ERAM. D2 and other new capabilities not included in ERAM will probably not be implemented until 2009 at the earliest.

EDP will contribute to greater automation of the NAS, with tools to guide controller decision making. This is a project with a farsighted vision, not necessarily one that present-day users would be willing to adopt. However, this is the type of project NASA should do because it sets the stage for long-term breakthroughs. The project appears to leverage work of others. However, since it is farsighted, it may not be perceived as acceptable to present-day users and may not retain political support.

Finding: Expedite Departure Path. EDP is the type of research that befits NASA because it has a farsighted vision that goes beyond the constraints of current operational concepts and sets the stage for potential breakthroughs. EDP also has the potential to hasten the adoption of noise- and emission-reducing departure paths.

Recommendation: Environmental Benefits of Expedite Departure Path. Acknowledging that the benefits of EDP are described primarily in terms of the potential to reduce delays, NASA should also characterize the benefit in terms of potential to mitigate the environmental effects of aviation.

Surface Management System Task

SMS research is well planned, with clear goals and objectives. Execution has been highly successful. The expertise of the contractors doing the work and the funding are adequate to complete the program. External participation in SMS research has been excellent. Personnel from the FAA and airline operations centers have been involved with design and testing. This system seems ripe for implementation. Simulations and prototype demonstrations have been successfully completed, and the research will be transitioned to the FAA in FY04.

SMS research has minimized the need to customize SMS installations at different airports to accommodate local airport configurations. The system will complement current FAA programs related to ASDE-X displays and the use of digital maps for ASDE-X as part of the Safe Flight 21 program.[4]

NASA estimates the benefit-cost ratio of SMS is 12.6 for an initial deployment at 18 sites; the committee did not independently verify this estimate. The SMS would do an excellent job of predicting aircraft arrival times at airport gates. It also has the potential to balance departure traffic among multiple runways and departure points once an aircraft is under way. However, given the short time for aircraft to reach runways once they begin taxiing and the disparate start points that exist at many airports, optimization of the departure process will be somewhat limited without reliable predictions of aircraft pushback and/or taxi start times—information that is not readily available at most large airports.

Finding: Surface Management System. SMS has strong user support, site adaptation requirements should be minimal, and the system should be able to take advantage of other FAA programs (e.g., ASDE-X displays and digital maps). However, SMS would benefit from better predeparture prediction capabilities.

Recommendation: Continuation of Surface Management System. NASA research on SMS should continue beyond the planned end date to add more predeparture prediction capability.

En Route Subproject

Regional Metering Task

Goals and objectives are clearly defined through TRL 4/FY04, but plans for further research have yet to be defined, although the Regional Metering task has been proposed for inclusion in NExTNAS. Research personnel are very knowledgeable, progress metrics have been defined, human factors are fully integrated, and required laboratory facilities and support contractors are in place. Modeling and human-in-the-loop testing are well planned, but human-in-the-loop testing is expensive and is limited by budgets.

Regional Metering is an enhancement to TMA. The Regional Metering enhancement will take time-based metering to more local airports, so the more TMA becomes accepted by users, the better understood the Regional Metering concept will be. NASA is well aware that user acceptance of time-based metering (as opposed to miles in trail) is critical to ultimate success of Regional Metering. Regional Metering addresses

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[4] Airport Surface Detection Equipment Model X, better known as ASDE-X, is an advanced traffic management system for aircraft on the ground.

real-world problems and the hypotheses upon which it is based are highly plausible.

Finding: Regional Metering. NASA and the FAA understand that automated traffic flow management tools have the potential to provide important benefits, thereby justifying the effort to take Traffic Management Advisor, Regional Metering, and Multi-Center Traffic Management Advisor research a step further. However, like Multi-Center Traffic Management Advisor, Regional Metering uses a time-based metering concept that is not fully endorsed by the FAA controllers at many Air Route Traffic Control Centers, which could limit the actual use of this concept by FAA controllers and traffic management coordinators.

Recommendation: Time and Workload Savings of Regional Metering. NASA should thoroughly analyze the time and workload savings created by the Regional Metering time-based metering concept to validate its benefits. NASA should decide whether to continue support of Regional Metering research under the NExTNAS project after this analysis has been completed.

En Route Descent Advisor Task

EDA works in conjunction with TMA and uses the logic of the Center TRACON (Terminal Radar Approach Control) Automation System (CTAS)[5] and D2 to enhance these tools. The EDA task has well-defined goals and objectives; it is focused on reducing controller workload and aircraft flight times through automation. User benefits have been validated through simulation, but the FAA has not yet endorsed the concept. Support contractors are in place for coding and testing. Researchers working on this task are well aware of controller concerns about active advisory tools. NASA researchers are knowledgeable, and laboratory facilities are adequate to support research through TRL 4. There is a very good plan to take EDA to TRL 4 and to continue research beyond FY04 as part of NExTNAS.

EDA research is using active and retired controllers for human-in-the-loop testing. Lessons learned from pFAST are improving user acceptance. Human factors studies have been included from the beginning.

EDA is applied research at this point. Real-world problems are defined and well addressed.

Finding: En Route Descent Advisor. NASA is making good use of existing software as the core of the EDA concept and is taking advantage of new concepts, such as datalink, that are included in the FAA's Operational Evolution Plan. However, the FAA has not committed to support EDA development past technology readiness level 4. Also, FAA controllers seem reluctant to accept decision support tools that provide active advisories; they prefer tools they can call on when needed.

Recommendation: Transition Plan for En Route Descent Advisor. NASA and the FAA should agree to a Research Transition Plan or Research Management Plan for EDA to ensure continued FAA support before NASA commits to including EDA in the NExTNAS project.

Direct-to-Controller Tool Task

D2 research has clear goals and objectives with realistic deliverables. Early operational testing of CTAS indicated the need for a tool to help controllers identify conflict-free direct routes to downstream fixes. This testing serves as the underlying system-level assessment that demonstrates the need for and value of tools like D2. D2 software has been integrated in the release version of CTAS that is in use at the Fort Worth en route center, and NASA's D2 research is almost complete.

To avoid the implementation problems encountered by pFAST, researchers would like to stay connected to the research after it is turned over to the FAA by serving as "high-powered consultants." However, as discussed above, implementation of D2 will be delayed or canceled because the FAA did not include D2 in ERAM.

NASA D2 researchers are very focused on user adoption, and a prototype D2 tool has been successfully tested under operational conditions at one of the FAA's ARTCCs. NASA researchers have demonstrated that a tool like D2 that automatically generates optimum flight paths without prompting by controllers can be more effective (at, for example, reducing air-

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[5] The goal of CTAS is to provide automation tools that help controllers reduce aircraft delays, increase airport capacity, and reduce fuel consumption without reducing safety or increasing controller workload.

craft flight times) than a tool that is active only upon controller request. However, controllers interviewed by the committee seemed to prefer the latter, and the FAA has decided to implement such a tool instead of D2.

Human factors are an integral part of the project. The mix of personnel appears appropriate.

Finding: Direct-to-Controller Tool. D2 research reportedly has a high benefit-to-cost ratio and is closely connected to implementation research and design work at the FAA. However, for reasons not directly related to technical performance and specifications, FAA may decide not to implement D2, which greatly weakens the justification for its continued development.

Recommendation: Deferral of Research on the Direct-to-Controller Tool. Further work on D2 should be deferred until the FAA has established a likely implementation date for D2.

Traffic Flow Management Task

The TFM task expands upon existing manual and automated systems, mostly at ARTCCs and TRACONs, that try to deal with situations when demand exceeds available capacity—for example, because of closed runways, hazardous weather, or staffing shortages. Expansion of local and regional systems into a national system is a logical step that will facilitate national (and even global) optimization instead of less-efficient local or regional optimization.

TFM research is driven by user needs, and NASA is testing TFM research results in an operational environment. Because TFM addresses flight planning and routing by airlines rather than operational control of aircraft by controllers, live testing has no safety implications. Early systems are already in use by some airlines and FAA facilities. TFM research should continue under NExTNAS so this technology can be fully implemented.

Development of the Future ATM Concepts Evaluation Tool (FACET) has been a very successful part of the TFM task. FACET has many potential uses—some of which are not suggested by its name. For example, field testing is examining the ability of FACET to identify congested areas so airline dispatchers can reroute flights around them. The initial system seems ready for expansion into other airline facilities. A version of FACET known as the Systemwide Evaluation and Planning Tool (SWEPT) is being implemented by the Department of Transportation's Volpe National Transportation Systems Center on behalf of NASA for testing by FAA TFM managers at the FAA's Air Traffic Control System Command Center in Herndon, Virginia.

NASA estimates that national deployment of a decision support tool based on FACET for direct routing would produce annual savings on the order of $200 million. The committee did not independently verify this estimate.

Finding: Traffic Flow Management and the Future ATM Concepts Evaluation Tool. FACET can be implemented quickly without pilot or controller involvement, which greatly reduces implementation risk. Postevent analysis using FACET helps identify operational and training problems. However, standardization of flight planning data and procedures by the FAA and the airlines would maximize the benefits provided by FACET. This may be difficult to achieve because changing data and procedures used by an airline operations center may raise institutional issues at individual airlines that would be difficult to overcome. Airlines would benefit from better operational support predictions, but the flight planning data and procedures used by an airline also reflect business considerations that may have a higher priority.

Recommendation: Traffic Flow Management and the Future ATM Concepts Evaluation Tool. NASA should use the results of operational testing to further improve FACET and its derivatives, such as the Systemwide Evaluation and Planning Tool (SWEPT), and assist the FAA with its implementation.

Distributed Air-Ground Traffic Management Subproject

DAG-TM research is based on the premise that "large improvements in system capacity, airspace user flexibility, and user efficiency will be enabled through (1) sharing information related to flight intent, traffic, and the airspace environment; (2) collaborative decision making among system participants on the ground and in the air; and (3) distributing decision authority to the most appropriate decision maker."[6] Part of the paradigm shift included in DAG-TM is the transfer of some responsibility for aircraft separation from ground controllers to air crews. NASA expects DAG-TM research to produce definitions of operational concepts, prototype systems and procedures, system descriptions and specifications, validation results, requirements for supporting technologies, safety assessments, and cost-benefit assessments.[7]

The overarching DAG-TM operational concept originally included 14 specific elements covering every phase of flight, from preflight planning and surface departure to terminal approach and surface arrival (two or more concept elements were originally proposed for some phases of flight). Some concept elements, however, have been dropped or delayed because of a lack of resources. Demonstrating the feasibility, costs, and benefits of DAG-TM will require that work continue beyond the end of the AATT project (e.g., by including DAG-TM in NExTNAS).

The ground segment portion of DAG-TM seems to be well accepted by the controllers who participated in the research. Similarly, the airborne segment was well accepted by individual pilots. However, senior FAA managers and airlines seem to have relatively little awareness of DAG-TM.

DAG-TM research is well coordinated with comparable work worldwide. Academic and other work has been highly leveraged. DAG-TM goals and objectives are clearly defined. Distributed air-ground decision making could produce large benefits, but DAG-TM research is a long-term effort, and it will be some time before benefits can be validated. The airborne components are in early stages of development and will require extensive human factors research, which NASA is well positioned to do. DAG-TM research has successfully completed low-fidelity simulations of both ground and airborne elements, and high-fidelity simulations are scheduled. Field tests may be required to validate some benefits and to generate support within the aviation community for DAG-TM operational concepts.

DAG-TM is conducting cutting-edge research that shows great promise and can best be performed by NASA.

Increasing airport capacity may be the single most important factor in improving the total capacity of the NAS. To conduct independent landings during instrument meteorological conditions (IMC), the current minimum separation between parallel runways is 4,300 ft (or 3,400 ft with the Precision Runway Monitoring system). An earlier NASA project, Airborne Information for Lateral Spacing, conducted research on a system that would enable independent parallel approaches on parallel runways separated by as little as 2,500 ft, but the project ended without convincing the FAA that the proposed concept was ready to move forward to implementation. One of the DAG-TM concept elements (concept element 13, Closely Spaced Approaches) addressed this issue, but no work is currently under way. Existing separation requirements inhibit or prevent the construction of new runways at many airports. Reduced separation requirements would generally lower the cost of new runways and reduce environmental impacts, making it easier for expansion projects to be approved.

Finding: Distributed Air-Ground Traffic Management. Because DAG-TM involves revolutionary changes to current operational concepts, it will be neither quick nor easy to overcome the technical challenges associated with system development, transition, performance, safety, reliability, and affordability or the policy, regulatory, cultural, and other nontechnical or quasitechnical issues and concerns that must be overcome to achieve broad community consensus on any major change to the air transportation system. Also, many DAG-TM concept elements have been dropped because of insufficient funding, including the element that supports research to reduce runway separation requirements.

Recommendation: Continuation of Distributed Air-Ground Traffic Management. NASA should continue DAG-TM research beyond the end of the Advanced Air Transportation Technologies project.

Recommendation: Air-Ground Balance of Distributed Air-Ground Traffic Management. As DAG-TM research progresses, trade studies should continue to evaluate the balance between airborne and ground components. A complete shift of decision

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[6] R. Mogford, NASA Ames Research Center, and M. Ballin, NASA Langley Research Center, "Distributed Air/Ground Traffic Management," page 3 of a presentation to the Airspace Systems Panel on February 26, 2003.

[7] Ibid., p. 4.

authority from the ground to the air should be evaluated for oceanic and low-density airspace.

Recommendation: Reactivation of Concept Elements in the Distributed Air-Ground Traffic Management Subproject. DAG-TM concept elements dropped because of insufficient funding should be evaluated for reactivation. In particular, DAG-TM should support research with the goal of significantly reducing runway separation requirements for parallel runways in instrument meteorological conditions.

Advanced Communications for Air Traffic Management Task

Research being conducted by this task concerns an area that is being vigorously debated in the community. Some FAA staff have selected a particular communications standard—very high frequency (VHF) Data Link Mode 3 (VDLM3)—as the favored long-term solution for line-of-sight voice and data communication. Many airspace users, however, believe it is too early to establish a long-term standard for voice and datalink communications. Furthermore, international air carriers believe a global standard for voice and datalink communications should be established, and VDLM3 has not yet been accepted as a global solution. The scope of the research includes a mixture of voice and digital datalink technologies via both ground-based and satellite-based transmissions with a focus on new and promising satellite Ku-band techniques. The researchers are well informed about other work, especially the work being conducted at Boeing.

Finding: Advanced Communications for Air Traffic Management. The Advanced Communications for ATM task is conducting basic research on a well-thought-out collection of techniques to improve the throughput of voice and datalink communications to and from aircraft.

Recommendation: Global Compatibility. In conjunction with similar research by other organizations throughout the world, NASA research on advanced communications for air traffic management should focus on concepts and provide technical information to help inform the ongoing, international debate about the future shape of global voice and datalink communications.

Small Aircraft Transportation System Project

Background

The SATS vision is to provide "equitable, on-demand, widely distributed, point-to-any-point, near all-weather, 21st Century mobility. . . . The first step is 'to prove SATS works' [by providing a] technical, operational, and socio-economic basis for national investment and policy decision."[8]

The SATS project has two fundamental components. The first component, which is being executed by the Systems Technology Development task and the Flight Infrastructure and Operations task, is focused on demonstrating "the technical and operational feasibility of the four operating capabilities."[9] These capabilities are as follows:

- Higher volume operations in nonradar airspace and at nontowered airports,
- Lower landing minima at minimally equipped landing facilities,
- Increased single-pilot crew safety and mission reliability, and
- En route procedures and systems for integrated fleet operations.

The technology demonstrations will include an integrated flight evaluation to assess the "performance and operational feasibility . . . of the four operating capabilities in an integrated fashion" to verify that "pilots can safely perform HVO [higher volume operations] and LLM [lower landing minima] operations together."[10]

Specific goals and the general approach for each operational capability are depicted in Table 3-2. Demonstrating these capabilities will require the new application of existing technologies as well as advances in ground and airborne technologies. New airborne technologies being developed by SATS are intended primarily for incorporation in a new generation of aircraft, although some of the airborne technologies could also be incorporated in current production aircraft.

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[8] J. Hefner, NASA Langley Research Center, "Small Aircraft Transportation Systems project overview," pages 9 and 10 of a presentation to the Airspace Systems Panel on February 25, 2003.

[9] Ibid., p. 28.

[10] S. Johnson, NASA Langley Research Center, "Small Aircraft Transportation System: systems technology development," page 56 of a presentation to the Airspace Systems Panel on February 25, 2003.

TABLE 3-2 NASA Summary of the Goals and General Approach for SATS Operating Capabilities

Goal	Capability of the Current National Airspace System	Minimum Success Criteria	Stretch Goal	Approach
Higher-volume operations	One operation at a time in nonradar airspace (~3 landings per hour)	Two simultaneous operations	Up to 10 simultaneous operations	Enable simultaneous operations by multiple aircraft at nonradar, nontowered airports in nearly all weather conditions.
Lower landing minima	Expensive ground infrastructure required[a]	Cloud ceiling of 200 ft and visibility of ½ mile	Visibility of ¼ mile	Enable safe low-visibility operations at minimally equipped landing facilities.
Single-pilot performance	Advanced flight-deck technology just emerging	Performance of a private pilot equal to that of an airline transport pilot (ATP)	Performance of a private pilot equal to a crew of two ATP-rated pilots	Increase single-pilot safety, precision, and mission completion through the use of human-centered automation.
En route integration	SATS not included in current simulation and assessment tools	Assess impact of SATS-enabled traffic on NAS operations	Mitigate impact of SATS on NAS operations	Develop models and tools to assess integration of SATS-enabled aircraft into en route air traffic flows and controlled airspace.

[a] The FAA's Wide Area Augmentation System, which was commissioned for initial use in July 2003, can support operations with cloud ceiling down to 250 ft and visibility of down to ¾ mile without any ground infrastructure at local airports.

SOURCE: S. Johnson, NASA Langley Research Center, "Small Aircraft Transportation System: systems technology development," presentation to the Airspace Systems Panel on February 25, 2003.

The second component of the SATS project, which is being executed by the Transportation Systems Analysis and Assessment task, is focused on (1) providing "program management and partners with analytical tools and information necessary to make strategic and tactical resource allocation decisions," (2) translating the "technical results of the demonstration into outcome-based meaning for public consumption," and (3) projecting the "impact of SATS Program accomplishments on potential SATS implementation in 2010 and on the SATS vision for 2025."[11] Because the components are so different, they will be evaluated separately under the headings "Demonstration" and "Assessment."

NASA has formed the National Consortium for Aviation Mobility to participate with NASA in the SATS project. The major participants in the consortium are four SATSLab Partnerships, whose memberships include industry, small airports, and local and state agencies from 12 states: Maryland, Delaware, and New Jersey (Maryland Mid-Atlantic SATSLab); North Carolina, Oklahoma, Nebraska, Kansas, North Dakota, and South Dakota (North Carolina and Upper Great Plains SATSLab); Florida and Georgia (Southeast SATSLab); and Virginia (Virginia SATSLab). The consortium contributes to the SATS project by sharing costs, contributing expertise and capabilities, and en-

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[11] S. Cooke, NASA Langley Research Center, "SATS transportation systems analysis and assessment (TSAA) overview," page 3 of a presentation to the Airspace Systems Panel on February 25, 2003.

hancing opportunities for technology infusion, commercialization, and certification.[12]

The SATS Project Office includes representatives from the FAA and the Department of Transportation's Volpe National Transportation Systems Center. Collectively, the SATS Project Office and the National Consortium for Aviation Mobility are referred to as the SATS Alliance.

Portfolio

Demonstration

The current allocation of resources by the SATS project, which emphasizes technology development to achieve important operational capabilities rather than economic assessments and demand studies, is appropriate and is most likely to improve the operability and utility of general aviation aircraft, business aircraft, and small airports.

Assessment

NASA describes the deliverables planned for this component as follows:

- a "series of business case plans outlining the political, operational, environmental, technical and socioeconomic benefits of a SATS implementation at regional and national levels"
- a "Transportation Mobility Assessment Report that details progress towards the NASA OAT [Office of Aerospace Technology] mobility goal as a function of the SATS operating capabilities"
- a "Comprehensive Technology Assessment Report for the four SATS operating capabilities"
- a "series of multimedia (interactive audio, video, simulation & analysis) stakeholder value proposition packages designed to provoke follow-on investments towards a future SATS implementation"
- a "gap analysis and roadmap for follow-on investments"

Finding: Deliverables of the Small Aircraft Transportation System Project. Many SATS deliverables, particularly the business case plans and the "stakeholder value proposition packages" call for financial and business expertise that lies outside NASA's core competencies.

Recommendation: Roles of NASA and the Consortium. The National Consortium for Aviation Mobility should focus on business case development and stakeholder deliverables that require expertise outside NASA's core competence. Technology assessments should be completed using NASA's in-house expertise.

Program Plan

Demonstration

Planning to demonstrate the operational capabilities is thorough, especially with regard to the airborne systems. Even so, the goals are quite ambitious, and after the planned demonstrations are complete much will still need to be done before the capabilities can be deployed. For example, demonstration of operations with reduced landing minima is just the first step in development and certification of commercially available systems that satisfy the performance and safety considerations of the FAA and aircraft owners and operators. The SATS project is relying on the FAA to provide information on certification requirements and acknowledges the need to increase interactions with the FAA in this area.

Finding: Certification and Implementation of Small Aircraft Transportation System Technologies. Much more is required beyond planned work to ensure that certification issues do not unnecessarily delay the operational availability of new technologies being developed by SATS, especially with regard to lower landing minima at non-towered airports.

Recommendation: Certification and Implementation of Small Aircraft Transportation System Technologies. NASA should increase interactions with the FAA regarding certification issues and plans for incremental implementation of SATS technologies and systems to minimize the likelihood that certification and planning issues will unnecessarily delay their operational availability.

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[12] J. Hefner, NASA Langley Research Center, "Small Aircraft Transportation System project overview," page 28 of a presentation to the Airspace Systems Panel on February 25, 2003.

Finding: Human Factors Issues with the Small Aircraft Transportation System. Many unanswered questions remain about human factors issues, especially as they relate to single-pilot performance and self-separation of aircraft for higher-volume operations.

Recommendation: Human Factors Research for the Small Aircraft Transportation System. NASA should ensure that SATS human factors research adequately addresses the following issues:

- **Man/machine interface issues associated with SATS cockpit displays and management of aural and datalink products delivered to the cockpit, including weather data;**
- **Shift of responsibility for separation from controllers to pilots during IMC approaches, particularly with regard to pilot work load, situational awareness, and safety; and**
- **Pilot decision making and judgment before flight and in flight.**

Finding: Benefits of Small Aircraft Transportation System Technologies. SATS technologies, particularly the new cockpit technologies, could provide important benefits both to small aircraft and to aircraft larger than those envisioned for the SATS project.

Recommendation: Expedited Deployment of Selected Small Aircraft Transportation System Technologies. NASA should seek opportunities to expedite the incremental introduction of enhanced cockpit and air traffic management technologies and procedures, which could benefit a large segment of the general aviation community and would likely generate greater user support for SATS. Continued development of SATS technologies, particularly cockpit technologies and related human factors issues, should be the focus of any SATS research that continues beyond the 2005 end date of the current SATS project.

Assessment

The SATS Alliance has made a substantial effort to predict the future demand for SATS technologies and aircraft. While it would be useful to project the demand for SATS technologies and aircraft if it could be done accurately, the demand projections completed to date are generally unconvincing to organizations without a stake in the outcome.

The committee also questions the impetus behind the demand analyses. A previous assessment of SATS research, conducted by the National Research Council, endorsed research directed at the four operational capabilities but questioned the validity of many of the demand studies conducted by the Alliance.[13] This committee supports the results of the earlier study and cautions that continued reliance on these questionable demand studies might diminish rather than enhance the prospects for continued development of SATS technologies. In the end, it may not be possible to project future demand with enough accuracy to justify the cost of deploying a small aircraft transportation system, especially given the current state of the aviation industry. In fact, the current state of the industry, which has been devastated in large part by unforeseen (and unforeseeable) events like the 9/11 attacks and the SARS epidemic, illustrates the practical limits of trying to predict the future.

Strong demand for business jet purchases and fractional ownership has been used to support the argument that there will be strong demand for SATS aircraft once they are available. Since the SATS project began, however, the market for business aircraft has diminished significantly. Just during the first half of 2003, NetJets, the largest fractional operator of business jets (and the only one currently making a profit) reduced the size of a large order. In response to reduced demand, Cessna is laying off 10 percent of its workforce during 2003 and furloughing over half of its remaining employees for 7 weeks. The downturn in the economy—and an accompanying glut of used business jets—is probably the main factor leading to this situation.

If the value of SATS research is tied to the demand for SATS aircraft, and if the demand for SATS aircraft is tied (directly or indirectly) to the overall demand for air travel, then the current downturn in commercial and business air travel could be used to argue that the value of SATS research has been diminished. However, the committee firmly believes that the operational capabilities under development by SATS will be worth-

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[13] National Research Council. 2002. Future Flight: A Review of the Small Aircraft Transportation System Concept. Transportation Research Board. Washington, D.C.: National Academy Press.

while and should be pursued, regardless of current trends and expectations of future demand for commercial air transportation or business jets.

In 1996, aircraft of all types (civil and military, commercial and general aviation) operating under instrument flight rules (IFR) made 14.8 million trips through the NAS. About half of these trips (7.2 million) were by commercial air carriers and about one-fifth (3.1 million) were by air taxis.[14] In 2000, commercial air carriers made 9.0 million trips of all kinds (IFR and visual flight rules).[15] By one estimate, the SATS project could lead to 31 million trips annually by SATS aircraft 22 years after the technology becomes operational.[16] This tremendous increase in the number of flight operations would be a huge burden for the NAS, given the capacity and delay problems that the system was experiencing from the normal expansion of commercial aviation until 9/11.

One of the objectives of the SATS project is to "assess SATS' economic viability and impact on National airspace and airport infrastructure."[17] Demand projections seem focused on accomplishing the first part of this objective; the last part is being addressed by the En Route Integration operational capability (see Table 3-2). Given (1) the questionable accuracy and utility of long-term demand projections for a new transportation system and (2) the challenging technical issues that would need to be overcome to allow the NAS and local airports to accommodate a large fleet of SATS aircraft, the committee believes that the resources and expertise that NASA is devoting to the demand projections should be focused instead on assessing the impact of SATS on the NAS, including airport infrastructure.

Finding: Demand Projections for the Small Aircraft Transportation System. The demand projections for SATS technologies are generally unconvincing and misdirected.

Recommendation: Demand Projections for the Small Aircraft Transportation System. NASA should use demand projections to identify a range of flight activity that SATS aircraft and technologies might create for specific city pairs. The Transportation Systems Analysis and Assessment task should then use this information to help the SATS project as a whole assess the impact of SATS technologies and aircraft on the National Airspace System (including infrastructure requirements at local airports) and the environment (in terms of noise, fuel consumption, and emissions). These assessments should also explore options for minimizing the impacts and thereby improving the viability of the SATS concept.

Technical Performance

Demonstration

The overall execution of the technology demonstration effort is superior, with competent NASA staff, adequate facilities, and an acceptable level of contractor support.

Assessment

The NRC's previous assessment of SATS research[18] raised substantial questions about the SATS vision, the assessments being conducted by the SATS project, and the assumptions upon which the vision and the assessment seemed to be based. Since the earlier report was published, NASA has made progress in conducting more rigorous assessments, but not all of the questionable analyses that predated the NRC's earlier study have been purged from the SATS project.

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[14] FAA. 1997. FAA Statistical Handbook of Aviation 1996. Table 2.2, Air traffic activity at ARTCCs, by aviation category, fiscal years 1992 to 1996. Available online at <www.api.faa.gov/handbook96/sh2-296.pdf>.

[15] Bureau of Transportation Statistics (BTS). 2001. Airport Activity Statistics of Certificated Air Carriers: Summary Tables 2000. Publication BTS01-05. Table 1, Summary of aircraft departures and enplaned passengers, freight, and mail by carrier group, air carrier, and type of service: 2000. Washington, D.C.: BTS. Available online at <www.bts.gov/publications/airport_activity_statistics_of_certified_air_carriers/2000/index.html>.

[16] S. Dollyhigh. 2002. Analysis of Small Aircraft as a Transportation System, NASA/CR-2002-211927. Hampton, Va.: Swales Aerospace.

[17] J. Hefner, NASA Langley Research Center, "Small Aircraft Transportation Systems project overview," page 14 of a presentation to the Airspace Systems Panel on February 25, 2003.

[18] National Research Council (NRC). 2002. Future Flight: A Review of the Small Aircraft Transportation System Concept. Transportation Research Board. Washington, D.C.: National Academy Press.

The SATS project seems to have been redirected during the 2002 to 2003 time frame. NASA has emphasized that SATS is more about mobility than capacity and should be considered as an alternative to travel on existing commercial carriers and other modes of transportation. SATS technologies could increase use of on-demand air taxis for passenger traffic. However, widespread use of SATS aircraft could also have negative environmental effects given that SATS aircraft may consume more fuel and produce more emissions per passenger-mile than either large commercial transports or private automobiles. SATS aircraft may also result in higher levels of aviation noise at small airports. It will be difficult for the SATS project to dispel ongoing uncertainty about the ultimate impact of SATS on congestion and delays at hub airports; the ability of rural and suburban populations to access the air transportation system via small, minimally equipped airports; aviation safety; and the environmental effects of aviation globally, regionally, and in the vicinity of small and large airports.

User Connections

The National Consortium for Aviation Mobility has created a network of over 150 interested organizations, including aircraft and equipment manufacturers, aircraft operators, airports, academia, state and local government agencies, and academic institutions. Many of these outside organizations have already participated in the SATS project by providing goods or services to support accomplishment of the SATS vision, and more plan to do so. The SATS project is well connected to the small communities with airports and current air taxi operators who would be critical to the success of the first phase of operational deployment of SATS aircraft and technologies.

Finding: Outreach Efforts by the Small Aircraft Transportation System Project. The SATS outreach effort does not include air taxi companies or other commercial operators who have publicly stated their intention to incorporate in their operations SATS technologies and systems as they become available.

Recommendation: Membership of the Small Aircraft Transportation System Alliance. To enhance the credibility of deliverables produced by the SATS Alliance, NASA should expand the SATS Alliance with potential SATS customers—that is, current or potential air taxi companies and other commercial operators that are willing to publicly state their intention to incorporate SATS technologies and systems in their operations by modifying existing aircraft and/or acquiring new aircraft.

Virtual Airspace Modeling and Simulation Project

Background

The VAMS project was initiated in November of 2001 to improve the ability to identify and assess capabilities that will increase the capacity of the NAS while maintaining safety and affordability. The project is motivated by shortcomings in current capabilities for assessing the systemwide impacts of proposed improvements. The VAMS project builds on ongoing near-term technology development and system modernization efforts by the FAA, NASA, and industry.

The objectives of the VAMS project are to define and evaluate new operational concepts, generate roadmaps for developing and enabling applicable technologies, and establish the capability to assess these concepts. Products will include advanced airspace system operational concepts at the domain and system levels, a validated modeling and simulation capability to assess new operational concepts at the domain and system level, preliminary evaluations of the concepts, and technology roadmaps to implement proposed concepts. These preliminary evaluations will identify gaps and transitional issues.

The VAMS project supports research in four areas, as follows:

- Systems Level Integrated Concepts (SLIC) subproject
  - —Advanced Airspace Concept task
  - —Automated Airport Surface Traffic Control task
  - —Centralized Terminal Operation Control task
  - —Massive Point-to-Point and On-Demand Air Transportation System task
  - —Surface Operation Automation Research task
  - —System Level Capacity Increasing Concept Research task
  - —Systemwide Optimization of the National Airspace System task
  - —Terminal Area Capacity Enhancement Concept task

- Virtual Airspace Simulation Technologies (VAST) subproject
  - —Communications, Navigation, and Surveillance task
  - —Non-Real-Time Modeling task
  - —Real-Time Modeling task
- System Evaluation and Assessment (SEA) task
- Wake Vortex Avoidance System (WakeVAS) task

NASA Ames has the lead for all of the above research, except for the Communications, Navigation, and Surveillance portion of VAST (Glenn) and WakeVAS (Langley).

Portfolio

The VAMS portfolio is focused on three interrelated areas: developing revolutionary operational concepts at least 10 to 15 years in the future; developing modeling capabilities to evaluate these and other future concepts; and establishing metrics to support the concept evaluations. The VAMS tasks are well balanced across these three areas. As discussed in the following section, close linkage of the work in all three areas is essential to take full advantage of this balance.

Program Plan

Planning of the VAMS project seems to have focused initially on a suite of open models and simulation tools that are intended to allow researchers to evaluate any airspace system concept. Shortly after the program was initiated, NASA funded industry to develop new airspace system concepts.

The models are being developed in an iterative fashion, with the first increment consisting of generic, low-fidelity models linked together in an architecture for assessing NAS-wide impacts. The first increment is intended to validate systemwide processing while the various operational concepts are being developed in parallel. Past efforts to develop generic models in other fields have failed, and the generic models and simulations developed by VAMS will not be able to accurately model all of the new concepts. Accordingly, subsequent increments will replace the generic models with increasingly higher-fidelity representations of the new elements of the operational concepts. However, given the relatively large number of concepts being developed and the large number of elements in many of the concepts, VAMS will not have sufficient resources to represent all elements of all models at equal fidelity. The program plan calls for a synthesis of the most promising concept elements into one or more preferred operational concepts.

Finding: Virtual Airspace Simulation Technologies Models. Modeling efforts are more likely to succeed when the modelers know what concepts they will be required to model.

Recommendation: Virtual Airspace Simulation Technologies Models. Model development by the VAST task should be closely tied to the operational concepts that the models are intended to evaluate, primarily by concentrating on the most promising elements of the preferred operational concept as they are identified.

Technical Performance

NAS Ames has highly capable systemwide modeling capabilities for evaluating future ATM concepts. The VAMS project is making full use of these capabilities. The models produced by VAMS are intended to far exceed the capabilities of most current models, which generally represent only a single entity within the national airspace system (such as an airport) and thus are not capable of evaluating systemwide impacts. Although some existing models do evaluate systemwide impacts, the capabilities of VAMS models will also go beyond existing systemwide modeling capabilities.

User Connections

Many of the operational concepts under development by VAMS were initially defined by processes outside the auspices of the VAMS project that had substantial user involvement. Now, however, development of these concepts has little user involvement. More user involvement would be helpful and—hopefully—would lead to broad support from the user community.

Finding: User Connections to the Virtual Airspace Modeling and Simulation Subproject. User involvement is a crucial ingredient in evaluating and selecting elements of various operational concepts for integration into a preferred concept.

Recommendation: User Connections to the Virtual Airspace Modeling and Simulation Subproject. NASA should work with the user community to identify criteria for downselecting operational concepts, prioritizing features to be included in the modeling and evaluation tools being developed by the Virtual Airspace Simulation Technologies task, synthesizing the operational concepts, and determining what further technical investigations are required to support development of each element of the preferred concept.

Assessment by Subproject

Systems Level Integrated Concepts Subproject

The objective of the Systems Level Integrated Concepts subproject is to identify revolutionary operational concepts with the potential for large increases in capacity at the system and domain levels over a 20-year time frame. The intent is to evaluate the concepts using VAST and, ultimately, more in-depth technical investigations.

NASA is sponsoring the development of a broad set of operational concepts by academia, industry, and government to complement NASA's established in-house programs for operational concept development. These concepts currently exist at varying levels of maturity, from new, outside-the-box ideas to broadly coordinated concepts that are already gaining wide acceptance in the stakeholder community.

Fourteen concepts are under development, but the available resources (budget, time, and staff) will not allow developing all of them to the level of detail required for VAST to evaluate them at an acceptable level of fidelity. The current plan for the integration (or synthesis) of the operational concepts needs to be enhanced, especially in terms of downselect criteria and cost-benefit analyses.

The intent is to integrate individual operational concepts into a preferred, comprehensive, NAS-level operational concept. However, an integration process has not been developed. In addition, NASA should generate a plan for involving stakeholders and gaining their support for the resulting integrated concept, especially with respect to existing operational concepts developed by RTCA and the FAA and concepts that will be developed or endorsed by the new joint project office.

Finding: Systems Level Integrated Concepts. The process being used to develop new operational concepts is sound, and the concepts under development are comprehensive in scope. Although none of the concepts targets the en route domain, this domain appears to be adequately addressed within the system-level concepts. Also, although future interactions are planned, to date there has been no linkage between the concept development activities and the Virtual Airspace Simulation Technologies task, which is intended to develop the models and simulations that will be used to evaluate the concepts. Also, there is no plan for including the concept developers in the evaluation process, which may limit its effectiveness.

Recommendation: Interactions between Virtual Airspace Simulation Technologies and Systems Level Integrated Concepts. NASA should foster an ongoing interchange between the SLIC and VAST development teams to ensure that VAST models will contain the features needed to fully evaluate new operational concepts.

Recommendation: Use of Virtual Airspace Simulation Technologies by Concept Developers. NASA should establish a plan for supporting Virtual Airspace Modeling and Simulation concept developers in their use of VAST models.

Recommendation: Assessment of Virtual Airspace Modeling and Simulation Operational Concepts. NASA should review and better define the process that will be used to select which concepts will be integrated into a preferred, comprehensive system-level operational concept that will provide the basis for future technical investigations. This process should include constraints on available resources, clear decision criteria, and the inputs from stakeholders.

Virtual Airspace Simulation Technologies Subproject

VAST includes separate efforts focused on real-time and non-real-time modeling. The non-real-time portion of VAST seeks to create and assemble agent-based models, simulations, and tools (federates) to form a high-level collection of models (a federation) that will support fast-time assessment of new operational concepts at both the domain and systemwide levels.[19] This is an ambitious goal.

The real-time portion of VAST is intended to play a major innovative role in the modeling of the NAS through the integration of distributed real-time simulation models and human-in-the-loop simulators (of aircraft and air traffic control centers). The resulting system is intended to support the assessment of proposed operational concepts that involve human ATC personnel and aircraft crews.

VAST is supported by a well-qualified staff, and NASA has demonstrated a strong commitment to maintaining an in-house core capability in airspace modeling. The staff is well acquainted with the Department of Defense (DoD) High Level Architecture (HLA)[20] and employs the processes and tools developed for use within DoD.

Agent-based models could enhance the flexibility of the federates that are created, allowing their rapid adaptation to both the current system and its future embodiments. The use of agent-based models in the real-time portion of VAST is especially important because it can also reduce the number of human operators required for some concept evaluations, offering the potential to significantly reduce the cost of using the federation and increasing its availability.

Although VAST is intended to support the evaluation of operational concepts, VAST staff have not actively collaborated with concept developers. The lack of interaction could lead to the creation of operational concepts that cannot be evaluated by the simulation tools under development. Moreover, NASA has made little effort to involve the intended user community (i.e., the FAA) in this program.

Finding: Use of Existing Models for Virtual Airspace Modeling and Simulation. At the outset of the Virtual Airspace Simulation Technologies task, NASA considered whether existing models should be incorporated into the federation being developed by the non-real-time portion of this task to reduce costs and accelerate development. Based on information provided by the contract proposals NASA received for VAMS work and a quick internal assessment, NASA determined that few, if any, existing models could be employed without extensive work and that most models should be developed from scratch because of the difficulty of adapting existing models and because many models are proprietary and cannot be used to produce the open model environment envisioned by NASA. The committee was unable to independently evaluate this determination.

Recommendation: Use of Existing Models for Virtual Airspace Modeling and Simulation. NASA should initiate a more detailed study to reevaluate the merit of including existing models in the Virtual Airspace Simulation Technologies (non-real-time) federation.

Recommendation: Integration of NASA Modeling Efforts. NASA should develop large-scale models that integrate submodels of multiple aircraft vehicles (including aerodynamics, propulsion, and avionics); geometry of airports and physical terrain; weather, environmental, and ecological variables; humans (pilots, controllers, and other operational decision makers); procedures; and other elements of the overall system. Ultimately, these large-scale mathematical models would be executable programs capable of being run with iterative changes in variables to explore the effects of changes in system design variables. In the near future they would be mainly qualitative but contain some quantitative elements. The effort to define such models should be done in conjunction with formulating a far-reaching vision for NASA research.

Finding: Simulator Modeling. Simulator model development by the Aviation Safety Program has similarities with modeling research by the Virtual Airspace Simulation Technologies task.

Recommendation: Simulator Modeling. Modeling research by the Virtual Airspace Simulation Technologies task and the Aviation Safety Program should be coordinated.

Over the past 3 years, the U.S. Air Force's Distributed Mission Training Program has developed the abil-

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[19] "Domain" refers to an area or set of activities, such as ATC operations for aircraft approaching an airport, that deals with common capabilities and data.

[20] HLA allows the assembly of different models to address a simulation requirement.

ity to link aircraft simulators to enable multiple aircrews to operate in the same simulated airspace while occupying simulators in diverse locations. VAST personnel have had no interactions with this effort, which is directly related to the real-time portion of VAST. The federation object model being used by the Distributed Mission Training Program is particularly relevant (see <www.afams.af.mil/programs/projects/afdmt.htm and http://dmt.wpafb.af.mil/links.htm>).

Finding: Department of Defense Involvement in Virtual Airspace Simulation Technologies. NASA has not invited experienced DoD personnel to participate in VAST. Since the DoD has significant experience in the development of large federations with High Level Architecture, such participation could provide useful insights and access to lessons learned.

Recommendation: Department of Defense Involvement in Virtual Airspace Simulation Technologies. NASA should establish an ongoing dialogue with DoD experts in large-scale federation development and invite them to join an integrated product team associated with the real-time and non-real-time portions of VAST. Similarly, DoD experts in the Distributed Mission Training Program should be invited to join an integrated product team associated with the real-time portion of VAST.

System Evaluation and Assessment Task

The SEA task is developing scenarios and metrics that will be used to provide a common evaluation framework when VAST (real-time and non-real-time) is used to assess new operational concepts developed by the Systems Level Integrated Concepts subproject. In an iterative process, the SEA task will develop requirements for a common set of scenarios and metrics appropriate for the VAMS concepts. The task will gather inputs for scenarios and metrics from stakeholders and refine requirements using concept testing and feedback from concept developers. The goal is to conduct detailed evaluations of new concepts throughout their development to assess their feasibility and their potential for enhancing capacity while maintaining safety.

Finding: System Evaluation and Assessment. The SEA task is well planned and well focused, with a common evaluation framework under development. The researchers are knowledgeable and well versed in the development of metrics. However, it is not clear that efforts to achieve broad stakeholder input in metrics development will succeed.

Recommendation: Early Stakeholder Involvement in the System Evaluation and Assessment Task. NASA should involve a broader group of industry stakeholders as early as possible in the SEA task to obtain (1) concurrence on the definitions of metrics, (2) prioritization of the metrics in terms of importance to each stakeholder, and (3) valuation of the metrics in cases where metrics are to be converted to dollars.

Wake Vortex Avoidance System Task

The WakeVAS task is conducting high-risk, high-payoff research that is well suited to NASA's specialized scientific knowledge and analytical capabilities. WakeVAS is developing concepts to mitigate (1) the hazard posed by wake vortices during airport approach and departure operations and (2) the impact that wake vortices have on the capacity of individual airports and the NAS as a whole, while maintaining or improving current levels of safety. The goal of WakeVAS is a validated concept from which specifications for an operational prototype system could be derived that would reduce separation requirements for aircraft (1) in trail (for single-runway operations) and (2) landing or departing on closely spaced parallel runways.

Understanding wake vortex phenomena well enough to define flight regions that are free of hazardous wake vortices is a worthwhile goal because wake vortices are hazardous and the safety procedures prompted by them degrade system capacity. Research aimed at providing wake information to pilots in all phases of flight would be very useful and could help reduce accidents. The committee sees three options for trying to solve the wake vortex problem:

1. Predict the position of hazardous wake vortices produced by a given aircraft in real time.
2. Detect the position of hazardous wake vortices using an airborne or ground system.
3. Predict zones around an aircraft that will always be free of hazardous wake vortices (i.e., zones where other aircraft can operate safely).

Attempts to model the behavior of wake vortices as a function of aircraft weight, engine size, and weather have been going on for many years, and the time frame for operational benefits remains uncertain, although the FAA may be approaching the point where a better understanding of wake vortices will lead to relaxed separation standards during approach, landing, and takeoff, thereby increasing runway utilization rates and system capacity.

It seems that WakeVAS intends to mitigate the effect of wake vortices on the operation of parallel runways by allowing paired approaches in IMC, which relies on option 3 above. However, closely spaced parallel approaches in IMC would create safety hazards even if wake vortices were not a concern. In other words, option 3 would require the development of many technologies not related to wake vortices to allow aircraft to operate on closely spaced parallel runways in IMC. Since these other technologies seem unlikely to become operational in the near term, it may be more worthwhile to pursue research that supports options 1 and 2, above.

Finding: Wake Vortex Avoidance System. NASA has been a leading organization with world-class researchers working in this area, and the WakeVAS task builds on the results of previous NASA research, such as the Aircraft Vortex Spacing System. However, the limited scope of WakeVAS may reduce its payoff.

Recommendation: NASA/FAA Wake Vortex Avoidance System Coordination. NASA's wake vortex research plans should do the following:

- **Describe how WakeVAS research fits into the total context of wake vortex research by NASA and the FAA (e.g., wake vortex detection and avoidance, displays, and reducing wake at the source).**
- **Take into account the need for separation technology unrelated to wake vortices to allow aircraft to operate in close proximity to each other in instrument meteorological conditions.**
- **Consider the merit of wake vortex research to (1) predict the position of wake vortices produced by a given aircraft in real time and (2) detect the position of wake vortices using an airborne system.**

Airspace Operations Systems Project

Background

Safely achieving long-term goals for mobility and capacity of the air transportation system may require complex, highly automated tools, technologies, and operational procedures. Careful consideration of human capabilities throughout the research and development process is necessary to minimize the cognitive, perceptual, and physiological workloads of future pilots and controllers. The AOS project intends to minimize human error and enhance the performance of the future air transportation system by improving the design of human-centered automation and interfaces, decision-support tools, training protocols, team practices, and organizational procedures. Areas of particular interest include the following:

- Computational models for optimizing operator sensory-motor interactions with automated systems,
- Collaboration among systems designers and human factors experts to identify, mitigate, and/or eliminate automation-related errors during the design phase,
- Mitigation and/or elimination of operator confusion about functions and modes of operation of automated systems,
- Improved understanding of how cognitive limitations combine with fatigue to cause human error, and
- Improved understanding of how risk and uncertainty affect team decision making.

The AOS project supports 11 research tasks grouped in three subprojects:

- Human-Automation Integration Research (HAIR) subproject
  - —Prototyping for Evaluation of Automation: Data Link Human Factors task
  - —Human Automation Theory (Degani) task
  - —Human Automation Theory (Meyer) task
  - —State Awareness and Prediction task
  - —Supervisory Control task
  - —System Design and Analysis/Design of Displays and Procedures task
- Psychological and Physiological Stressors and Factors (PPSF) subproject

  - —Perceptual Models and Metrics task
  - —Cognitive Models and Metrics task
  - —Physiological Factors task
- Human Error Countermeasures (HEC) subproject
  - —Fatigue Countermeasures task
  - —Managing Risk and Uncertainty in Team Decision Making task

NASA Ames has the lead for all AOS research.

Portfolio

AOS human factors research provides a useful knowledge base that applies to many operational concepts where humans are in the loop. NASA has been a worldwide leader in aviation human factors and has contributed significantly to national achievements in space and aviation.

Many AOS research tasks are focused on developing principles, formal methods, and tools for evaluating human interaction with advanced automation technologies and systems. These tasks can best be described as advancing the state of the art in aviation human factors research rather than meeting specific user requirements. Research results typically take the form of published articles and presentations at technical conferences. However, some of the research—for example, the Design of Displays and Procedures task and research into spatial reasoning and ATC communications by the Cognitive Models and Metrics task—has found applications in cockpit data link and display designs that are being used by a large airframe manufacturer. Also, some of the research findings have been used by airlines (to improve the safety of operations) and avionics manufacturers (to support product development).

The research is primarily conducted in-house, which the committee believes is appropriate given the nature of the work and the expertise of NASA's scientists. Researchers work cooperatively with air traffic controllers, pilots, airline operations center personnel, industry, and universities.

Finding: Balance of the Airspace Operations Systems Project. Unlike most of the elements of NASA's Aeronautics Technology Programs, much of the AOS project's human factors research is basic in nature.

Recommendation: Balance of the Airspace Operations Systems Project. The AOS project should place more emphasis on the development of precise guidelines, specifications, and tools that can be used to support product design and implementation.

Program Plan

The AOS program plan seems to be well developed and specified, with clearly defined goals, objectives, and metrics and a good roadmap for reaching those goals and objectives. For some program elements, research is focused on advancing science and not on supporting near-term FAA requirements or goals. Program deliverables consist primarily of journal articles, research papers, and professional presentations. The utility of the AOS project would be enhanced by (1) establishing closer ties to other programs at DoD and NASA (including other projects within the Airspace Systems Program), (2) improving coordination among the three AOS subprojects, and (3) coupling project objectives more closely to the goals of the Aeronautics Technology Program. This would also provide a more compelling justification for continued funding of the AOS project's valuable basic research into human factors. This is especially true for PPSF research, which is more basic than the rest of the AOS research portfolio.

The investment in AOS human factors research has been very modest; the budget for many tasks is less than $100,000 per year. The modest funding of some tasks limits their ability to contribute to Airspace Systems Program objectives. Many research tasks require additional resources to support research related to technology validation, technology transition, team decision making, distributed performance, and multicultural aviation human factors issues.

Finding: Funding for the Airspace Operations Systems Project. The biggest challenge to program planning and execution is uncertainty over current and future funding for many tasks, particularly to support validation and transition activities and to assess key neglected areas—for example, team decision making and cross-cultural issues, tower head-mounted display issues, and the effects of acute stress on flight crew performance.

Recommendation: Funding for the Airspace Operations Systems Project. NASA should couple the objectives of AOS applied research more closely to Aeronautics Technology Program goals to provide

a more compelling justification for continued funding and should include AOS basic research in a new aeronautics base research program.

Technical Performance

The AOS project has had a good track record over the last few years, as measured by research results used by industry and/or published in the open literature. AOS facilities are world-class, and AOS research staff seem to be highly dedicated, experienced, and motivated. Most principal investigators have many years of experience in their respective areas, and the project has some of the leading researchers in the world in various areas of human factors. NASA has established a worldwide, first-class reputation for aviation and space human factors, although that has been threatened in recent years by the departure of many senior human factors researchers from the Aviation Safety Program. The continued success of the AOS project requires that NASA continue to attract and retain top-level scientists.

User Connections

It seems that some AOS research is driven by the interests and/or the experience of individual researchers. Another approach would be to integrate some AOS research with the AATT, VAMS, and SATS projects to, for example, produce human factors design guides.

Finding: User Connections to the Airspace Operations Systems Project. Some research tasks have a weak user focus in that they are not closely tied to user requirements.

Recommendation: User Connections to the Airspace Operations Systems Project. The AOS program should have more user involvement and establish formal mechanisms (e.g., Research Transition Plans) for transitioning research findings into NASA product and tool development.

Finding: Coordination of Research by the Airspace Operations Systems Project. The AOS project does not have an integrated plan that explains how the AOS research tasks are organized and work together to achieve the overall objectives of the Airspace Systems Program.

Recommendation: Coordination of Research by the Airspace Operations Systems Project. The AOS project should make a more concentrated effort to coordinate applied research by each AOS subproject with related research by the other projects included in the Airspace Systems Program (Advanced Air Transportation Technologies, Virtual Airspace Modeling and Simulation, and the Small Aircraft Transportation System).

Assessment by Subproject

Human Automation Integration Research Subproject

HAIR is developing cognitive models for analyzing and predicting human performance in complex aerospace systems. The goal is to predict workload and human error more accurately, reduce design time, and minimize design-induced errors. HAIR research is carried out using analytical and laboratory studies coupled with computational modeling and field surveys. The luxury of employing full motion simulation was rarely available because of limited resources.

One HAIR task is developing a model to predict the impact of display design on the workload and situation awareness. This will be a useful tool, especially when it is made available to academia, industry, DoD, and the FAA. It is not clear whether Boeing, Airbus, and other aircraft and avionics manufactures have similar models. In any case, models that belong to the private sector are likely to be proprietary and closed to other users.

Some HAIR research, which is focused on developing formal mathematical methods to verify the adequacy of the human-machine interface, is basic and very pertinent. It will help to reveal safety inadequacies, if any, of automation. The committee agrees with NASA that this effort would be a success if the FAA were ultimately to use these concepts in regulatory materials and certification criteria.

The supervisory control task under HAIR focuses on developing computational architectures that can represent human capabilities and limitations. It is focused on advancing science and is not tied directly to achieving ASP objectives. One tool being developed by HAIR can rapidly apply known characteristics of human performance to evaluating the performance of candidate systems. NASA claims that the tool has been used recently to reduce by at least a factor of 10 the time required to model human-system interactions. This would significantly reduce the cost to airframe manufacturers, avionics manufacturers, and system integrators of assessing the impact of advanced control and display concepts and automation schemes. It is expected that the tool will benefit ASP in the long term.

Development of a tool that provides software instantiation of display layout guidelines would support the design of advanced controls.

Psychological and Physiological Stressors and Factors Subproject

PPSF research is developing perceptual, cognitive, and physiological computational models and tools to enable designers of aviation systems and high-fidelity displays to predict, assess, and enhance human performance. This subproject contains three tasks:

- Perceptual Models and Metrics
- Cognitive Models and Metrics
- Physiological Factors

The Perceptual Models and Metrics task is focused on developing new methods, computational models, and metrics that will enable the optimization of operator (pilot and controller) sensory-motor interactions with display and controls to enhance the safety and capacity of the NAS. This task has eight subtasks, one of which is developing auditory displays that could be used to prioritize and spatially segregate auditory information. NASA has made significant advances in three-dimensional audio displays, which might ultimately be used to assess controller situational awareness and workload as part of the DAG-TM subproject of the AATT project.

The Cognitive Models and Metrics task is supporting basic research to better understand fundamental human performance limitations and how they lead to error. This requires improving the understanding of the human cognitive resources, which would facilitate the development of error-tolerant systems and improved training curricula. This task, which has resulted in the publication of more than 40 peer-reviewed articles, includes research on spatial reasoning and ATC communications to reduce miscommunication between flight crews and air traffic controllers.

The goal of the Physiological Factors task is to develop tools and procedures to predict cognitive fatigue, which can lead to lapses in situational awareness. The research is trying to define an integrated measure of brain, heart, and autonomic nervous system activity that will lead to a reliable, noninvasive technique to predict cognitive fatigue. The ultimate objective is to allow operators to take appropriate countermeasures before their performance suffers. It is primarily an analytic study, focused more on advancing science than on solving any particular problem. The task was initiated in 2000 with very modest funding. In the past 3 years this research effort has not led to implementation guidelines, but it shows future promise for providing tools and methods for assessing human performance and reducing the occurrence of human errors due to fatigue or loss of situational awareness.

The ultimate value of tools developed by the Physiological Factors task will be determined by their ability to support the design of flight decks, controller stations, simulations, training systems, and crew procedures.

AOS research is supported by researchers who are definitely leaders in their fields. For example, Cognitive Models and Metrics researchers have strong ties to academia and the user community, including airlines and the FAA.

The Cognitive Models and Metrics task shows promise; it is going in the right direction and should continue. The results of Cognitive Models and Metrics research have been employed by many users. ATC procedures at two airports were changed based on this research, resulting in significant operational improvements, and two major airlines have also used the results of this research to improve performance.

Finding: Coordination of the Airspace Operations Systems Project with the Small Aircraft Transportation System and Advanced Air Transportation Technologies Projects. The AOS Physiological Factors task is not well integrated with the SATS and AATT projects.

Recommendation: Coordination of the Airspace Operations Systems Project with the Small Aircraft Transportation System and Advanced Air Transportation Technologies Projects. NASA should integrate research by the Physiological Factors task with the SATS project and, separately, with the AATT project. Such integration would allow the Physiological Factors task to obtain empirical data under more realistic conditions; analysis of these

data by the Physiological Factors task would benefit the SATS and AATT projects by providing additional information to validate their system concepts.

Human Error Countermeasures Subproject

HEC research is developing training protocols, operational procedures, and technologies to help pilots manage concurrent tasks, improve the quality of decision making, overcome the effects of fatigue and disruption of the circadian rhythm, and facilitate accurate pilot-controller communications during flight-critical operations.

More so than other AOS research, HEC research is concerned with enhancing the safety and operational efficiency of the airspace system. To be of significant use, research results must be able to predict the safety and operational impacts of new hardware and software during the design process.

The Fatigue Countermeasures task is focused on developing techniques and tools for assessing fatigue during long flights and other work assignments and on mitigating the consequences of fatigue. This work is also relevant to the space industry. The research includes a combination of analytical and laboratory studies, coupled with simulation and field studies. Much of it is conducted in collaboration with researchers from universities and airlines.

The Managing Risk and Uncertainty in Team Decision Making task is an attempt to understand the factors that influence decisions made by the pilots under dynamic, high-stress conditions. The results of the research will be used to develop training guidelines and training programs for pilots and crews. Like the PPSF subproject, HEC research on managing risk and uncertainty would benefit from integration with the AATT and SATS projects.

Human Error Countermeasures research is the most operational of the three AOS subprojects and could be immediately useful to end users. The success of this subproject will require that industry accept the guidelines it develops and incorporate them in cockpit designs, simulations, and training systems.

Finding: Coordination between the Airspace Operations Systems Project and Virtual Airspace Modeling and Simulation Project. Human Error and Countermeasures research on managing risk and uncertainty does not focus adequately on distributed team performance issues in coordination with research by the Virtual Airspace Simulation Technologies task, which is part of the VAMS project.

Recommendation: Coordination between the Airspace Operations Systems Project and Virtual Airspace Modeling and Simulation Project. NASA should integrate research by the Managing Risk and Uncertainty in the Team Decision Making task with VAMS research.

4

Assessment of the Aviation Safety Program

BACKGROUND

Program Information

The Aviation Safety Program (AvSP) is one of three programs in the Aeronautics Technology Programs of NASA's Aerospace Technology Enterprise. AvSP was created in 2000 as an outcome of a formal process initiated by NASA to develop a research investment strategy in the area of aviation safety.

The goal of the AvSP is to protect air travelers and the public. Its research and development strategy is to increase safety by three primary methods:

- *Aviation system modeling*. Identify and correct problems using aviation system-level data,
- *Accident prevention*. Identify interventions and develop technologies to eliminate recurring types of accidents, and
- *Accident mtigation*. Reduce injury and decrease fatalities in survivable accidents.[1]

These methods are applied in the three major research and development components:

- *Vehicle Safety Technology*, which includes Single Aircraft Accident Prevention, Accident Mitigation, and Synthetic Vision Systems,
- *Weather Safety Technology*, which includes Aircraft Icing and Weather Accident Prevention, and
- *System Safety Technology*, which includes Systemwide Accident Prevention, Search and Rescue,[2] and Aviation System Monitoring and Modeling.

A fourth research component, security research, will be added in FY04. The committee did not evaluate this component since no research and development work is currently under way. The AvSP also has an effort in Technical Integration, which is separate from the three research projects.

Research and development for AvSP is performed at NASA Langley Research Center, NASA Glenn Research Center, NASA Ames Research Center, and NASA Dryden Flight Research Center, with the program headquarters at Langley. A program organization chart is shown in Figure 4-1.

AvSP was funded at $156.2 million in FY03 under

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[1] G. Finelli, NASA Langley, "NASA Aviation Safety Program Overview," presentation to panel, February 2003.

[2] Search and Rescue is funded through AvSP but is implemented through the Office of Space Flight. Since all programmatic development and all technical research are performed under the Office of Space Flight, the Aviation Safety Panel did not review this work.

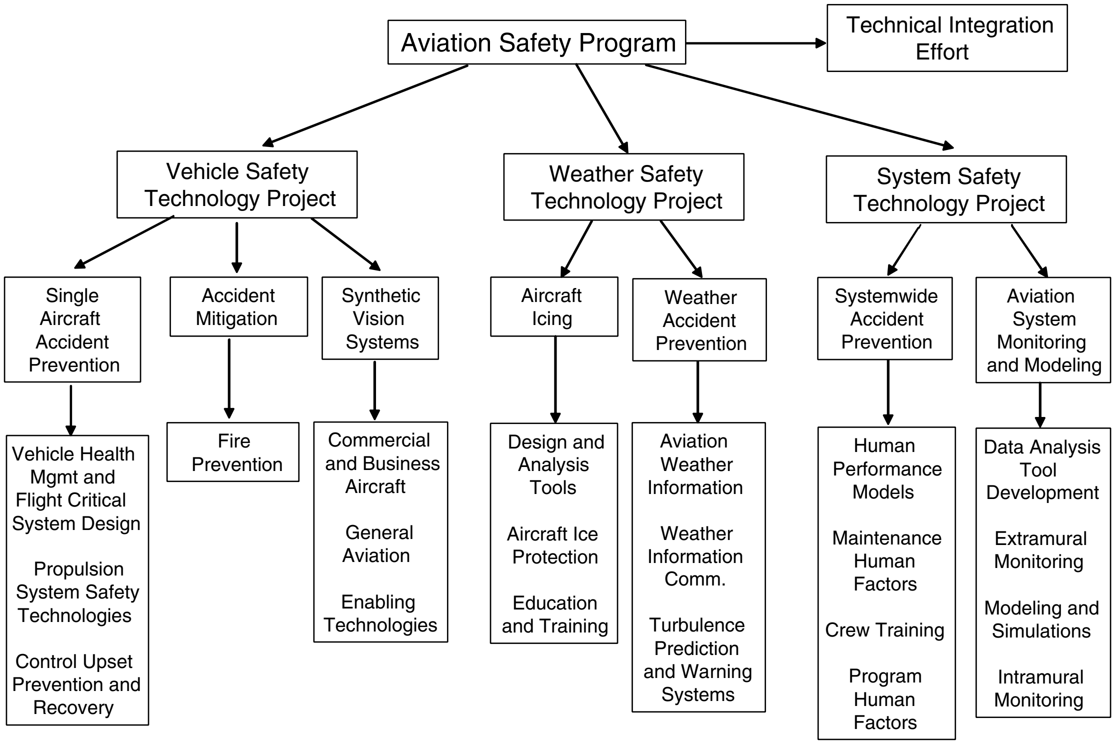

FIGURE 4-1 Aviation Safety Program organization chart.

the full-cost accounting scheme.[3] Vehicle Safety Technology accounted for \$83.9 million (54 percent of the AvSP total), Weather Safety Technology accounted for \$31.6 million (20 percent of the total), and System Safety accounted for \$40.7 million (26 percent of the total). NASA is in the process of transitioning to full-cost accounting from a net accounting scheme; previously, NASA managers assessed their budgets by the amount of funding available to them for contracts, grants, and other types of procurements. Under the net accounting scheme, Vehicle Safety Technology is budgeted at \$19.8 million, Weather Safety Technology at \$14.7 million, and System Safety Technology at \$18.4 million. In this report, specific subprojects and tasks are discussed in net dollars only, as this was the only information provided to the committee. The net budget breakdowns by subproject are shown in Table 4-1.

Like other NASA programs, each AvSP project has a 5-year lifespan. This does not imply that the program ceases to exist after 5 years, however. Project plans are reevaluated after each 5-year time period to phase in new projects that build upon previous research and development.

Review Process

The Aviation Safety Panel was formed in December 2002 as one of three panels that would review NASA's Aeronautics Technology Program. The Aviation Safety Panel met for the first time on February 26-28, 2003, in Washington, D.C. At this first meeting, the 10-person panel received technical briefings from the program and project managers in AvSP on the overall program, specific projects, and individual tasks. After the first meeting, panel members participated in site visits to each of the relevant NASA facilities (NASA Langley, NASA Glenn, and NASA Ames). The purpose of the site visits was to obtain a deeper understanding of the research and development in the program, to speak directly with the principal investigators for each project task, and to observe the products

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[3] Full-cost accounting encompasses all costs, including research and program management; institutional infrastructure costs, such as research operations support; direct procurements; direct civil service workforce, benefits, and travel; service pools; center general and administrative (G&A); and corporate G&A.

TABLE 4-1 Net Budget for the Aviation Safety Program

	Budget (million $)			
Project/Subproject Name		FY03		FY04
Vehicle Safety Technology	19.8		19.8	
Single Aircraft Accident Prevention		10.4		10.2
Accident Mitigation		2.2		2.6
Synthetic Vision Systems		7.2		7.0
Weather Safety Technology	14.7		13.9	
Aircraft Icing		5.0		5.0
Weather Accident Prevention		9.7		8.9
System Safety Technology[a]	18.4		17.7	
System-Wide Accident Prevention		5.0		5.1
Aviation System Monitoring and Modeling		8.4		8.6

[a] System Safety includes Search and Rescue, which is not reviewed here.

SOURCE: Information provided to the NRC panel by G. Bond, Aviation Safety Program Office, NASA Langley Research Center.

and facilities firsthand. The site visits are listed in Appendix C. Panel members visited on-site or spoke via teleconference with NASA personnel from every AvSP task. Panel members, who were experts in their fields, also reviewed technical reports and journal articles and followed up with individual principal investigators by means of teleconference calls and written questions.

Before the first meeting, the NRC asked each principal investigator to complete a short questionnaire with 12 questions relating to the research and development goals, products, roadblocks, users, and technical outcomes. A blank questionnaire is shown in Appendix D. The completed questionnaires were distributed to the panel for review prior to the first panel meeting. Thus, the panel members were already somewhat familiar with the programs and projects under review before they were briefed in person by the NASA researchers and program managers. The questionnaires proved to be a valuable tool for the panel in performing its program assessment.

Upon completion of the three site visits, the panel met for a second time, again in Washington, D.C., on May 27-29, 2003, to come to consensus on findings and recommendations for the program. The panel discussed outstanding questions and issues of concern with program staff from NASA. It also developed crosscutting observations across the different projects and tasks within AvSP. The panel then provided its input to the Aeronautics Technology Programs parent committee in the form of working documents. Four of the ten panel members represented the panel on the committee.

PORTFOLIO

The committee evaluated the appropriateness of the AvSP research portfolio based on the amount of basic research versus user-driven research; the presence of gaps or incomplete areas of research; the balance between high-risk, high-payoff research and more evolutionary work; and whether or not the portfolio addresses real-world problems.

The committee is concerned about the balance between fundamental and product-driven research in the Aviation Safety Program. It observed a shift away from essential basic research over recent years. Such basic research is necessary for the development of future safety products that will enable the AvSP to reduce accident rates. In some instances, the committee observed ineffective work-arounds created out of necessity to divert resources from funded, low-payback projects to accomplish unfunded but critical basic research. Furthermore, with a few notable exceptions (such as the Aircraft Icing subproject and the Modeling and Simulations task in the Aviation System Monitoring and Modeling subproject), the committee felt that this problem was widespread within the program.

The committee found examples of research that is essentially complete and ready for transition (such as Fault Tolerant Modular Architectures, Personal Electronic Device electromagnetic susceptibility, virtual and augmented reality for maintenance crews, and the Performance Data Analysis and Reporting System). The committee also found places where basic research was lacking—for example, high-temperature materials for engines, weather display interfaces, turbulence warning systems, and human factors work in many areas. The committee's findings and recommendations regarding specific instances where research is too product-driven or where additional basic research is needed are presented in the discussion of each task.

Finding: Support for Basic Research. There has been a shift away from essential basic research in the Aviation Safety Program in recent years.

Program Recommendation: Support for Basic Research. The Aviation Safety Program should reinstate a core competency program dedicated to basic research that is essentially unencumbered by short-term, highly specified goals. Without a strong basic research program, the more applied research eventually suffers from a lack of good ideas and trained personnel. The criterion for starting or restarting such an activity within a Center is that a need must exist for knowledge that is not now available.

The committee noted specific gaps in the portfolio at the subproject and task levels in subsequent sections. It found one significant program-wide omission in the research portfolio: rotorcraft.

Finding: Rotorcraft. Rotorcraft safety can be improved with additional research in the areas of decision aids, synthetic vision, training, workload, and situational awareness.

Program Recommendation: Rotorcraft. The Aviation Safety Program should reincorporate rotorcraft research into its program. The research should consider the most effective approaches for reducing the workload of rotorcraft pilots and improving their ability to conduct safe, low-speed, low-altitude rotorcraft operations in obstacle-rich environments and in adverse weather.

PROGRAM PLAN

The AvSP program plan emerged from a series of strategic planning sessions on aviation safety in 1997 known as the Aviation Safety Investment Strategy Team (ASIST). ASIST established a vision and prioritized the research and development investment areas for the AvSP. The AvSP approach includes system modeling, accident mitigation, and accident prevention, with an emphasis on mitigating problems that contribute most heavily to accident and fatality rates. The AvSP was established in 2000 with a 5-year program plan.

Each individual task within the AvSP is structured to last 5 years. This 5-year programming cycle is more suitable for a product-oriented program. It is difficult, if not impossible, for NASA to maintain core competencies with these 5-year programs. In addition, there do not appear to be sufficient off-ramps to transition research that has been completed before the 5-year time window closes.

Finding: Use of Sunset Requirements. NASA functions on a 5-year schedule to the detriment of solid research.

Program Recommendation: Use of Sunset Requirements. The Aviation Safety Program should structure its program based on the natural duration of each research effort and not compel conformity to a 5-year cycle for every task. NASA should eliminate arbitrary time constraints on program completion and schedule key milestones based on technology maturity, task complexity, and resource limitations.

Research involving the human-machine interaction and causes of human error should be a major focus of any aviation safety research program. The AvSP contains a wide array of human factors research, from synthetic vision displays to aviation weather information requirements to tools for aircraft maintenance teams. In general, the committee found evidence of high quality in all of NASA's human factors research; however, it also found that the work was not always well integrated into a cohesive program without overlaps. The committee approves of the efforts of the Aviation Safety Program Office in pulling together some of the disparate human factors tasks through cross-center meetings and through the Program Human Factors task of the Systemwide Accident Prevention subproject. However, the committee did not observe any improvement in the intertask communication or any synergy from the human factors research within the program.

Aviation accident data make clear that human error is a much greater factor than hardware or software failure or environmental conditions. Ideally, every technology effort should be examined from a human factors perspective at an early design phase to anticipate problems. However, the advice of human factors professionals, who must necessarily draw on the softer behavioral sciences, is often disregarded by the engineering designers, who view it as negative or irrelevant. NASA has traditionally supported research in human factors, and the human factors group at NASA Ames has truly been a national resource.

Finding: Human Factors Research. In recent years the Aviation Safety Program's work in human factors has been eroding; senior in-house research staff have left, and in order to get the work done, more human factors professionals have found themselves managing contractors, a task for which they often are not well qualified. Crosscutting efforts to integrate human factors have also suffered.

Program Recommendation: Human Factors Research. Critical human factors expertise should be better supported in order to maintain critical mass, to foster basic research in this field, to identify gaps in our understanding of safety, and to be available to consult with various NASA projects.

Program Recommendation: Early Analysis of Human Factors. Project requirements should include requirements for human factors analysis early in the design phase.

The committee found that the considerable layers of both line management and project management obscure the lines of accountability in AvSP. In at least one case, a person's subordinate in the research project hierarchy is his or her superior in the line staff hierarchy. The committee felt that subproject- and task-level plans, goals, metrics, and responsibility could not be clearly traced back to an overarching plan and vision for the AvSP. In other words, the planning appeared to be more bottom-up than top-down. Additionally, the committee heard from a number of technical civil servants in the program that too much of their time was spent "doing management" (e.g., making PowerPoint slides) and not enough doing science and technology.

In addition, it was not clear to the committee what methods and metrics NASA uses to evaluate objectively the status of its research projects against its own stated goals. The program effort in Technical Integration (described in a subsequent section) would be a natural place for such an evaluation.

Finding: Management Structure. The organizational structure is unnecessarily complex, making it difficult to trace lines of responsibility. Subproject- and task-level plans, goals, metrics, and responsibility could not be clearly traced back to an overarching plan and vision for the Aviation Safety Program.

Program Recommendation: Management Structure. NASA should articulate a clear, long-range plan for the Aviation Safety Program and a hierarchy of goals, and it should adopt a less complex management system that enables program accountability and implementation to be clearly traced.

The committee suggests that NASA reexamine its names for the AvSP activities (many terms sound like they overlap or are ambiguous) so that the goals of each major project are easily understood. This ambiguity is particularly evident in the Single Aircraft Accident Prevention subproject.

TECHNICAL PERFORMANCE

The committee asked a variety of questions to assess the technical quality of the work, to evaluate the facilities and personnel, to find evidence of system-level assessments, and to determine the balance between experimental and theoretical work. The committee also compared the quality of the AvSP work relative to that of other work in industry, academia, and government, including international work.

The committee found the technical quality of the AvSP to be very good. In some cases, particularly in specific parts of the weather work, NASA personnel can be considered among the world leaders in their respective fields. The review committee found the facilities to be adequate for achieving the research goals; in some cases (such as the icing wind tunnel), the facilities can be considered true national assets.

The committee identified several specific tasks and subtasks that have achieved an outstanding level of technical achievement:

- Structures health management subtask of the Vehicle Health Management and Flight Critical System Design task in the Single Aircraft Accident Prevention subproject,
- Mode confusion subtask of the Vehicle Health Management and Flight Critical System Design task in the Single Aircraft Accident Prevention subproject,
- Scale model development and testing work in the Single Aircraft Accident Prevention subproject,
- Design and Analysis Tools task in the Aircraft Icing subproject,
- Aircraft Ice Protection task in the Aircraft Icing subproject, and
- Crew Training task in the Systemwide Accident Prevention subproject.

A number of outstanding products have been developed, but many of these (an example being the Performance Data Analysis and Reporting System (PDARS) trajectory monitoring tool) are ready for handoff to industry. Much of the low-TRL research is excellent, but its relevance and potential usefulness seem not to have been made clear to potential users (a good example is human performance models).

USER CONNECTIONS

User connectivity was evaluated in two separate ways. First, the committee asked how well NASA personnel reflect and leverage work being conducted elsewhere and how well NASA research results are accepted and adopted by the outside community. Second, the committee asked how the research itself is conducted—for example, if it uses an appropriate mix of internal and external personnel.

In comparing the work of the Aviation Safety Program with other work in the community, the committee found several instances of products being developed by NASA that are similar to or have considerable overlap with products developed by industry. (Specific examples will be discussed in the task-specific sections.)

Finding: Redundancy with Industry. Some products being developed by NASA are similar to or have considerable overlap with products already developed by industry.

Program Recommendation: Benchmarking Against Industry. The Aviation Safety Program should compare (benchmark) its research projects against those of other research and development entities in government and industry to ensure that NASA's work is leading. If it is not, NASA should terminate the work.

Exploring the second aspect of user connectivity (how well the program uses expertise from the outside community), the committee found that the answer varied from task to task. In some cases (particularly the Vehicle Safety Technology project), the committee felt the project would benefit from additional involvement with the outside community. In particular, the committee believes NASA's fundamental research projects would benefit from increased university participation. In other cases (especially in the System Safety Technology project), the committee felt there were too few in-house personnel and that too much of the research was being conducted by contractors. This tends to weaken the core competencies of NASA.

ASSESSMENT BY PROJECT

Technical Integration Project

The AvSP has an effort in Technical Integration, which is designed to provide program assessments, develop systems-level implementation strategies, and integrate research and development efforts across program tasks, particularly in flight testing.

The committee believes the concept behind the Technical Integration project is very important, provided it plays a significant role in deciding what research to undertake and when such research should be modified, transitioned to industry, or discontinued. The committee understands that because the Technical Integration project began after the current 5-year plan had begun, it has been playing catch-up with regard to its status in the overall program. However, the committee had difficulty determining the effect of the Technical Integration activities on current planning. The Technical Integration project seemed to be running almost as an independent activity somewhat disconnected from project management. The committee also observed that subjective evaluations are being made, mostly by NASA project managers, and it believes that NASA should have more input from customers and industry and from lower-level managers, scientists, and engineers engaged directly in the various efforts. For example, the market penetration of AvSP products should be studied.

The Technical Integration effort as currently constituted seems best suited for evaluating AvSP's near-term products. However, the committee is concerned about how Technical Integration will integrate project "stovepipes" into a workable whole. For example, there appears to be little integration of NASA Ames human factors activities with the synthetic vision work at NASA Langley. The committee also sees a need for anticipatory or prospective integration of the Human Performance Models task, the Monitoring and Simulation task, and the other monitoring tools efforts.

Finding: Use of the Technical Integration Project. The Technical Integration effort does not play the role it needs to play in deciding what research to undertake, in performing cost-benefit analyses for projected and ongoing projects, and in deciding when such research should be modified, transitioned to industry, or discontinued.

Recommendation: Use of Systems Engineering. NASA project managers should employ systems engineering approaches to ensure proper integration of projects.

Recommendation: Use of a Quality Assurance Program. NASA should institute a quality assurance activity, separate and independent from project management, the results of which should be reported directly to the Aviation Safety Program manager and to the Aerospace Technology Enterprise associate administrator.

As discussed in the assessment of the Airspace System Program, above, there appear to be significant overlaps in the various system modeling efforts within NASA, and it may be feasible to consolidate or integrate some projects. In particular, modeling research by the AvSP should be coordinated with Virtual Airspace Simulation Technologies, which is part of ASP. NASA should also develop and implement a plan for evolving current models, simulations, and analysis tools into large-scale models.

The committee applauds the Technical Integration support of the Commercial Aviation Safety Team and the Joint Implementation Measurement Data Analysis Team.

Vehicle Safety Technology Project

Background

The Vehicle Safety Technology project is designed to strengthen aircraft against vehicle system and component failures, loss of control, loss of situational awareness, and postcrash and in-flight fires. The project focuses on applications for the aircraft itself. The majority of the research is conducted at NASA Langley, with a relatively small amount of work in propulsion safety and fire prevention conducted at NASA Glenn. The Vehicle Safety Technology project was funded at \$83.9 million (full-cost)/\$19.8 million (net) in FY03 and is divided into three subprojects: Single Aircraft Accident Prevention, Accident Mitigation, and Synthetic Vision Systems. In net dollars, Single Aircraft Accident Prevention is funded at \$10.4 million, Accident Mitigation at \$2.2 million, and Synthetic Vision at \$7.2 million.

Portfolio

The goals of the project are focused on the vehicle itself, in applications related to the flight deck, flight critical systems, propulsion, and airframe. The research focuses on loss-of-control prevention and recovery; flight critical systems; vehicle health monitoring; propulsion systems safety; fire mitigation, detection, and prevention; and improving low-visibility conditions by providing a synthetic picture of the outside world.

This is an ambitious project with many diverse goals, applications, and areas of research expertise. The folding of such diversity into a single project and the integration of the results of each research effort present a considerable challenge. As with all AvSP programs, the projects within the Vehicle Safety Technology project have a 5-year life span. The termination point for the Vehicle Safety Technology Project tasks is scheduled to be 2005, although many of the projects will probably be continued in some form into the next phase of the AvSP.

The committee found the researchers stretched in many directions in the Vehicle Safety Project and believed it was unlikely that every subtask could achieve its stated goals to an appropriate level of detail by the project termination point in 2005. Further, the fact that the names of many research tasks seemed to be similar suggested that some tasks could be combined.

Overall, the committee believes there is an appropriate balance of low-TRL work with more application-driven research in the Vehicle Safety Technology project. Across the AvSP as a whole, the committee has some concerns about the increasing trend toward product-driven research and development, so it was pleased to see several fundamental, low-TRL tasks within Vehicle Safety Technology, such as the design work in the Control Upset Prevention and Recovery (CUPR) task. The committee urges a continued emphasis on this basic research in the next phase of the Aviation Safety Program. At the same time, the committee notes that several tasks—for example, some of the fire prevention work and fault-tolerant integrated modular architectures—have already attained a high level of technology readiness and should be transitioned to industry.

The committee is sensitive to the fact that by focusing on fewer concepts, the project eliminates other worthy research ideas. However, despite recommending that the Vehicle Safety Technology project focus on fewer tasks in greater detail, the committee also found a significant omission in the array of activities in this project—namely, rotorcraft. The committee believes that NASA could have a significant impact on rotorcraft safety by including the topic in this project. The committee believes that NASA's decision to terminate rotorcraft work is a mistake, as there are a number of real-world problems in rotorcraft safety that apparently are not being addressed outside NASA.

Program Plan

The committee believes that NASA will make significant impacts if it can mature the technologies in the Vehicle Safety Technology project. However, the committee judges the program plan for technology maturation to be overoptimistic.

Finding: Portfolio Breadth. Despite the encouraging progress reported to date, the time remaining is insufficient to achieve the goals set forth in the program plan. The breadth of the work in Vehicle Safety Technology is coming at the expense of technical depth.

Recommendation: Portfolio Breadth. The Aviation Safety Program should narrow the scope of activities in the Vehicle Safety Technology project to increase the depth of research activities and focus them in fewer, more specific, higher-priority areas.

A few tasks within the Vehicle Safety Project have already reached a high TRL, and the committee noted that there were no appropriate off-ramps or transitions for those tasks that have reached or will reach completion before the 2005 project end date. Specific instances are noted in the commentary on the individual tasks, below.

Technical Performance

The committee found the individual researchers to be bright, aware of the relevant literature, and able to answer both theoretical and application-related questions. The facilities are state of the art and appropriate for carrying out the project.

The committee found evidence of several noteworthy research tasks within this project that have a high level of technical achievement, such as the structures health management subtask. Several other tasks perhaps should be transitioned because they have already completed their research objectives, such as fault-tolerant integrated modular architectures and some of the fire mitigation work. In no case did the committee recommend research termination for lack of quality.

The committee is concerned about the functional integration of the many diverse activities taking place across the different NASA research centers. NASA should develop software and hardware interface specifications that connect the various subsystems early on to aid in the integration and definition of the scope and plans for program research. These specifications can be spiraled into more detail and refined accordingly as the program evaluations progress. They form the basis for integrating the work taking place between the NASA centers and NASA contractors. These interfaces should include interactions between all the vehicle subsystems, including the controls and display tasks.

Finding: Interim Integration Milestones. There appears to be a lack of interim task-level milestones to track the progress of integration activities.

Recommendation: Interim Integration Milestones. NASA should integrate the information that systems evolving from individual tasks such as Vehicle Health Management and Flight Critical System Design and Control Upset Prevention and Recovery can provide to the flight-deck crew.

Recommendation: Interim Integration Milestones. NASA should develop software and hardware interface specification documents that address the various subsystems early on to aid in the integration and definition of the scope and plans for program research.

Recommendation: Interim Integration Milestones. NASA should incorporate interim test and evaluation milestones for its flight simulation facilities to measure the impact of its design integration on ongoing crew performance activities.

User Connections

In general, the committee found that the researchers are collaborating with the appropriate outside agents; by and large, there is the right degree of involvement with industry, and the connectivity to the research community is impressive. In a few cases, especially in areas with low-TRL work, the NASA research could be augmented with university research. Specific instances are noted below. It appears that university involvement is relatively minor, notably in formal methods of software verification and validation and in some of the propulsion safety technologies.

Assessment by Subproject

Single Aircraft Accident Prevention Subproject

The Single Aircraft Accident Prevention (SAAP) subproject is designed specifically to develop and implement technologies that enhance aircraft airworthiness and resiliency against loss of control while in flight. Again, the work focuses on onboard technologies for the individual vehicle. The subproject contains three tasks: Vehicle Health Management and Flight Critical System Design (VHM and FCSD), Propulsion System Safety Technologies, and Control Upset Prevention and Recovery (CUPR). The net budget for SAAP is $10.4 million in FY03, with $4.8 million for VHM and FCSD, $4.1 million for Propulsion Safety Technologies, and $1.5 million for CUPR.

NASA's effort to expand and improve industry knowledge of the aerodynamic performance envelopes of transport-category aircraft appears to be on target for reducing the incidence of loss-of-control accidents. This subproject promises to improve the fidelity of flight simulators used as tools for improving pilot performance in manual recovery from extreme attitudes. The research could lead to better avoidance of such conditions as well as to systems that effect automatic recovery.

By their nature, many of the modeling and analysis efforts do not have a well-defined end point, and there is always room for improvement. The lack of a clear completion point for some of the SAAP work was nevertheless troubling, and the committee believes that NASA should develop ways to "declare victory" and make clear the degree to which the effort has succeeded and the amount of research still needed to achieve success. For example, the modeling of follower aircraft interaction with wake vortices from lead aircraft is in its infancy because of the complexity of the problem, but it should continue to be pursued in future years. On the other hand, the work in fault-tolerant integrated modular architectures is at a high TRL and ready for transition to industry.

Finding: Wake Vortex. While wake vortex interactions have an obvious impact on capacity, there are equally important safety considerations, and the AvSP is not sufficiently involved in the wake turbulence effort.

Recommendation: Wake Vortex. NASA should include wake turbulence interaction models in its Control Upset Prevention and Recovery dynamics modeling and simulation technologies work. Current models used in airline training simulators are quite crude and provide insufficient fidelity for effective pilot training purposes.

The committee was pleased to observe the excitement in using the 1/20 scale model 757 for both flight and wind tunnel tests of control upset and other tasks. Such tests could integrate and coordinate the diverse activities in SAAP.

The collaboration with other relevant parties (the FAA, DoD, and industry) appears to be excellent in this subproject.

Vehicle Health Management and Flight Critical System Design Task

The goal of this task is to research technologies to reduce loss-of-control accidents and system or component failures on the vehicle itself. Even within this single task, there is a large array of activities, from structures health evaluation to software integrity evaluation. Research is conducted in the following areas:

- Structures health management
- Flight systems health management
- Verification of neural networks
- Mode confusion
- Software safety
- Requirements modeling
- Recoverable computing
- Modular avionics
- Electromagnetic susceptibility of avionics
- Neutron particle effects on flight critical systems
- Validation methods

The TRL also varies widely across the work in this task: Some of the software work is at a relatively low TRL, while some of the structures health monitoring work is near product development stage. The net funding for the Vehicle Health Management and Flight Critical System Design work is \$4.8 million for FY03 and is scheduled to be \$5.1 million for FY04.

The committee found a number of activities in this task worthy of commendation. It was particularly impressed by the specific research activity in two areas: structures health management, particularly the fiber-optic strain systems (FOSS), and pilot confusion over automation control-display modes.

The structures health management activity is an area that NASA should showcase in the program. It has made significant progress in a relatively short amount of time, and NASA has truly catalyzed breakthroughs in this area. In general, the cost-benefit analysis work done in this area is impressive, and it is clear that NASA knows what it would take to install and field its systems. The committee found the task to be well thought out in terms of the interaction between corrosion and other properties of aging materials and the measurement and diagnosis of structural faults. The FOSS work at NASA Langley is interesting with an appropriate blend of fundamental and user-driven research. The potential payoff in this area is very high. The mode confusion work also has a very high potential payoff, and the work being performed in this area is novel and of high quality.

The committee also encourages NASA's continued involvement in the verification of flight systems, particularly as software becomes more complex and new issues must be addressed, bringing corresponding increases in cost and development time. In addition, NASA should continue to foster the introduction of object-oriented (OO) programming into the flight critical software area.

Flight critical software is software onboard an air vehicle that is used to control the vehicle and whose failure would lead directly to the loss of that vehicle. Because of the cost of recertification, this is an area in which commercial companies are slow to invest, even though all recognize the eventual payoff. The payoff of OO techniques, while not directly related to safety, comes from reuse, savings in cost and time, and increased efficiencies in verification and validation activities.

It would be useful if NASA could determine or demonstrate ways to reduce the risks and costs of recertifying software, and its activity in OO programming with the FAA is a good step in that direction.

As the committee noted in its subproject discussion, this task could benefit from fewer tasks. There is such a broad range of activities within this subproject that the committee found it unlikely they all can be brought to meaningful closure, with an appropriate TRL, by the task's end in 2005. Specifically, the committee believes NASA should reorganize that portion of the SAAP that combines VHM (including the model-based diagnostics of the propulsion arm) and the detection, identification, reconfiguration, and recovery part of CUPR in a single anomaly detection, identification, and reconfiguration/recovery structure. This would eliminate the appearance of redundant research efforts and further enable functional integration.

Finding: Portfolio Breadth. The Single Aircraft Accident Prevention activities are linked by their common goal (reducing system or component failures on the aircraft) but not necessarily by common expertise or research methodologies. Similar activities appear to be taking place in multiple subtasks.

Recommendation: Portfolio Breadth. NASA should restructure or descope this task.

In several specific areas the committee has doubts about the utility of NASA's continued involvement. While the committee understands NASA's desire to offer a complete solution to the Flight Critical System problem, the committee is not convinced that NASA should be working in fault-tolerant integrated modular architectures. Commercial companies are in this business and competing heavily with one another. The TRL of this technology is well above 6, and NASA is not needed to foster innovation. The second area that the committee questions is in personal electronic device electromagnetic susceptibility. This work seems more appropriate for industry (i.e., airlines and airframers). The committee understands that part of this work is sponsored by an airline but believes that the effort should have low priority in the NASA research plan.

Finding: Modular Architectures and Personal Electronic Devices. The work in fault-tolerant integrated modular architectures and personal electronic device electromagnetic susceptibility is at a high TRL and more appropriate for industry.

Recommendation: Modular Architectures and Personal Electronic Devices. NASA should terminate its involvement in modular architecture development and electromagnetic interference activities in order to concentrate resources in other less-researched areas of the program.

Propulsion System Safety Technologies Task

The purpose of the Propulsion System Safety Technologies task is to reduce propulsion system failures as a factor in civil aircraft accidents through the prediction, detection, and testing of propulsion system malfunctions and failures. The propulsion system safety team works in system health monitoring, crack-resistant blades and disks, and engine containment. This effort is conducted at NASA Glenn and has a net budget of $4.1 million per year in FY03 and FY04.

The committee found the researchers to be knowledgeable and familiar with the relevant work in the outside community. In general, the task was well organized and had a more focused goal and approach than the other tasks in SAAP. The committee found two areas worthy of notice: model-based diagnostics and engine sensor technology, particularly the eddy current sensors. Also, the committee found that NASA has played a key role in integrating the various aspects of crack-detection technologies—sensors, algorithms, and testing resources.

NASA's involvement in model-based diagnostics shows promise for onboard diagnostics and is a worthwhile investment, but it could benefit from integration with related subtasks in SAAP.

Finding: Integration of Related Activities. The model-based diagnostics subtask is not well integrated with related activities in Single Aircraft Accident Prevention.

Recommendation: Integration of Related Activities. NASA should integrate model-based diagnostics with the vehicle health monitoring activities in the Vehicle Health Management and Flight Critical System Design task when it plans the future of these tasks.

NASA efforts in embedded technologies with eddy current sensors offer good promise in the early detection of faults. Engine companies are also working on these technologies, however.

Finding: Eddy Current Sensors. Some of the eddy current sensor work may be redundant with the work by industry.

Recommendation: Eddy Current Sensors. NASA should perform additional experimental work and operational testing on these resilient sensors and other sensors under development by the engine companies only if it is leading and not following the engine companies.

In general, the work in engine disk crack detection and engine materials research is well integrated and following good experimental practices. The committee believes this work could be enhanced with additional research at high temperatures.

Finding: High-Temperature Engine Materials. NASA lacks some basic research activities in alternative high-temperature engine materials.

Recommendation: High-Temperature Engine Materials. NASA should also foster progress into other engine materials and heat-treating technology. This work might benefit from additional university involvement.

Control Upset Prevention and Recovery Task

The CUPR task works to reduce accidents due to vehicle loss of control. This task focuses on three activities: modeling and simulation, to characterize aircraft dynamics under upset conditions; system technologies, to develop onboard prevention and recovery methodologies; and validation, to evaluate the technologies developed and transition them to the commercial sector. This task is operating with a net budget of $1.5 million in FY03 and $1.0 million in FY04.

The committee believes that the research being performed by NASA in this area is well justified. There are different regimes for loss of vehicular control, and scientists and engineers have been unable to map these regimes thoroughly as yet. The aeronautics databases usually do not adequately describe the attitude, angle of attack, and sideslip envelopes encountered during loss of control. Furthermore, there is a significant difference between extrapolated data and experimental data. Without experimental data, valid classes of upset responses cannot be developed.

The emphasis of this research program is addressing core NASA issues and is on target. Based on the progress made to date, the committee believes that NASA should ensure continuation of the task beyond the current 5-year plan.

The committee found the work on the free-flying airplane for subscale environmental research (FASER), a small remote control vehicle, to be promising. Work on a simple aircraft such as FASER can lead to discoveries that will apply universally to all aircraft and is a way for NASA to gain meaningful insights into control upset and recovery.

The committee applauds the work in extending the aerodynamic database of airline training simulators to include poststall recovery training. The end result will be a validated process for developing and validating large angular and angular-rate mathematical models for upset training. This is a prime example of NASA drawing successfully on the expertise of its research centers' personnel in a particular area.

The committee believes the CUPR research, particularly in recovery and upset dynamics, may contribute to the research being performed at the FAA and NASA (including the ASP WakeVAS project) on the wake vortex spacing problem. Currently, conservative in-trail and lateral spacing buffers are used to prevent wake encounters during IMC approaches. However, pilots are allowed to develop their own spacing when flying VMC. Procedures might be significantly improved (in particular, departure delays might be reduced) if, rather than waiting until the required 2 minutes has elapsed before the next IMC departure can take place, the pilot were able to proceed as soon as the wake has dissipated. There are two outstanding research issues here: assessing the strength of the wake and developing an understanding of tolerable wake strengths for each type of aircraft. The current NASA research focuses on upset recovery. To apply CUPR work to wake vortex encounters, NASA should perform additional research to better understand the onset of loss of control, especially when it results from a wake encounter.

As in other tasks within this subproject, a number of diverse areas are being worked on. A wide range of technologies is required to solve problems related to loss of control, and it is difficult to produce an effective product if the research components are isolated from one another. The committee mentioned earlier that it believes the fault detection, isolation, and recovery work in CUPR should be combined into a general category of anomaly detection, identification, and reconfiguration/recovery. The committee believes the work involved in scale-model testing serves to integrate the diverse components involved in the CUPR tasks, and NASA should increase its efforts in such integration activities.

Finding: Involving Academia. The committee is aware of the partnerships with institutions such as the State University of New York, the University of Minnesota, the University of California at Berkeley, and the Georgia Institute of Technology but finds that university involvement is generally not a well-integrated part of the program.

Recommendation: Involving Academia. NASA should increase its partnerships with academia in the Control Upset Prevention and Recovery task. Because of the low TRL of the CUPR activities, academia could make meaningful contributions in this area.

Accident Mitigation Subproject

The Accident Mitigation subproject is composed of two tasks: Systems Approaches to Crashworthiness and Fire Prevention. Because the crashworthiness task reached completion at the end of 2002, it is not part of the NRC review. The Fire Mitigation effort is funded at $2.2 million net for FY03 and $2.6 million net for FY04.

The committee notes that NASA has announced plans to close the Impact Dynamics Research Facility at NASA Langley. This facility is the sole U.S. facility for crash test research pertaining to aeronautical structures. While the budgetary constraints that may have contributed to this closure are understandable, the loss of this facility is tantamount to the end of full-scale, experimental research on crash-resistant and survivable aircraft structures in the United States. This state of affairs is of concern to the committee.

Fire Prevention Task

The goal of the Fire Prevention task is to develop technologies to reduce fatalities from in-flight fires, postcrash fires after a survivable crash impact, and fuel tank explosions. The Fire Prevention task is composed of three subtasks: safe fuels, fire detection sensors, and fuel inerting.

The committee found the researchers to have a high level of technical competence in all areas and to have a good understanding of the problems they are addressing.

The safe fuels objective of reducing the likelihood of fuel tank explosions is one of the transportation safety improvements most wanted by the National Transportation Safety Board. The main thrust of the research is to create a jet fuel with a higher flash point, using a variety of approaches. This work requires close ties with all of the relevant players: the FAA, DoD, Boeing, refineries, and the Environmental Protection Agency.

Finding: Safe Fuels. The safe fuels subtask is quite mature and essentially at a maintenance level while awaiting a phase where all the players are ready to tackle the enormous job of introducing a new, safe aviation fuel.

Recommendation: Safe Fuels. When NASA reprioritizes its activities for future program phases, it should reinvestigate the need for near-term activity in the safe fuels area.

The sensors subtask focuses on the use of chemical species detection sensors to augment smoke sensors, particularly in aircraft cargo bays. This subtask has made good progress, and the path to fielding a viable system seems fairly straightforward assuming that there are no major problems with scheduled field tests and that packaging and installation issues can be resolved quickly. NASA and its partners appear to be taking advantage of the advances in microelectronics and processing to arrive at an effective technology for fire detection. This work is also quite mature.

NASA's fuel inerting subtask is focused on providing efficient onboard air separation techniques that provide the nitrogen-rich gas needed to inert the fuel in the tanks. It may be possible that the separated oxygen from the process can satisfy requirements for the onboard oxygen also. The technology relies on efficient membranes for the separation.

Finding: Fuel Inerting. In December 2002, the FAA performed representative tests on the ground with an apparently less sophisticated inerting system and obtained encouraging results. Both the FAA and NASA are working with industry to provide the inerting capability.

Recommendation: Fuel Inerting Cost-Benefit Analysis. NASA should perform a cost-benefit analysis involving the FAA, NASA, and industry to determine if further basic research in fuel inerting is warranted at this time.

Recommendation: Long-Term Research in Fuel Inerting. The fuel inerting task should be separated into a near-term, product-oriented activity and a longer-term, research-oriented activity involving industry to produce more efficient air separation techniques.

Synthetic Vision Systems Subproject

The Synthetic Vision Systems (SVS) has as its goal "to eliminate low-visibility-induced incidents and accidents."[4] SVS utilizes a terrain database, the Global Positioning System (GPS), and altitude sensing to give the pilot a computer graphic of the out-the-windscreen view of the ground with key instrument data superposed.

The objectives of the SVS subproject address several of the most critical aircraft safety concerns: controlled flight into terrain, runway incursions, and low-

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[4] D. Baize, NASA-Langley, "Synthetic Vision Systems subproject introduction," presentation to the panel in February 2003.

visibility-induced approach and landing mishaps. The subproject is divided into three tasks: Commercial and Business Aircraft, General Aviation, and Enabling Technologies. The entire subproject has a net funding level of $7.2 million in FY03 and $7.0 million in FY04.

The SVS work stimulated a very spirited discussion among the panel and committee members, and they still have many unresolved questions about the viability and future of synthetic vision systems, particularly with regard to their operational implementation. The committee agreed that the technology is exciting and holds promise for both safety and efficiency but was uncertain about its market value. Overall, however, the committee believes there are substantive research issues yet to be addressed in SVS, particularly in display human factors, pilot training, and the integrity and reliability of the terrain database system.

The committee believes the display interface remains one of the most substantial research issues. It also believes that head-mounted display technology may enable 360-degree viewing and that NASA should thoroughly evaluate such methods of display. In addition, although experienced instrument-rated pilots may be able to revert to conventional means for aircraft control in the case of SVS system degradation or failure, those with limited conventional instrument flying experience may be more susceptible to disorientation and loss of control. NASA should conduct studies to determine if additional training will be needed. The committee believes that basic research in these human factors considerations should be continued within NASA. If these questions can be answered, the committee sees SVS as a promising tool in the long run.

Finding: Synthetic Vision Systems Long-Term Research. NASA is overemphasizing the synthetic vision product at the expense of the long-term research questions in synthetic vision technologies.

Recommendation: Synthetic Vision Systems Long-Term Research. The Synthetic Vision Systems activity should be separated into two parts: a short-term product for handoff to and market evaluation by industry and air carriers in competition with the Enhanced Ground Proximity Warning System and long-term development work emphasizing human interface requirements, new applications to runway incursions, and other applications currently at low TRL.

The committee found that SVS researchers are aware of similar work going on at DoD and are collaborating with the Air Force at the Wright-Patterson Air Force Base. The committee encourages continued close partnering with the defense community, as SVS work has obvious relevance to that community.

The committee recognizes that there are additional challenges associated with database integrity and field of view for rotorcraft, but the number of controlled flight into terrain accidents experienced by rotorcraft warrants the additional research effort.

Finding: Synthetic Vision Systems and Rotorcraft. Synthetic vision could significantly enhance rotorcraft safety.

Recommendation: Synthetic Vision Systems and Rotorcraft. NASA should expand its synthetic vision work into the rotorcraft area. The potential safety improvements that could be obtained with synthetic vision would warrant its extension to rotorcraft.

Most of the above comments regarding SVS hold true for the subproject as a whole; a few additional task-specific comments are provided in the following paragraphs.

Commercial and Business Aircraft Task

The committee found the simulations associated with the Eagle-Vail Airport in Colorado to be impressive.

Finding: Synthetic Vision Systems Cost-Benefit. The incremental value provided by Synthetic Vision Systems for commercial and business aircraft is unclear given the capability of many existing flight management systems on these aircraft and given the proficiency of their pilots under instrument flying conditions.

Recommendation: Synthetic Vision Systems Cost-Benefit. NASA should perform, with industry, a cost-benefit analysis for the technologies necessary to improve the existing enhanced ground proximity warning system capability and should reprioritize the activities in this area accordingly.

Finding: Synthetic Vision Systems Field of View. There is no research into field-of-view requirements for either head-down or head-mounted Synthetic Vision Systems displays.

Recommendation: Synthetic Vision Systems Field of View. NASA should establish field-of-view requirements for head-down synthetic vision displays. This would include addressing the efficacy of synthetic vision in large excursion maneuvers. NASA should thoroughly investigate head-mounted display technology that may improve field-of-regard operation by the pilot.

General Aviation Task

Again, the committee found the SVS systems as demonstrated to be impressive. The system potentially gives a general aviation pilot with minimal instrument flying skills the opportunity to operate under a broader spectrum of flight conditions. Concerns about cost effectiveness and market value are particularly prevalent in the general aviation area. The committee has some concerns about both the operational concept (how the system will be used and the pilots trained) and the expected final system costs. A review of earlier cost-benefit assessments and predictions is warranted, as they may affect NASA's future research priorities. The committee suggests that NASA develop a rigorous method for establishing field-of-view requirements for head-down SVS displays and that it draw upon the wide array of literature in optimal display characteristics when developing SVS displays.

Finding: Synthetic Vision Systems and General Aviation. The biggest benefit of synthetic vision in the near term is in the general aviation arena.

Recommendation: Synthetic Vision Systems and General Aviation. In future continuations of Synthetic Vision Systems, NASA should solidify the human-aircraft interface requirements in general aviation through tests and evaluations. NASA should work with DoD to utilize DoD's current and soon-to-be-available synthetic vision display technologies for these evaluations.

The committee had several other more specific suggestions for applications of SVS to general aviation. In particular, the committee encourages NASA to research the efficacy of all SVS presentations in the prevention and recovery of upset maneuvers. Peripheral cues can be vital to the pilot in coping with upsets; these cues are essentially absent in current SVS applications. Second, the committee suggests that NASA seize Project Capstone as an excellent opportunity to obtain empirical data that could help optimize the way pilots perform when they use the technology. NASA and FAA project managers should collaborate closely in the design and execution of this valuable phase of the research. The committee encourages NASA to develop a list of research questions to incorporate into the evaluations.

Enabling Technologies Task

For proprietary reasons, the committee was unable to assess the use of high-resolution WXR2100 radar to detect airborne and surface aircraft. Reports of such a use are encouraging, but without substantive information, the committee doubts that weather radar can be applied to the detection of other aircraft, both in the air and on the ground, at a nonprohibitive cost.

Finding: Synthetic Vision Systems and Weather Radar. The use of WXR2100 to detect aircraft is unlikely to be successful.

Recommendation: Synthetic Vision Systems and Weather Radar. NASA should thoroughly evaluate the results of the 2003 flight test involving WXR2100 radar to determine its efficacy in detecting surface obstacles as part of runway incursion research. In addition, NASA should review this approach in light of current FAA activities to mitigate runway incursion and determine whether it would be useful and cost effective.

Currently, SVS is not a high-priority technology for runway incursion prevention owing to high costs and a lack of infrastructure. If better ground surveillance becomes available, some form of wide-angle viewing becomes practical, and SVS costs are reduced, SVS may have great promise for reducing runway incursions. This is especially important as pressures mount to crowd more and more aircraft into major airports with closer and closer separations.

Weather Safety Technology Project

Background

The goal of the Weather Safety Technology project is to reduce the frequency and severity of weather-related accidents and injuries. This project was funded at a net value of $14.7 million in FY03 and is composed of two subprojects: Aircraft Icing and Weather Accident Prevention. The Aircraft Icing subproject is funded at $5.0 million (34 percent of the project budget) and the Weather Accident Prevention subproject is funded at $9.7 million (66 percent of the budget). The Weather Safety Technology project is spread across several NASA research centers. Icing work is performed at NASA Glenn, turbulence work is split between NASA Dryden and NASA Langley, communications work is performed at Glenn, and the aviation weather information work is conducted at Langley. The project management is based at Glenn.

Portfolio

The project objective is to develop and foster technologies that will significantly reduce aviation accidents and incidents due to atmospheric conditions, including convection, limited visibility, turbulence, and icing. The project encompasses a broad set of activities, including sensors, decision aides, design and analysis tools, data dissemination, and training aids.

The activities range from fundamental research, such as in the Aircraft Icing subproject, to applied research, such as in the Aviation Weather Information (AWIN) task, where work is approaching TRL 6. Many, but not all, of the activities involve strong interaction with the FAA, other national laboratories, and industry.

The Weather Safety Technology project, with the exception of the Aircraft Icing subproject, is weighted toward applied research more than basic research, but the selected projects respond to well-recognized weather safety risks.

Finding: Terminal Area Operations. The weather safety portfolio focuses solely on en route operations and not on terminal area operations, where many weather-related accidents occur.

Recommendation: Terminal Area Operations. NASA should include weather research in both regional and terminal area operations in its future work plans for Weather Safety Technology.

Program Plan

This project has a variety of subprojects, with planning that is designed to address the individual goals and objectives. For instance, the Aircraft Icing subproject is an important sustaining activity that provides a mix of fundamental research, design and analysis tools, and educational products. In contrast, the Aviation Weather Information task has already completed some of its objectives, such as developing graphical weather displays in the cockpit and fostering their development by industry, and is now turning to integrating information from a variety of diverse sources.

The committee found the overall project planning to be good, with goals and objectives appropriately designed to address aviation weather hazards. There is, however, a serious concern that the planning of some subprojects led to a large number of participants, requiring considerable coordination efforts for NASA managers. This has diminished the internal technical base at the various NASA centers.

Finding: Research Outsourcing. The Weather Safety Technology project is outsourcing too much of its research effort.

Recommendation: Research Outsourcing. NASA should determine whether the current practice of using a large number of contract participants is diminishing the technical skills of government staff, who are being called on to manage contracts, and should modify it as necessary.

Finding: Project Exit Criteria. There are no clear exit criteria for many of the projects.

Recommendation: Project Exit Criteria. NASA should develop clear exit criteria for each of its projects.

The committee recognizes that it is difficult to assess the impact of weather safety research because there is a lag between the development of new technologies and their implementation in significant enough numbers to obtain useful field data. In addition, the existing data-collecting mechanisms at NASA and FAA do not formally obtain weather incident information, which is vital to understanding the exposures to various risks and to better guide safety programs such as the AvSP.

Finding: Evaluating Research Impact. It is unclear how the weather safety projects and products will measure their impact on aviation safety.

Recommendation: Evaluating Research Impact. NASA should work with the FAA and industry to develop a risk assessment methodology and associated field indicators that together would document how safety is enhanced as the result of a weather technology product, even with limited deployments of the product.

Technical Performance

The committee was very impressed with the overall technical performance of the Weather Safety Technology project. The Aircraft Icing subproject is a nationally recognized facility with top-notch staff, is well managed, and has excellent collaborations with other federal government organizations and industry. Its educational outreach work is highly valued by general aviation.

The AWIN and Weather Information Communications (WINCOMM) tasks have also been successful in dramatically increasing the availability of graphical weather in the cockpit during en route flight by very high frequency (VHF) and satellite communications methods. If the tropospheric airborne meteorological data reporting (TAMDAR) subtask to provide meteorological data from aircraft to the ground weather infrastructure is successfully completed and deployed, it will be a great benefit to aviation weather forecasting and, in turn, safety. The committee is, however, very concerned that calibrated TAMDAR data have not yet been made available to the meteorological community and that the business case was based on turboprop commuter aircraft, which are rapidly being replaced by regional jets. This is discussed in more detail in the AWIN section.

The Turbulence Prediction and Warning System (TPAWS) task had a major success when it demonstrated an in-flight 95-second warning of turbulence using forward-looking microwave Doppler radar. However, this work needs to continue in order to meet the industry request for longer warning times. Further, it needs to be more connected to the research sponsored by the FAA; recent meetings suggest that the issue is being addressed.

User Connections

Most of the subprojects within the Weather Safety Technologies project are well connected to the aviation community and to industry. The NASA Glenn icing facility has staff that are highly respected by industry and academia and works very closely with the National Center for Atmospheric Research and other organizations. The AWIN and WINCOMM tasks have also worked closely with pilot groups and industry. The turbulence activity has worked closely with a commercial airborne weather radar manufacturer but has not collaborated with the FAA turbulence product team, a matter that has been recently addressed (but not solved) by both parties.

Assessment by Subproject

Aircraft Icing Subproject

The focus of the Aircraft Icing subproject is to enable the elimination of icing as a cause of aircraft accidents. This is accomplished through a combination of (1) basic research in icing physics, (2) more applied, focused work in tool design and technologies for icing detection, anti-icing, and deicing, and (3) the development of icing educational materials for pilots, operators, and engineers. The Aircraft Icing subproject is funded at $5.0 million in FY03 and FY04. It is composed of three tasks: Design and Analysis Tools, Aircraft Ice Protection, and Education and Training.

The committee was very impressed with the icing program, its facilities, and staff. The icing test facility is clearly a unique national asset that is vital to the air transportation community, both civil and military. The effort is well managed, and the key staff are experienced professionals, knowledgeable in both the theoretical and practical aspects of icing phenomena and their effect on aircraft aerodynamics. They are also well versed in the FAA certification process. The icing activity is characterized by high quality and productivity.

The committee was pleased to observe a strong coupling with the National Transportation Safety Board (NTSB), the FAA, industry, and the icing effort at the National Center for Atmospheric Research (NCAR). Several dozen test flights are conducted each year using NASA Glenn's instrumented aircraft in collaboration with NCAR remote-sensing experiments. This cooperative effort is extremely important and should be maintained.

Finding: Icing. The Aircraft Icing subproject represents the best technical work in the Aviation Safety Program and is an important national asset.

Recommendation: Icing. NASA should ensure the Aircraft Icing subproject continues as a well-balanced research effort to understand and mitigate aircraft icing. If possible, work should be increased in areas such as anti-icing fluids and the assessment of holdover times.

Design and Analysis Tools Task

The Design and Analysis Tools task develops products to assist in the design, certification, and qualification of aircraft and aircraft components. This task conducts research in six areas: super-cooled large droplet (SLD) engineering tools, LEWICE, SmaggIce, LEWICE3D, experimental methods and databases, and flight testing. This task has developed and implemented a number of tools in ice growth prediction, ice shape prediction, thermal ice protection system performance, and the aerodynamics of aircraft with ice. It is funded at $2.9 million in FY03 and FY04.

The work of supporting the FAA in its efforts to modify the criteria for icing certification based on a better understanding of SLD is very important and has already yielded a significant amount of new information. This should be continued vigorously.

Development of the LEWICE computer code has produced a program that is ready for production and will be subject to evolutionary improvements. However, the LEWICE3D program is still in the development stage and needs continued strong support. This is a very important tool for aircraft designers and researchers who work with three-dimensional bodies. For example, a wing, which usually uses LEWICE for analysis, has unique three-dimensional flow and droplet trajectories that can only be handled accurately by LEWICE3D.

The work on experimental methods and flight testing has been of a very high quality and should be continued vigorously to provide real-world results that augment and validate theoretical investigations. There is still much to be learned about the effects of icing on aircraft aerodynamics.

Aircraft Ice Protection Task

The Aircraft Ice Protection task has two objectives: to develop remote sensing technologies to detect and measure icing conditions and to develop methods to assess the performance of an aircraft under icing conditions ("smart icing" systems). This task is funded at $1.7 million per year in FY03 and FY04.

The FAA-sponsored NCAR program to develop methods to forecast icing conditions more accurately and the NASA effort to sense and document actual icing conditions have met with considerable success. This is one of the most critical areas for improving the safety of general aviation airplanes with respect to icing. The vast majority of general aviation airplanes have little, if any, ice protection equipment installed. Their best defense is the ability to know where icing conditions exist, and then to avoid those conditions. This collaborative work has the end goal of incorporating successful methods and technologies into the official weather forecasting system. It should be vigorously supported until that end goal is met.

Smart icing systems, which take the critical decision making out of the pilot's hands and place them in the system, are still in the early stages of development. More work will be required before the results reach a practical stage, but this is an important area to pursue further.

Education and Training Task

The Education and Training task seeks to create and disseminate a suite of training materials on in-flight icing. The task has developed and distributed five training guides thus far (three video-based and two computer-based) and expects to develop more guides, as well as plan curricula for pilot training. Clearly, this is a highly applied effort on the part of NASA and is a different type of work and work product than the rest of the program under evaluation. Education and Training is funded at $400,000 in both FY03 and FY04.

The committee, in reviewing icing training aids, found the materials to be well made, with good information on how to plan flights in icing conditions, how to use weather reports, and how to identify escape routes. They contain some science and have interesting video clips of aircraft in icing conditions. However, the committee found the recovery procedures to be somewhat weak on piloting techniques: The aids should emphasize more fully how a pilot can tell the difference between wing stall and tail stall based on aircraft response, and they could benefit from additional information on pilot perceptions and initial cues of problems. The committee suggests that the education materials should incorporate recovery methods and also discuss asymmetric icing (such as occurred in the Roselawn accident and the Detroit accident).

The efforts to improve pilot education have contributed significantly to the enhancement of aviation safety. The Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation (ASF) is pleased with the work done in this area. That being noted, the committee believes that the dissemination of the icing training materials seems much too limited; perhaps with assistance from the FAA and broader efforts on the part of industry, they can be more widely distributed.

Finding: Icing Education. The good work in icing education notwithstanding, several recent ice-related aircraft accidents indicate that pilots are still ignoring warnings of potential icing conditions.

Recommendation: Icing Education. The Aviation Safety Program should evaluate how to have a greater impact on the education and training of pilots and how to focus research on aids for pilot decision making in icing conditions. A greater effort should be made to distribute such training aids.

Weather Accident Prevention Subproject

The Weather Accident Prevention (WxAP) subproject goal is to develop technologies that will reduce weather-related accident causal factors by 50 percent and turbulence-related injuries by 50 percent by the year 2007. To accomplish that goal, it has three objectives: develop means to provide better weather information to the cockpit during en route flight, develop supporting communications, and develop turbulence avoidance technologies. WxAP is funded at $9.7 million in FY03 and $8.9 million in FY04. It has three tasks: Aviation Weather Information (AWIN), Weather Information Communications (WINCOMM), and the Turbulence Prediction and Warning Systems (TPAWS).

The committee finds the WxAP goal to be ambitious but appropriate, for three reasons. First, weather continues to be involved with a significant number of aviation incidents and accidents. Second, national investments in Next Generation Weather Radar (NEXRAD) Doppler weather radars, Terminal Doppler Weather Radars, the National Convective Weather Forecast, and the Integrated Terminal Weather System are expected to significantly improve the timely dissemination of weather and weather hazards to aircraft cockpits. Third, airborne weather radar with advanced signal processing could improve turbulence sensing significantly.

The committee finds that the goals and planning were appropriate as originally formulated. However, the committee noted a certain inflexibility in the plan that prevents the investigation of topics not originally defined, such as pilot penetration of storms in the terminal or transitional areas (not an en route issue, but clearly a weather safety matter).

Aviation Weather Information Task

The AWIN task is designed to provide the pilot with accurate, intuitive, informative, and timely weather-related information that will help to reduce the number of accidents and incidents due to weather. The task conducts research in airborne hazard awareness, satellite aviation weather products, tropospheric airborne meteorological data reporting, and interface and display technologies. The task has a budget of $4.1 million in FY03 and $3.7 million in FY04.

The AWIN task goal is to reduce en route accidents attributed to a lack of weather information by 25 to 50 percent. This is an important goal, since the annual AOPA ASF Nall reports indicate that adverse weather continues to be a major safety concern for air transportation, especially for low-end general aviation. For transportation aircraft, turbulence encounters are causing serious passenger injuries and are a major safety issue with flight attendants. The 2002 ASF report states “weather is usually the culprit in cruise accidents, and was the cause in 15.2 percent of all pilot-related fatal accidents in 2001.”[5] However, the Nall report also indicates “attempted VFR flight into IMC continues to be the most deadly weather-related accident cause, with 84 percent involving fatalities.”[6] This suggests that the AWIN program should consider expanding its scope to improve weather situational awareness during the terminal and approach phases of flight.

The committee finds that the plan to achieve the stated objective is well formulated and reflects a competent understanding of the issues and developments needed to reduce the en route weather risks. The airborne weather data collection, fusion, and decision aide

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[5] AOPA Air Safety Foundation. 2002. 2002 Nall Report, p. 4.

[6] Ibid., p. 7.

approaches are particularly important. Also important are the collaborations with the FAA, NCAR, the National Oceanic and Atmospheric Administration (NOAA), and academia to learn how to incorporate current and future satellite observations into aviation forecasts. Future weather satellites can be expected to provide high-rate, high-resolution, multispectral imagery cued by numerical model forecasts to areas of bad weather, so it is appropriate that NASA participate in their development. An effort is planned for 2007 using the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) satellite to determine the benefit of altitude-resolved temperature, moisture, and wind, as well as other advanced weather satellite technology insertion. If this effort goes forward, it will be a noteworthy and potentially very valuable element in the program and NASA should actively participate.

It is not clear whether the objective goal of reducing accidents by 25 to 50 percent will be achieved, and the evidence confirming the success of the effort is unlikely to be available for some years after the AWIN task has been completed. However, as mentioned above, the committee recommends that NASA develop some field indicators to help understand the potential benefits of this initiative, perhaps with the help of industry groups such as the Air Line Pilots Association (ALPA), the Air Transport Association (ATA), and AOPA.

The committee observes that this program involves many other organizations and is concerned that the effort to coordinate such a complex activity is preventing NASA staff from becoming fully involved in the technical aspects.

The AWIN effort to stimulate commercial methods to transfer graphical weather images to the cockpit appears to have been successful, as measured by the variety of commercial methods now on the shelf. The program is now focusing on the integration of various onboard weather data to help the flight crew avoid weather hazards, and that effort is also appropriate and needed.

Finding: Aviation Weather Information Integration. The operational deployment of the Integrated Terminal Weather System provides an opportunity to integrate existing Aviation Weather Information products with Integrated Terminal Weather System graphical six-level weather images to provide an improved awareness of weather when operating in the Integrated Terminal Weather System coverage areas.

Recommendation: Aviation Weather Information Integration. NASA should conduct an assessment of the benefits of integrating existing onboard aviation weather information with uplinked convection and wind data from the Integrated Terminal Weather System. Should this appear beneficial, part task or full task human factors studies on pilot decision making and follow-on field demonstrations should be conducted.

Aircraft penetration of convective weather in the terminal area is an unresolved issue. Basic studies were conducted in the 1960s at the National Severe Storms Laboratory by J.T. Lee,[7] providing advice to airline crews on avoiding areas with heavy precipitation. More recently, however, a NASA-sponsored study of aircraft operations in the Dallas-Fort Worth area indicated that airline crews are penetrating areas of high precipitation during arrivals.[8] This work raised several unaddressed key issues regarding pilot penetration of convective weather.

Finding: Pilot Penetration. It is unclear whether traditional six-level precipitation is the appropriate indicator of turbulence and why pilots choose to penetrate those levels against their training and airline operating procedures.

Recommendation: Pilot Penetration. The Aviation Weather Information task should work with the FAA, airlines, and pilot communities to address the issue of pilots penetrating convective weather, including the adequacy of existing onboard weather radars for portraying flight hazards, the adequacy of current pilot training in their use, and related pilot decision making.

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[7] J.T. Lee. 1962. A Summary of Field Operations and Data Collection by the National Severe Storms Project in Spring 1961. Norman, Okla.: National Severe Storms Laboratory; J. T. Lee, L.D. Sanders, and D. T. Williams. 1964. Field Operations of the National Severe Storms Project in Spring 1963. Norman, Okla.: National Severe Storms Laboratory.

[8] Dale Rhoda and Margo Pawlak. 1999. An Assessment of Thunderstorm Penetrations and Deviations by Commercial Aircraft in the Terminal Area. Project Report NASA-A/2. Lexington, Mass.: Massachusetts Institute of Technology Lincoln Laboratory.

In the last 10 years, the FAA Aviation Weather Research Program has developed new automated forecasts that predict the future location of convective systems. For example, the National Convective Weather Forecast is being used operationally by FAA traffic flow managers. In development are similar tools that will show current and future areas of turbulence and icing. Since these tools may be very beneficial to flight crews, it is important that appropriate research be conducted to determine how they can efficiently be provided to the cockpit and used safely by pilots. Many of these products are available today in the Aviation Digital Data Service system and could be used by AWIN as in-flight display products.

Finding: Weather Display Interfaces. There are a number of outstanding research questions in the area of weather display interfaces.

Recommendation: Weather Display Forecasts. NASA should include weather research to determine the methods and value of providing evolving 1- to 2-hour automated weather forecasts of convection, turbulence, and icing to the flight crews of various classes of aircraft. Such information would maximize avoidance of unsafe conditions in terminal, transition, and en route airspace.

Finding: Weather Display Consistency. There is a need for consistency in weather information displays in the aviation weather community. It is particularly important that the information being presented to the flight crew be consistent with that seen by FAA air traffic controllers and the airline operations centers.

Recommendation: Weather Display Guidelines. The Aviation Weather Information program should help the FAA and industry to develop best practices guidelines for the integration and display of uplinked and onboard weather information.

The value of uplinked weather to general aviation aircraft is convincing for both safety and utility purposes, especially for less costly piston aircraft. However, the business case for provisioning transport-category aircraft with graphical uplinked weather products is not compelling. Unless the cost-benefit case can be made, what seems to be of great value may come to naught.

Finding: Uplinked Weather. NASA's justification for research in uplinked weather to transport aircraft is unconvincing.

Recommendation: Uplinked Weather. When evaluating the potential benefits and costs of new technologies, especially those for transport aircraft, NASA should ensure that the views of corporate operations officers and financial decision makers, as well as those of the pilot community, are heard to ensure that the return on investment is sound.

Lower atmosphere data such as humidity and temperature are becoming increasingly important for supporting forecasts of convective growth, ceilings, and visibility. The Tropospheric Airborne Meteorological Data Reporting (TAMDAR) system is designed to meet that need, and the committee supports the use of such a system.

Finding: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Data Availability. Data from the developmental TAMDAR are still not available to others who will use the information to support advanced meteorological forecasts. It appears that there are ongoing sensor problems, which may account for the delayed access to output data. It is vital that the data measurement methods be well understood if the instrument is to be useful for aviation weather forecasting.

Recommendation: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Data Availability. Information about TAMDAR and its data should be made available to appropriate aviation weather scientists as soon as possible to enable verification and validation.

The TAMDAR test flights must be done in such a way as to allow a side-by-side comparison of the TAMDAR turbulence eddy dissipation rate (EDR) data and data produced when the turbulence EDR algorithm is implemented on the large commercial fleet. A way must be found to ascertain comparability. In addition, there needs to be close collaboration with the FAA Aviation Weather Research Team, which will be a key recipient of the data.

Finding: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Data Comparison. The

TAMDAR project is somewhat disconnected from FAA and industry activities.

Recommendation: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Data Comparison. The TAMDAR flight tests planned for 2004 should not commence until the results of the Twin Otter and WP3-D flight tests show compliance with the stated requirements. Also, the TAMDAR project should ensure that the needs of the FAA Aviation Weather Research Convective Product Team are carefully understood, in particular their strong need for humidity data to support tactical storm growth and decay forecasts.

Finding: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Data Value. The TAMDAR project assumed the sensors would be carried by turboprop commuter aircraft that operate at the lower altitudes. With the large-scale replacement of turboprop aircraft by turbine aircraft that operate at higher altitudes, the value of TAMDAR data may be significantly lessened.

Recommendation: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Data Value. The business case for TAMDAR should account for the ongoing replacement of turboprop aircraft by regional jets.

Weather Information Communications Task

The WINCOMM task seeks to develop advanced communications technologies to assist in the dissemination of weather information to the cockpit. This effort is funded at $2.8 million in FY03 and FY04.

The research into ways of making current weather information accessible to pilots has been quite successful. Several representatives from industry report that their progress in developing air-ground data links has been significantly helped by the WINCOMM program. As a result, a number of unique media for accessing and transmitting weather data into the cockpit have been successfully demonstrated. This program appears to be reaching maturity, and the committee was uncertain what additional value NASA could provide in this area.

NASA intends to continue the AWIN task, focusing on the development of increased uplink bandwidth in anticipation of the need for more uplinked weather. NASA also intends to establish an aviation uplink infrastructure that it believes will not be available from industry owing to the low volume of aviation traffic.

Finding: Uplinked Weather Needs. There does not appear to be a convincing need for significant additional uplinked weather. Until that case is made, the development of yet another aviation data link is not compelling.

Recommendation: Uplinked Weather Needs. NASA should develop a prioritized list of weather information communications requirements and adjust the goals of the weather communications research accordingly.

Turbulence Prediction and Warning Systems Task

The goal of the TPAWS task is "to develop technology to reduce turbulence-related injuries for the traveling public and aircrew."[9] The task is funded at $2.8 million in FY03 and $2.4 million in FY04.

Recent NASA-funded tests demonstrated a 95-second turbulence warning based on spectral analysis (second moment) of an airborne weather radar. The results, which were confirmed by NASA flight testing, are a significant accomplishment that recently received a NASA award and a sign of healthy collaboration between NASA researchers and a manufacturer. The work is impressive and may be offered as an optional feature on airborne weather radars in the future, since its probability of detection ($\geq$0.2 g) is 81 percent, a value that is consistent with the CAST goal of 80 percent detection probability of moderate or severe turbulence.[10] However, the system was also found to have a nuisance (false alarm) alert rate of 10.53 percent. Although this is a metric about which CAST is silent, the acceptability of a turbulence warning system such as TPAWS will depend strongly on airline and pilot acceptance of false alert performance as well. The com-

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[9] R. Bogue, NASA-Langley, "Turbulence prediction and warning systems," questionnaire completed in January 2003 (see Appendix D).

[10] L. Cornman, NCAR, "Turbulence prediction and warning system, FY02 Flight Test Data, Weather Accident Prevention Annual Project Review," presentation to Massachusetts Institute of Technology Lincoln Laboratory on November 20-21, 2002.

mittee is also concerned that the cost of this forward-looking radar may be too great for implementation by the civil transport industry during difficult times, especially since the use of such a system is not a high CAST priority.

The transfer of successful research results to the airborne microwave weather radar industry appears to be very good, although the committee was concerned that the connectivity between NASA turbulence research and the vendors was not being maintained as well as in the past, a situation that may be related to the difficult economic times for civil aviation.

The level of TPAWS collaboration with other agencies and industry appears inconsistent at best. Some industries are associated with the effort, and here the collaboration is good; however, the record of collaboration with the outside community of scientists and engineers is often unsatisfactory. There appears to be a sense of secrecy in the effort, which should not be the case with a healthy program. The committee was informed by NASA that there are tentative plans to develop a singular plan in collaboration with the FAA in this area, and the committee strongly encourages NASA to establish and strengthen such collaborations.

Separately, NASA has been funding work on in situ (onboard) turbulence detection, using accelerometer data to compute gust load, with the plan to datalink the information to other aircraft as a turbulence warning. There has been some concern at the FAA and on the part of other scientists working in the airborne turbulence arena that this approach would seriously conflict with the FAA approach, which uses eddy dissipation rate. It is critical that NASA management establish and maintain a consistent approach to in situ turbulence detection and reporting to avoid technical conflicts with FAA in the future.

The current advanced warning from light detection and ranging (lidar) is 45 seconds, far less than the 95 seconds of the radar system. There appears to be little value to the airlines and little evidence of reliability, safety, or cost effectiveness. Unless a much more powerful (and more expensive) lidar could be developed, there is no operational concept to justify the lidar work.

Finding: Lidar. The potential for lidar as a sensor for turbulence detection is very limited.

Recommendation: Lidar. The lidar initiative should be terminated.

Finding: Turbulence Warning. The Commercial Aviation Safety Team stated that turbulence detection was a lower priority issue but important nevertheless and that a 95-second warning would be inadequate. A study has been done by industry to establish a practical warning time.

Recommendation: Turbulence Warning. NASA should initiate a research activity in advanced airborne-based turbulence detection to significantly improve the airborne turbulence warning time to satisfy the needs of the airline industry.

System Safety Technology Project

Background

The System Safety Technology project is designed to reduce the frequency and severity of aviation accidents and incidents through proactive management of safety risks using a systemwide approach. The project is composed of two subprojects: Systemwide Accident Prevention (SWAP) and Aviation System Monitoring and Modeling (ASMM). The two subprojects focus on mitigating risks associated with human error and human performance and continuously monitoring the national airspace to identify and analyze safety trends and precursor events. System Safety Technology is funded at \$18.4 million net in FY03 and \$17.7 million in FY04. Approximately 27 percent (\$5.0 million) is allocated to SWAP and 46 percent (\$8.4 million) to ASMM. The remaining funds support the Search and Rescue effort, which was not assessed in this review.[11] SWAP and ASMM are based at NASA Ames.

Portfolio

NASA has been a mainstay of aviation system safety research for many years. It has carried the vision for what is possible and must continue to do so if the United States is to maintain the safest possible flying environment for the American traveling public. There are many safety programs in NASA research initiatives

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[11] The Search and Rescue work is funded by the AvSP, but Goddard Space Flight Center is responsible for management of the subproject. As the AvSP does not have programmatic responsibilities in Search and Rescue, the panel did not evaluate this effort.

that have served the aviation community well for years and there are sure to be many others that show great promise for future applications. Many of the programs are user driven, both internally and externally. Unfortunately, the expectation that projects can be completed in 5 years appears to constrain NASA's ability to articulate a consistent and clear vision for long-term core research. It also seems to impact the ability to create well-defined goals that lead to an integrated research program. The goal of providing a general knowledge foundation, as in the case of human performance modeling, should be part of a core research program. Balancing the System Safety Technology suite of applied research activities with more basic research would help sustain essential core competencies within the associated groups.

A specific long-range goal such as creating a fully integrated virtual National Air Space model by 2020 or 2050 for modeling total system safety and efficiency would be helpful in focusing and balancing research projects. Research initiatives should support such a central long-range goal, and the AvSP should work closely with the VAMS effort in the ASP program to achieve this. Requirements could then be more easily developed, including problem statements, standards, and test procedures. These should be established in a way that encourages innovation while maintaining focus and accountability. Additionally, a continuous systems analysis approach would be constructive in identifying research priorities and allocating resources to projects with the greatest impact on safety.

Program Plan

Many of the safety tasks have articulated very desirable outcomes, but plans to achieve these outcomes were often unclear or lacked measurable milestones. For example, a number of outcomes are in the form of a percentage reduction in accidents or in fatalities. There appears to be no method in place in the research program for evaluating such outcomes or for assessing progress. This gap appeared to be driven by a disconnect between the resources or time required to accomplish the target outcomes and the availability of assets and time. The committee acknowledges that some of this work is low-TRL and difficult to relate directly to measurable changes in accident mitigation. Nevertheless, the committee believes that NASA should develop interim milestones and metrics for internally evaluating the success of the System Safety Technology project relative to intended project deliverables. This should be done in conjunction with the Technical Integration effort.

The process of research project selection, planning, resourcing, programming, and accountability within the matrix management scheme was complex and difficult for the committee to understand. Some programmatic decisions appear sensible from a safety perspective but do not seem to relate to an overall research plan.

Technical Performance

The committee was impressed with the technical capabilities of the NASA Ames staff associated with the System Safety Technology project. NASA Ames has an excellent reputation for "basic applied" research. The committee encourages NASA to uphold this strong reputation by sustaining basic research programs at Ames, where scientific publication is a core value.

The committee is concerned that the balance of in-house and contractor personnel is becoming heavily weighted toward outsourcing to an extent that could compromise the ability to maintain core competencies. Additionally, heavy outsourcing forces scientific personnel to focus on management oversight rather than on building internal scientific activities. This discourages young researchers from joining the NASA team or even remaining with NASA.

Basic research seems constrained in a number of areas owing to either lack of access to data or lack of resources to process available data. Good examples of this are the highly respected Aviation Safety Reporting System product and the Maintenance Human Factors task. As long as there are barriers to accessing data, basic research could languish.

User Connections

The committee was impressed with the establishment of an integrated FAA/NASA Aviation Safety R&D Plan, an Aviation Safety Working Group, and an Aviation Safety Program Executive Council, all to ensure greater coordination of FAA/NASA research. Effective use of these groups will be vital to establishing post-2004 safety research goals.

In some areas NASA seems to be pursuing technologies or tools that have reached maturity or are complementary to items already available in industry or other government agencies. This is true, for example, with Performance Data Analysis and Reporting System (PDARS), Aviation Performance Measuring System (APMS), and the virtual reality maintenance work. It is critical that regular, open, candid product benchmarking and communications occur among NASA, FAA, industry, and other research entities in order to avoid duplication, to ensure that valuable and limited resources are effectively and efficiently allocated, and to sustain world-class research standards and products.

Assessment by Subproject

Systemwide Accident Prevention Subproject

SWAP is the AvSP subproject devoted to human factors and its relationship to error mitigation. The focus of the research is primarily in error modeling, training procedures, and maintenance procedures. SWAP is also responsible for identifying crosscutting issues in human factors that relate to the AvSP as a whole or to other subprojects and tasks under the AvSP purview. SWAP is broken into four tasks: Human Performance Models, Maintenance Human Factors, Crew Training, and Program Human Factors. SWAP is funded at a net value of $5.0 million in FY03 and $5.1 million in FY04.

Human Performance Models Task

The Human Performance Models task utilizes cognition and perception models to detect and analyze human error and to develop tools for system design. The task works primarily with five human performance models: Air Man-Machine Integration Design and Analysis System (AirMIDAS), ACT-R/PM, A-SA, D-OMAR, and IMPRINT/ACT-R. Each model uses a different cognitive approach and each has a different application to sources of pilot error. The Human Performance Models task has also developed a tracking system, the Crew Activity Tracking System, to predict operator behavior and to interpret operator actions. The Human Performance Models task of SWAP is funded at a net value of $1.5 million in FY03.

The activities in this area are appropriately weighted toward fundamental research. The goal is clearly to create state-of-the-art modeling techniques. While resources seem adequate for the stated goals, the 5-year program constraint appears to limit the long-term potential of this core research area.

Error analysis appears to focus on error as deviation from nominal procedure rather than considering which deviations are dangerous and which are merely alternative but still acceptable ways to accomplish the task. These alternative methods may in some cases be better than the nominal (e.g., under off-normal conditions). Expanding the scope of work to include acceptability analysis may broaden the potential application of this effort.

While application of NASA human performance modeling research to other efforts at NASA, such as synthetic vision research, would seem promising, there is little to show as yet. There appears to be no connection with human performance modeling at other government agencies.

Finding: Collaboration with Other Agencies. There appears to be no substantive interface with human performance modeling at other government agencies such as the Air Force Laboratory's Human Performance Modeling Integration Program, the Department of Defense, or government laboratories such as the Human Emulation Laboratory at Sandia National Laboratories. NASA is not part of the Human Performance Modeling Special Interest Area.[12]

Recommendation: Collaboration with Other Agencies. NASA should conduct collaborative research with both the Defense Advanced Research Projects Agency and the DoD to leverage techniques developed by these other agencies for piloting, decision making, estimating human error in automated systems, and vigilance.

There is a well-documented, short-term plan with reasonable milestones, but the long-range vision and plan for this initiative lack definitive goals and metrics. Development of a method for comparison across models is encouraged, since current metrics vary from model to model.

Finding: Human Factors Outreach. Much of the Human Performance Models work was done by human factors engineers for human factors engineers. There is too little outreach to NASA engineers in other disciplines who should be future users of these models. Additionally, program deliverables and their purposes were not clearly articulated.

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[12] See <http://www.msiac.dmso.mil/hpm/default.asp>.

Recommendation: Human Factors Outreach. The NASA Human Performance Models group should work with the managers of all internal aviation research programs to identify each manager's need for human performance models and to support the testing of emerging models against human-in-the-loop simulation as well as flight demonstration.

Recommendation: Human Factors Outreach. NASA human factors programs should publish a book or CD on the state of human performance modeling to communicate what can realistically be done in this type of modeling and to measure progress in this research area.

Recommendation: Human Factors Outreach. NASA should create, document, and apply more clearly defined off-ramps for high-TRL Human Performance Models.

NASA Ames has maintained an excellent reputation for sponsoring and convening human performance modelers for several decades. It is essential to strive for continual high quality since human lives are affected by the accuracy of the safety estimates derived from these models. The committee applauds the participation of academia in the NASA Ames aviation safety work but strongly urges outreach to the government agencies listed in the finding on collaboration, above. In addition, this group has only been able to apply models to a limited number of real-world problems, such as taxiing errors. The committee feels that these models can be tested and improved by applying them to additional real-world problems.

NASA is developing tools in this area for others to use. However, actual and potential users, both managers and researchers, should be more clearly identified so their input can be solicited when research and applications are being identified and prioritized.

Maintenance Human Factors Task

The Maintenance Human Factors task is designed to develop "guidelines, recommendations, and tools directly to maintenance personnel and managers"[13] through a combination of research in understanding human error in maintenance and developing maintenance tools and aids to enhance safety. The maintenance program focuses on risk analysis, resource management, advanced displays, and human error baselines. The effort is funded at $1.1 million net for FY03 and FY04.

The importance of human error in the maintenance of aircraft was underscored recently by the US Airways Express Air Midwest Flight 5481 accident. The National Transportation Safety Board concluded in May 2003 that the probable cause of the accident, in combination with several other factors, was improperly set elevator control cables—a maintenance oversight. In this case, maintenance personnel skipped critical steps outlined in the maintenance manual because they felt the steps were superfluous.

This maintenance human factors initiative is critical to reducing maintenance errors as well as to preventing injuries to personnel and damage to equipment. Industry applauds the effort. There are many facets to this program, but the resources seem limited relative to the need. This research group has made significant contributions in raising maintenance human factors awareness within the aviation community. However, this type of research is still in its infancy and just beginning to receive enough attention to identify data sources from which to generate statistically sound trend information.

Finding: Maintenance Data Collection. Sources from which to collect data have been identified, but barriers to collection and processing seem to be slowing productive research.

Recommendation: Maintenance Data Collection. NASA should develop a clear plan to include inspection data and information from maintenance technician training in its research data set.

There is a coherent short-term plan for each of the projects, but the long-range strategic goals seem to be disjointed. The process used for selection of the particular research topics was unclear to the committee. All are potentially useful tools at some level but lack the anchor of a long-term research mission. Specifically, the committee is uncertain how the virtual reality and augmented reality work differs from or complements what industry uses already and how such work will be applied to real-world maintenance error mitigation. There also does not appear to be a systems analysis approach to setting priorities for the research effort.

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[13] B. Kanki, NASA-Ames, "Maintenance Human Factors," questionnaire completed in January 2003 (see Appendix D).

Finding: Goals for Maintenance Research. The Maintenance Human Factors task is an excellent activity but seems to lack clearly defined long-range goals.

Recommendation: Goals for Maintenance Research. NASA's Maintenance Human Factors task should set clear and quantitative long-range goals and test its research against these goals annually. This is an area for long-term research and should be an area for developing enduring core competencies.

Finding: Virtual/Augmented Reality. The project to create virtual and augmented reality tools for maintenance technicians seems to be operating without a clear understanding of what is available today in automation for maintenance technicians and the realities of an all-weather, real-world airline maintenance operation.

Recommendation: Virtual/Augmented Reality. NASA should formally assess the enhanced displays for maintenance research work, including what is currently in use by the airline industry, to determine a more focused and practical approach to virtual and augmented reality tools for maintenance.

The external community of maintenance human factors researchers was described as small, and there were said to be very close connections between agencies and academia. However, the allocation of roles and responsibilities among FAA, NASA, the Navy Safety Center, the Air Force Safety Center, and other research entities was not clear.

Finding: Outreach to Community. There are a few omissions in the links to the outside community in this task.

Recommendation: Outreach to Community. NASA should establish links to the Air Force Safety Center as well as airframe and power plant training institutions. NASA should perform an active outreach to the maintenance technician unions for program planning, research vetting, and research participation. NASA should collaborate with the Professional Aviation Maintenance Association on aviation maintenance research and with maintenance technician schools such as the Stratford School to collect data and provide research results to enhance safety training.

Crew Training Task

The goal of this task is to develop training techniques and tools to help pilots avoid making errors that lead to accidents and to manage in-flight problems in situations brought about by external circumstances such as weather or system failures. The effort is funded at $1.9 million net for both FY03 and FY04.

The Crew Training task of System Safety Technology has served the commercial aviation training community for many years, producing excellent research work that could occur nowhere else. The current scope of activities is excellent; however, without a long-term core research plan, the projects seem disjointed. Similarly, the individual subtasks in Crew Training are well planned but do not amount to a core training research program. Training research is inherently a long-term activity. Given the inability to go beyond the 5-year horizon for NASA program planning, the researchers in this task have tried to build longer-term research into the current 5-year plan; for example, they have developed an anchor procedure for solving issues relating to flaps and auxiliary power units.

In general, the committee found this research effort to be productive and of high quality, with several activities in this task judged to be outstanding. The research in distributed team performance is clearly state of the art and is vital in developing flight as well as maintenance training programs. This group has also developed a number of high-quality training tools that have been distributed to the aviation community, particularly the tool known as "How to Train Automation." It is clear that core competencies within this group must be preserved.

There is significant interaction and trust between this group and the aviation community operations and training personnel as well as labor unions. The ALPA training council had a meeting at NASA Ames in March 2003. Boeing will be at NASA Ames to review its internal research and development with NASA. These links keep NASA honest and enhance transition to industry.

Finding: Outreach to Community. The Crew Training task's already excellent user connection could be enhanced by greater interaction with entities outside the NASA aviation community, including high-level training decision makers at the officer level of major airlines and general aviation companies. Users could

be more involved than they currently seem to be in setting goals for NASA training research.

Finding: Use of Milestones and Feedback. Clear metrics for understanding the impacts of NASA-developed training materials were not apparent.
Recommendation: Use of Milestones and Feedback. NASA should institute a crew training quality assurance program complete with feedback tools that measure adherence to goals and objectives, exit criteria, and status in regard to similar research being performed throughout the world.

The committee identified several areas in which the training work could be expanded to have additional impact within the aviation community. In particular, there are needs and opportunities for research on maintenance training that could be addressed in addition to flight crew training. Rotary wing crew training could also benefit from the research expertise gained through this task.

The committee felt that some of the projects, such as research on the effects of low blood sugar on safety, would fit better in other venues like FAA's Civil Aerospace Medical Institute, which already has a longstanding program in this area. Additionally, some of the research results (such as "How to Train Automation") might better be disseminated through the FAA to avoid potential or perceived conflicts between regulator expectations and a respected research body such as NASA.

Program Human Factors Task

The goal of the Program Human Factors task is to identify crosscutting issues in human factors within the AvSP and to make specific human factors recommendations to other projects within the program. The effort is funded at $500,000 for both FY03 and FY04, in net dollars.

The cockpit integration of the various and disparate tasks of the aviation safety technologies is important and should be continuously and thoroughly addressed. The Program Human Factors task at NASA Ames is designed to cut across multiple subprojects, including Synthetic Vision Systems, Weather Accident Prevention, and Single Aircraft Accident Prevention. Each of these subprojects is to perform its own internal human factors research. However, it appears that many key researchers in human factors are affiliated with Ames, making this an appropriate group to evaluate the overall safety program from a human factors perspective.

The group has completed a crosscutting look at issues arising as a function of humans interacting with synthetic vision. The study revealed that off-nominal procedures were weak; the technology was built, but procedures were poorly developed. This was the only work looking at full integration of synthetic vision with other existing and emerging technologies. This is a critical, real-world issue being addressed by no one else.

The committee noted that the objectives of this task seem to have diminished over time, with corresponding reductions in allocated resources. Coupled with the 5-year life expectancy of research projects, the end result is that the plan to carry out the program seemed somewhat fragmented. The committee noted that there is only a single in-house researcher; all others come from outside contractors and academia. This threatens the future of the human factors core competencies at Ames that are so essential to long-term research.

Finding: Acceptance of Program Human Factors. The other projects within the Aviation Safety Program may be unresponsive to the recommendations of the Program Human Factors task.

Recommendation: Acceptance of Program Human Factors. NASA management should foster greater accountability for the findings of the Program Human Factors research and findings to ensure cooperation within NASA so that human factors issues identified in Synthetic Vision Systems, Single Aircraft Accident Prevention, and Accident Mitigation are well considered by and integrated into all appropriate projects.

The program is somewhat disconnected from the users. As with most of the Ames programs, the potential users are quite broadly defined and interaction with users is not sufficiently documented. Human factors engineering has to be assertive to make clear its relevance, and thus the committee encourages cooperation and outreach with both industry and NASA Langley and broad dissemination of research results. NASA should benchmark against similar external work, such as military projects like those at the Defense Advanced Research Projects Agency, Big Picture, and Quiet Knight and in forums such as the FAA and the Society of Automotive Engineers and leverage the results of that work. NASA researchers should present results of their work at the Institute of Electrical and Electronics Engineers and the American Institute of Aeronautics and Astronautics to improve outreach to potential users.

Finding: Human Factors for Commercial Carriers. The research in this area only considers commercial air carriers.

Recommendation: Human Factors for General Aviation and Rotorcraft. NASA's Program Human Factors research should add general aviation and rotorcraft to its work on human factors, as it could have great impact in these areas.

Aviation System Monitoring and Modeling Subproject

The ASMM subproject develops technologies to view aviation safety from a systemwide perspective, develops metrics for the safety of the NAS, and predicts systemwide effects of changes to the NAS. The subproject is composed of four tasks: Data Analysis Tool Development, Extramural Monitoring, Modeling and Simulations, and Intramural Monitoring. ASMM has $8.4 million in net funding for FY03 and $8.6 million in FY04.

Data Analysis Tool Development Task

The Data Analysis Tool Development task analyzes both digital and textual data. This work tends to be low-TRL. The task develops concepts that are then instantiated in some of the ASMM modeling efforts. This task emphasizes tool design and development over modeling. Currently, the task focuses on two major areas: digital data analysis tools and textual data analysis tools. The first set of tools, a system known as the Profiler, takes digital data from a system like the Aviation Performance Measuring System to generate and evaluate flight signatures. From these signatures, the researchers produce a list of atypical flights, identify the atypical parameters, and summarize the results. The second set of tools, known as PLADS (which stands for the steps in the preprocessing: Phrase ID, Leave, Augment, Delete, Substitute) and the Automatic Language Analysis Navigator (ALAN), preprocesses and processes the kind of text data that would be found in the Aviation System Reporting System. The goal is to identify atypical situations without any a priori information merely by sifting through the flight data. This task is funded at $1.7 million in FY03 and FY04.

The committee was impressed with the work of the contractors and their knowledge of analytical methods. However, it was concerned that the expertise for developing this system is contractor-based and is not part of the NASA Ames knowledge base. The committee was generally impressed with the Profiler work and its ability to identify atypical parameters from signatures. The committee also found the statistical methods used to be sound.

In the text area, NASA does not seem to have leveraged existing software in use by the Securities and Exchange Commission, the Defense Advanced Research Projects Agency, and the intelligence community. Data mining in the textual domain is a widely studied problem, and the committee suggests that the researchers build on existing methodologies. In addition, the text data research work should be disseminated and benchmarked at major text search venues such as the Text Retrieval Evaluation Conference sponsored by the National Institute of Standards and Technology.

The committee was encouraged to see collaboration with Office National d'Etudes et de Recherches Aerospatiales, the French research agency. Such collaboration should be extended further to other foreign agencies to assure quality benchmarking, including the Japan Aerospace Exploration Agency, the Departamento do Aviaco Civil (Brazil), the National Aerospace Laboratory (Netherlands), the State Research Institute of Aviation Systems (Russia), and the Defence Science and Technology Laboratory (United Kingdom).

Finding: Use of Milestones. The intended path to technology maturation for these data mining tools was not clear. In particular, it was unclear how data mining research was divided among the low-TRL tool development work in this task, the work on data mining applications taking place in the Extramural Monitoring task, and the work on Aviation Performance Measuring System analysis in the Intramural Monitoring task.

Recommendation: Use of Milestones. NASA should define clear goals and objectives, exit criteria, and a

set of milestones for technology transfer or for the next level of development.

Extramural Monitoring Task

The Extramural Monitoring task strives to create a database of information to serve as the repository of aviation safety events and trends and the basis for aviation safety decision making. In particular, the task works with two databases: the National Aviation Operations Monitoring Service (NAOMS) and Aviation Safety Reporting System (ASRS), with most of the task investment in NAOMS. The overall funding for Extramural Monitoring is $2.0 million.

NAOMS consists of a longitudinal survey of aircraft operators, gathering information about safety-related experiences of pilots, cabin crews, and maintenance operators for both general aviation and air carriers. NAOMS is a random survey in which staff proactively question active operators in a telephone call. It provides statistically reliable results about the frequency of occurrence of safety-related incidents.

In contrast, the ASRS is a joint FAA-NASA reporting system that asks for the voluntary participation of operators who have experienced a safety-related problem. ASRS is funded by the FAA, although NASA administers the program.

To encourage submissions to ASRS, NASA makes sure that the reporter remains anonymous. The FAA had agreed that an ASRS report cannot be used as evidence to substantiate an alleged violation in an enforcement action.[14]

Only a small portion ($250,000 of $2.0 million) of the Extramural Monitoring budget supports ASRS-related activities. That portion of the budget addresses data mining techniques applied to the ASRS database.

The NAOMS approach is built on research and implementation of national surveys such as those of the Bureau of Labor Statistics. The NAOMS sampling methods have been grounded in sound interview polling science; however, the interviews are conducted by professional pollsters, not aviation experts. The committee has some concern about the level of accuracy attained by pollsters who have no expertise in the area in which they are conducting the telephone interview.

The committee is also concerned about potential redundancy between NAOMS data and data available from the air carriers or through the ASRS database. The NAOMS project seems to be developing a methodology to establish trends in aviation safety performance that are already available through other sources within the industry and government. For example, NAOMS appears to duplicate what many airlines are already doing both voluntarily and in FAA-mandated programs to track trends—for example, in engine shutdowns. The NAOMS program may become more useful when applied to the general aviation community, however. NASA's decision to collect its own primary data in this case should rest on the type of research NASA wants to perform and whether that research can be supported by information obtained from the airlines. At this point, the committee does not see a compelling argument for independent data collection. Greater interaction with the Air Transport Association and the airlines might help to clarify the usefulness of this effort.

The ASRS program has been around for many years. It is highly trusted by the pilot community and is growing in acceptance by the maintenance technician group. Because the program provides limited immunity from certificate action by the regulator for errors by pilots, mechanics, and dispatchers (not willful acts), some tasks within the regulatory community resent the program, while others within the research community disparage its value because the inputs are voluntary. In truth, the threat of a certificate action strongly encourages the submission of an ASRS. Unfortunately, the ASRS program is currently resourced to input less than 25 percent of the reports received into the database. Direct follow-up for additional information from the reporting parties can rarely be accomplished. Significantly greater volumes of data are anticipated from emerging Airplane Safety Action Partnership (ASAP) programs, with no anticipated increase in research resources. This could create a serious shortfall in data available to researchers. While the committee is aware that the funding for the database collection work is provided by the FAA, not NASA, NASA is still responsible for maintaining the ASRS program. The committee finds the defined ASRS activity for NASA to be much larger than its resource allocation; one or the other requires modification.

It is important that when gaps in the ASRS data occur, phone calls should be made to fill in what is missing. The lack of resources to handle ASRS in a

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[14] Mark Blazy, 1999. "We all know about ASRS, but what's an ASRP?" FAAviation News Magazine, October.

statistically sound manner is a significant issue in understanding the safety trends in the NAS.

There are many opportunities to accomplish more research with the data available through the ASRS system. It was not clear if there were plans in this research task to optimize the joint use of ASRS and NAOMS.

Finding: Aviation Safety Reporting System. Regrettably, the Aviation Safety Reporting System database is only inputting about 25 percent of the submitted reports. Interviews to follow up on Aviation Safety Reporting System submissions are very limited owing to the lack of resources. The industry believes that the Aviation Safety Reporting System database has been underutilized for some time. The National Aviation Operations Monitoring Service is consuming the majority of the resources in this project area.

Recommendation: Aviation Safety Reporting System. NASA should combine the National Aviation Operations Monitoring Service methodology and resources with the Aviation Safety Reporting System program data to identify aviation safety trends.

Modeling and Simulations Task

The Modeling and Simulations task seeks to incorporate human performance models into an analysis of systemwide operations to identify safety-related characteristics and predict system response to safety interventions. This program is not responsible for model development, but it incorporates models from other research efforts (such as the AirMIDAS model developed in the SWAP program) into a larger, systems-level approach. The task is funded at $1.5 million in FY03 and $1.6 million in FY04.

The committee applauds NASA's efforts to integrate the various performance models with models of the aircraft and air traffic control systems. This is bold and difficult work and is the kind of research in which NASA should be engaged. The TRL is low, but that is a quality of long-range research that can only be accomplished by NASA. The weaknesses of the program seem to be a lack of interconnectivity and integration of tools as well as a limited ability to include issues such as clear air turbulence effects on traffic conflict and quality of performance. There is also no collaboration between the program and other programs that model environmental safety and noise.

The Reconfigurable Flight Simulator and Object Based Event Scenario Trees modeling programs are not tied to NAS models built using the FAA Consolidated Operations and Delay Analysis System and Aviation System Performance Metrics. Nor was there a tie to the Total Airspace and Airport Modeler, which has been validated by Eurocontrol, or the Traffic Organization and Perturbation Analyzer model (developed by the National Aerospace Laboratory in the Netherlands), which has been used to estimate the safety-capacity relationship that may be affected by airports at high operational workloads.

Finding: Outreach to the Modeling Community. The modeling programs in this area have excellent potential but appear to lack coordination with other similar modeling programs.

Recommendation: Outreach to the Modeling Community. This task should benchmark its performance against other modeling implementation efforts and consolidate programs where possible to achieve a master system performance, capacity, and safety model.

Intramural Monitoring Task

Intramural Monitoring refers to internal quality assurance and safety functions within each air carrier and air traffic management organization. The Intramural Monitoring products are the Aviation Performance Measuring System (APMS) and the Performance Data Analysis and Reporting System (PDARS). The APMS project is designed as a tool for analyzing aircraft flight data. APMS provides envelope data for each flight parameter in typical flights, provides information about atypical flights, and provides descriptive statistics on phase-of-flight performance. PDARS is designed to collect, process, and analyze air traffic management data. It generates daily reports, shares data among facilities, supports exploratory and causal analysis, and archives data for developing baselines. Its major strength is in the seamless integration of data from multiple sources. The overall task emphasis is on safety risk management. The task received $3.18 million in FY03 and expects $3.25 million in FY04.

Some committee members worried that APMS and PDARS were not novel. The committee believes competing and sometimes superior systems are already used by airlines.

Overall, the APMS program has been in the refinement stage for several years. A target and milestones for technology transfer or the next level of development were not clear. Benchmarking of APMS against similar programs in other government arenas and academia seems to be lacking.

The APMS tools to mine anomalous data are entirely appropriate and useful for airline flight operational quality assurance (FOQA) programs. However, there are significant barriers—among them litigation issues—to centralizing a general FOQA database at a government agency in the near term. This creates barriers to close interaction with the industry.

To make this array of activities more complete, emphasis and resources in this program need to shift further to integrating APMS and other complementary, commercially available FOQA software into an integrated operational efficiency and risk model.

Finding: Aviation Performance Modeling System. The APMS software is mature in its development and is ready for the off-ramp to the marketplace.

Recommendation: Aviation Performance Modeling System. NASA should redirect the APMS resources to pursue integrated data risk model research. The weather overlay work is a clear example of the kind of research that needs to be emphasized.

Finding: Performance Data Analysis and Reporting System. As a safety analysis tool, PDARS was well designed and is being utilized extensively by air traffic control management. PDARS is useful for airspace design, but it is at a fairly high TRL and is ready to be turned over to industry. The committee identified only one remaining gap in the research activity—data source integration.

Recommendation: Performance Data Analysis and Reporting System. NASA PDARS resources should be used to integrate PDARS data with traffic and weather information to feed NASA's modeling and simulation activities. In addition, methods to integrate the Flight Operations Quality Assurance (FOQA) program and Airlines Safety Action Partnership and Aviation Safety Reporting System information into the higher level models should be developed.

Appendixes

A

Committee and Panel Member Biographies

COMMITTEE FOR THE REVIEW OF NASA'S REVOLUTIONIZE AVIATION PROGRAM

JOHN M. KLINEBERG, *Chair,* retired in 2001 after serving in the dual positions of president of Space Systems/Loral and vice president of Loral Space and Communications. Currently he continues his association with the company as a member of Space Systems/Loral's board of directors. He is also on the board of directors of Draper Lab, Cambridge, Massachusetts, and Swales Aerospace, Beltsville, Maryland. Previously Dr. Klineberg spent 25 years with NASA in a variety of management and technical positions. He was director of the Goddard Space Flight Center, director of the Glenn Research Center, deputy associate administrator for aeronautics and space technology at NASA Headquarters, and a technical leader at the Ames Research Center. Before joining NASA, he conducted fundamental research in fluid dynamics at the California Institute of Technology and worked at the Douglas Aircraft Company and the Grumman Aircraft Company. Dr. Klineberg earned his bachelor's degree in engineering from Princeton University and his master's and doctoral degrees from the California Institute of Technology. Dr. Klineberg is a member of the Aeronautics and Space Engineering Board (ASEB) of the National Research Council.

RICHARD ABBOTT is a technical fellow emeritus at Lockheed Martin Aeronautics Company in Palmdale, California. In 1997, he received a Ph.D. in chemical physics from Northern Illinois University, where his research concentrated on cooperative phenomena in molecular systems and the renormalization group. He continued studies as a research associate in statistical mechanics at the University of Chicago, James Franck Institute, where he contributed to theories of energy relaxation in condensed media using Monte Carlo and molecular dynamics techniques. His career includes over 20 years of experience in the areas of guidance, navigation and control systems design and analysis, sensor data fusion design, and sensor system simulation and modeling for both manned and unmanned aircraft. He has also supervised the development and execution of large-scale simulations of complex air vehicles. He led the development of the avionics functional architecture for the demonstration/validation phase of the YF-22 program, which included the integration and fusion of numerous tactical sensor inputs. Lately he has developed fault detection and redundancy management algorithms for the navigation systems aboard the X-33 Single Stage to Orbit vehicle. He recently authored a technical report for the U.K. tactical UAV program in the area of onboard reconnaissance management. He served as principal investigator for the DARPA software enabled control technologies for reliable autonomous control project and has been the co-chair for the Technologies for Autonomous Control session of the 2001 and 2002 IEEE Aerospace Conferences. His present research interests include the exploitation of many-body system techniques in the control and management of large groups of cooperating vehicles.

WALTER S. COLEMAN recently retired as president of the Regional Airline Association (RAA), which represents U.S. regional and commuter airlines and suppliers of products and services that support the industry. He served as the RAA's president for 8 years and before that was director and vice president of operations for the Air Transport Association. From 1976 to 1981 he was director of the Airline Reservation Center of the Airline Scheduling Committees. He began his airline career in 1968 with Pan American World Airways, serving as a pilot, flight engineer, and superintendent of schedule development. He was a pilot in the U.S. Navy from 1960 to 1968 and served in the U.S. Naval Reserve from 1970 to 1986. Mr. Coleman earned a B.A. degree in business administration from Ohio University.

ROBERT HILB is manager of the Advanced Flight Systems Department at United Parcel Service. Captain Hilb graduated from the U.S. Air Force Academy with a B.S. in astronautical engineering and computer science. He attended Auburn University and received an M.S. in computer science. He has been an airline captain for over 21 years. He is type rated in Boeing 727, 737, 757, and 767 aircraft. He served in the Air Force and the Air Force Reserve in various operational and staff assignments from which he retired. From 1981 until 1988 he was a 737 captain and headed the Operations Computer Department at People Express Airlines. Captain Hilb joined United Parcel Service in 1988 as a 757 check airman and pilot supervisor. He currently heads the Advanced Flight Systems Department. He is also a member of the UPS CNS/ATM Working Group. He is chairman of various industry groups, including the RTCA Special Committee (SC) 186, Automatic Dependent Surveillance-Broadcast, Operations and Implementation Working Group and the ATA Flight Systems Integration Committee. He has chaired various other groups in RTCA, SAE, and ATA on various other new technologies such as Controller Pilot Data Link Communications, Flight Management Systems, and Airborne Separation Assurance. He holds patents on a number of aviation technologies.

S. MICHAEL HUDSON recently retired as vice chairman of Rolls-Royce North America. After Allison Engine Company was acquired by Rolls-Royce, Mr. Hudson served as president, chief executive officer, chief operating officer, and was a member of the board of directors of Allison Engine Company, Inc. Previously, during his tenure at Allison, he served as executive vice president for engineering, chief engineer for advanced technology engines, chief engineer for small production engines, supervisor of the design for Model 250 engines, chief of preliminary design, and chief project engineer for vehicular gas turbines. Michael Hudson brings insight into propulsion engineering issues, related business issues, and the European perspective on aviation issues. He has also served on four NRC committees.

RAYMOND LaFREY recently retired as manager of the MIT Lincoln Laboratory Air Traffic Control Mission Area. This activity encompasses surveillance, navigation, communications, and weather sensing, and involves 150 staff and support personnel. Key elements include the development of airport surface technology, modern open architecture surveillance systems, and integrated terminal and regional weather systems that provide time-critical weather knowledge directly to operational staff at FAA and airline facilities. After receiving a B.S.E.E. and an M.S.E.E. at Michigan State University, Mr. LaFrey served 6 years in the U.S. Army as a Signal Corps officer, installing satellite communications ground stations in Europe, Africa, and Vietnam. He joined MIT Lincoln Laboratory in 1969 and began developing air traffic control technology in 1974. During 1977-1982, he led the team that developed the first TCAS II flight hardware and conducted surveillance flight-test activities. He also led the design of TCAS II air-to-air coordination logic, which involved complex simulations and several hundred staged midair encounters. During the 1980s he led the development and flight-testing of a GPS navigation set for small aircraft. He also led the Precision Runway Monitor Program, which enabled simultaneous instrument approaches to parallel runways spaced as close as 3,000 feet. He has served on a variety of advisory boards, including the AAS Recovery Team, the FAA RE&D Advisory Committee (ATS Subcommittee), the Defense Science Board Task Force on Aviation Safety, and most recently he was appointed to the FAA Research Engineering Advisory Committee (REDAC). He has received FAA awards for his work on TCAS, PRM and the ASR-9. He is also an inactive instrument-rated pilot.

LOURDES Q. MAURICE is presently the chief scientific and technical advisor for the environment in the FAA's Office of Environment and Energy. She serves as the agency technical expert for basic and exploratory research and advanced technology development focused on aircraft environmental impacts and the application of such technology to noise and emissions certification. She previously served as the Air Force deputy, basic research sciences and propulsion science and technology, in the Office of the Deputy Associate Secretary of the Air Force for Science and Technology. In this position she managed the $220 million per year Basic Research Sciences and $240 million per year Propulsion Science and Technology portfolios at the Air Force secretariat. She also worked at the Air Force Research Laboratory's Propulsion and Power Directorate from 1983 to 1999 planning and executing basic, exploratory, and advanced development propulsion science and technology programs focusing on state-of-the-art aviation fuels and propulsion systems. Her areas of expertise include pollutant formation chemistry, combustion kinetics, hypersonic propulsion, and aviation fuels. She received a B.Sc. in chemical engineering and an M.Sc. in aerospace engineering from the University of Dayton in Ohio and a Ph.D. in mechanical engineering from the University of London's Imperial College. She is also a Distinguished Graduate of the National Defense University's Industrial College of the Armed Forces, where she earned an M.Sc. in national resource strategy. Dr. Maurice is serving her second term on the American Institute of Aeronautics and Astronautics (AIAA) Propellants and Combustion Technical Committee. She has authored over 80 publications and is a fellow of the AIAA, as well as a member of the Tau Beta Pi Honorary Engineering Society, the American Association for the Advancement of Science (AAAS), and the American Chemical Society (ACS).

THEODORE H. OKIISHI is associate dean for research and outreach at Iowa State University's College of Engineering. Aside from a tour in Vietnam as a hydraulics engineer at the Combined Intelligence Center in Saigon, Dr. Okiishi has spent most of his career at Iowa State. Among other positions, he served as the chair of the Mechanical Engineering Department. He is a fellow of the American Society of Mechanical Engineers and has twice received the George Wallace Melville Award from that society, the highest award for the best current original paper. He received the award most recently for research on boundary layer transition on the blades of compressors and low-pressure turbine blades of gas turbine engines. He is vice president for the ASME International Gas Turbine Institute and a member of the board of directors of the American Society for Engineering Education (chair of the ASEE Engineering Research Council). He is also the editor of the ASME *Journal of Turbomachinery*. He is coauthor of a widely adopted fluid mechanics textbook. Dr. Okiishi received his Ph.D. from Iowa State.

TOD PALM is the integrated product team leader for Space Structures at Northrop Grumman Corporation. He is currently serving as the program manager for development of advanced composite cryogenic tanks under the NASA Strategic Launch Initiative (SLI) Program. Mr. Palm has over 15 years of experience in composite structures R&D at Northrop Grumman. His roles over the last 5 years include lead structures engineer for the DARPA Quiet Supersonic Program, design engineer lead for composite fuselage development on the NASA High-Speed Civil Transport (HSCT) program, project manager for development and test of a BMI composite sandwich wing-box for the NASA HSCT, and Northrop Grumman project lead for the HSCT design integration trade studies. Previously he served as principal investigator for the U.S. Air Force ultralightweight trade studies contract and has supported structural issues on production platforms including the Kistler RLV, B2, F-18, and Global Hawk. Mr. Palm's diverse background in composite structures includes structural analysis, multidisciplinary optimization, durability and damage tolerance, materials characterization, advanced manufacturing development, and complex structural test article development/integration. He holds a B.S. degree in aeronautical engineering from California Polytechnic University, San Luis Obispo, and an engineering management certificate from the California Institute of Technology.

EDUARDO SALAS is a professor of psychology at the University of Central Florida (UCF), where he also holds an appointment as program director for the Human Systems Integration Research Department at the Institute for Simulation and Training. He is also the director of UCF's Ph.D. Applied Experimental and Human Factors Program. Previously, he was a senior research psychologist and head of the Training Technology Development Branch of the Naval Air Warfare Center Training Systems Division for 15 years. During that period, Dr. Salas served as a principal investigator for numerous R&D programs focusing on teamwork, team training, decision making under stress, and performance assessment. Dr. Salas has coauthored over 200 journal articles and book chapters and has coedited 11 books. He is on or has been on the editorial boards of the *Journal of Applied Psychology, Personnel Psychology, Military Psychology, Interamerican Journal of Psychology, Applied Psychology: An International Journal, International Journal of Aviation Psychology, Group Dynamics*, and the *Journal of Organizational Behavior*. In addition, he has edited two special issues (one focusing on training and one on decision making in complex environments) for *Human Factors*. He has edited other special issues on team training and performance and training evaluation (*Military Psychology*), shared cognition (*Journal of Organizational Behavior*), and simulation and training (*International Journal of Aviation Psychology*). He is also the current editor of the journal. He currently edits an annual series, Advances in Human Performance and Cognitive Engineering Research (Elsevier). Dr. Salas has held numerous positions in the Human Factors and Ergonomics Society during the past 15 years. He is the past chair of the Cognitive Engineering and Decision Making Technical Group, past chair of the Training Technical Group, member of the Jerome H. Ely Human Factors Articles award committee, and he served on the Alphonse Chapanis Best Student Paper Award Committee. He is also very active with the Society for Industrial and Organizational Psychology (SIOP), which is Division 14 of the American Psychological Association. He is currently the series editor for the Professional Practice Book Series and has served on numerous committees throughout the years. His expertise includes helping organizations to foster teamwork, design and implement team training strategies, facilitate training effectiveness, manage decision making under stress, develop performance measurement tools, and design learning environments. He is currently working on designing tools and techniques to minimize human errors in aviation, law enforcement, and medical environments. He has consulted to a variety of manufacturing, pharmaceutical laboratories, industrial, and governmental organizations. Dr. Salas is a fellow of the American Psychological Association (SIOP and Division 21—the Division of Applied Experimental and Engineering Psychology), the Human Factors and Ergonomics Society, and a recipient of the Meritorious Civil Service Award from the Department of the Navy. He received a Ph.D. (1984) in industrial and organizational psychology from Old Dominion University.

THOMAS SHERIDAN, *NAE*, is Ford Professor Emeritus of Engineering and Applied Psychology in the Departments of Mechanical Engineering and Aeronautics and Astronautics and director of the Human-Machine Systems Laboratory at Massachusetts Institute of Technology (MIT). His research has been on mathematical models of human operator and socioeconomic systems, on man-computer interaction in piloting aircraft and in supervising undersea and industrial robotic systems, on computer graphic technology for information searching and group decision making, and on arms control. He has an S.M. degree from the University of California, a Sc.D. from MIT, and an honorary doctorate from Delft University of Technology, the Netherlands. He has served as president of both the Human Factors and Ergonomics Society and the IEEE Systems, Man and Cybernetics Society and is a fellow of both organizations. He has chaired the National Research Council's Committee on Human Factors and has served on numerous other NRC committees. He is senior editor of the MIT Press journal *Presence: Teleoperators and Virtual Environments* and is a member of the National Academy of Engineering.

EDMOND L. SOLIDAY was employed by United Airlines for over 35 years as a pilot, human factors instructor, flight manager, and staff executive, serving the last 11 years as vice president of safety, quality assurance, and security. During his time in the safety role, he was responsible for flight safety, aircraft cabin safety, occupational safety, environmental compliance, operational quality assurance, security, computer security, and emergency response. During his career he made significant contributions in the development of emergency response methodologies, flight crew human factors safety initiatives, enhanced ground proximity warning devices, flight operations quality assurance programs (digital performance monitoring and analysis), union management occupational safety initiatives, code share and express carrier auditing, aviation industry security screening technology implementation, and risk analysis methodologies. He has served on numerous aviation-safety-related advisory boards and commissions, including the Gore Commission's Aviation Security Baseline Working Group and the Commercial Aviation Safety Team (chairman for 5 years), the Flight Operations Quality Assurance Advisory Rulemaking

Committee, past chairman of the Air Transport Association Safety Council, the IATA Flight Safety Committee, past chairman of the Star Alliance Safety Committee, and the Air Transport Association Environment Executive Subcommittee, and past chairman of the ATA Environmental Committee. He currently serves on the executive board of the Flight Safety Foundation, the NASA Aviation Safety Program Executive Panel, the Massachusetts Institute of Technology Global Airline Industry Program Advisory Group, vice chairman of the Adler Planetarium Board of Trustees, and the Trinity International University Board of Regents. Additionally, he teaches "Introduction to Aviation Safety and Security Programs" at George Washington University. He has most recently served as a consultant to the RAND Corporation, the Boeing Company, and Greenbriar Equity, LLP. Among his awards are the Bendix Trophy, the Vanguard Trophy, and the Laura Tabor Barbour International Air Safety Award, FBI and FAA distinguished service awards, the Distinguished Flying Cross, two Bronze Stars, and the Purple Heart.

ALFRED G. STRIZ holds the L.A. Comp Chair in the School of Aerospace and Mechanical Engineering at the University of Oklahoma. He runs the AME Computational Mechanics Laboratory and is the associate director of the Center for Engineering Optimization. Dr. Striz specializes in computational mechanics with an emphasis on multidisciplinary design optimization (MDO) and on the development of efficient structural optimization methodologies. In addition, he is interested in multicriteria optimization and in the high-performance computing aspects of optimization. He has concentrated on applying these techniques to aircraft and spacecraft systems. He is on the Board of the new University of Oklahoma Supercomputing Center for Education and Research. Since 1993, he has been a member of the AIAA MDO Technical Committee, where he presently leads an effort toward a new MDO white paper. He has published in excess of 100 refereed technical papers and journal articles and given a number of invited lectures. Dr. Striz received a Ph.D. in aeronautics and astronautics from Purdue University.

FRANK F. TUNG served as the deputy director of the Volpe National Transportation Systems Center prior to his retirement in July 2002. Prior to being named deputy director in 1989, Dr. Tung served in a variety of technical management roles at the Volpe Center, including chief of the Traffic Control Systems and Urban Transportation Systems Division (1971 to 1982), associate director of the Office of Systems Assessment (1982 to 1984), and associate director of Operations Engineering (1984 to 1989). He came to the center from NASA in 1971. He has also worked on the engineering staffs of the Lockheed Company and IBM. Dr. Tung's technical expertise includes navigation and surveillance, air traffic control management systems, system development and engineering, and requirement analysis. He has a very good understanding of the U.S. air traffic control system. Prior to his retirement, Dr. Tung took a 6-month detail with the FAA Office of Airports. His research during the detail was on the evolution of major airports in the United States and related capacity issues. Dr. Tung received a B.Sc. and an M.Sc. from the Massachusetts Institute of Technology and a Ph.D. from Columbia University.

THOMAS L. WILLIAMS is currently vice president of engineering, logistics and technology for Northrop Grumman's Air Combat System Business. He provides the engineering, logistics, test and evaluation talent tools and resources to support a number of programs at Northrop Grumman Air Combat Systems. These include the F/18 program, the B-2 Stealth Bomber program, the F-5/T-38 program, the DARPA Naval UCAV program, and the NASA Next Generation Reusable Launch Vehicle program. Prior to assuming his current position Mr. Williams served as program manager for the B-2 Stealth Bomber and the Future Long-Range Strike Product. He has held numerous senior program management and technical management positions at Northrop Grumman. Mr. Williams is a member of the Aeronautics and Space Engineering Board of the National Research Council.

DEBRA WINCHESTER is the director of strategy for Raytheon's Air Traffic Management Systems, where she is responsible for strategy development and implementation of key business issues, including air traffic management products and services along with ATM business and policy issues worldwide. Prior to working at Raytheon, Ms. Winchester spent 18 years with Hughes Aircraft Company, working as a program manager in oceanic air traffic control, as a manager of air traffic control marketing business development, and as a research engineer. Ms. Winchester has participated in a variety of industry working groups, including the FAA's Research, Engineering, and Development Advisory Committee. She received a B.S. in computer science from North Dakota in 1978 and an M.S. in electrical engineering/computers from the University of Southern California in 1981.

VEHICLE SYSTEMS PANEL MEMBERS

THOMAS L. WILLIAMS, *Panel Chair* (see biography above)

MARK BALAS is a fellow of the American Institute of Aeronautics and Astronautics (AIAA) and is currently a professor at the Center for Aerospace Structures and Aerospace Engineering Sciences at the University of Colorado at Boulder. Dr. Balas has published extensively in the field of controls, with emphasis on modeling, estimation, and control of large-scale and distributed parameter systems, including flexible structures. He is the general chair for the AIAA Guidance, Navigation and Control Conference. Dr. Balas received a Ph.D. from the University of Denver in Colorado.

ROBERT GOETZ obtained a master's degree in engineering mechanics from the Virginia Polytechnic Institute and State University and a B.S. in aeronautical engineering from the Georgia Institute of Technology. He recently retired as vice president of Lockheed Martin Skunk Works. He has served as the director of engineering, Lockheed Advanced Development Company; acting director of engineering and advanced programs, Lockheed Aeronautical Systems Company; and deputy director of engineering, managing engineering support for Advanced Development Projects. He served with NASA for 29 years in a variety of positions, the last of which was as deputy center director at NASA's Johnson Space Center in Houston. He has served as an officer in the U.S. Air Force. Under the NASA Executive Development Program, he was assigned to the Office of Aeronautics and Space Technology at NASA Headquarters in Washington, D.C. He is a fellow of the American Institute of Aeronautics and Astronautics and of the American Astronautical Society.

S. MICHAEL HUDSON (see biography above)

STEVEN IDEN is a senior staff engineer with Lockheed Martin Corporation in Fort Worth, Texas. During his 18 years of aerospace power work, Mr. Iden worked in the area of electrical and propulsion integration, with a heavy focus on integrated starter generators for main propulsion engines and directed energy weapons. Mr. Iden also has significant experience in electrical subsystem component modeling for both military and commercial aviation. He has a B.S. and an M.S. in electrical engineering from the University of Dayton.

SHEILA KIA is an engineering group manager for General Motors Manufacturing Engineering. She has been a member of the National Materials Advisory Board at the National Research Council since 1999. Dr. Kia holds a Ph.D. in chemical engineering from Cambridge University in England. Her expertise is in automotive finishing, coatings, polymer substrates, and multiphase interactions with an emphasis on manufacturing applications.

GARY KOOPMANN is a distinguished professor of mechanical engineering and director of the Center for Acoustics and Vibration at Pennsylvania State University. Dr. Koopmann has made significant contributions to the science and technology of noise and vibration control, both as an engineering educator and an accomplished researcher. Prior to Penn State, he served in a range of positions at the U.S. Naval Research Laboratory, the Institute of Sound and Vibration Research at the University of Southampton in Great Britain, and the University of Houston's Laboratory for Sound and Vibration Research. He collaborates on DOD-funded research focusing on adaptive structures. Dr. Koopmann's research accomplishments focus on noise-control-by-design strategies that combine the disciplines of structure dynamics, acoustics, and optimization into a united methodology. In 2001 Koopmann was awarded ASME's Per Bruel Gold Medal for seminal contributions to the theory and practice of noise and vibration control in mechanical systems

HARRY LIPSITT is professor emeritus in the Department of Mechanical and Materials Engineering at Wright State University, Dayton, an adjunct professor in the Department of Materials Science and Engineering at Ohio State University, and an honorary professor in the Interdisciplinary Research Centre for High Performance Materials at the University of Birmingham, U.K. He spent 30 years at the Air Force Wright Laboratories, where he was the leader of a research group working on the development and optimization of metallic and intermetallic materials for use in the hot sections of aircraft turbine engines. His earlier research included work on the fracture toughness of ceramics; deformation mechanisms in two-phase alloys; creep and fatigue; and deformation mechanisms in ordered intermetallics. Dr. Lipsitt has published more than 100 technical articles in refereed journals. He has just completed a 6-year tenure on the National Research Council's National Materials Advisory Board. In 1998 he served on the NRC Panel for Review of Air Force Office of Scientific Research (AFOSR) Mechanics Research Proposals, the NRC Panel for Review of AFOSR Materials Proposals, and was chair of the NRC Panel for Review of AFOSR Aging Aircraft Proposals. In 1999 he again served on the NRC Panel for Review of AFOSR Mechanics Proposals and was chair of the NRC Panel for Review of AFOSR Materials Proposals. Dr. Lipsitt was chair of the 2000 and 2001 NRC Panels for Review of AFOSR Materials Proposals. He is presently serving as a member of the Committee on Materials for the Defense After Next, chair of the Panel on Structural and Multifunctional Materials for that committee, and as chair of the Materials for 21st Century Army Trucks Committee. In 2001, Dr. Lipsitt was selected to receive the Laudise Award from the National Materials Advisory Board for his outstanding and dedicated service to that board.

LOURDES Q. MAURICE (see biography above)

DUANE McRUER, *NAE*, is concurrently an independent consultant and chairman of Systems Technology, Inc. (STI). He received his undergraduate and graduate education at the California Institute of Technology. Since 1950, his research has focused on aerospace and ground vehicle and human pilot dynamics, automatic and manual vehicular control, and vehicle flying/handling qualities. He has published more than 125 technical papers and seven books, including *Analysis of Nonlinear Control Systems* (Wiley, 1961; Dover, 1971) and *Aircraft Dynamics and Automatic Control* (Princeton, 1973). He has also been involved with applications of these topics in more than 50 aerospace and land vehicles, and he has five patents on flight control and stability augmentation systems. Besides a career as president and technical director of STI (until 1993), he has been Regent's Lecturer at the University of California, Santa Barbara, and was the 1992-1993 Hunsaker Professor at the Massachusetts Institute of Technology . His past service for various governmental and professional societies includes terms as president of the American Automatic Control Council and chairman of the National Research Council Aeronautics and Space Engineering Board, the American Institute of Aeronautics and Astronautics (AIAA) Technical Committee on Guidance and Control, the Society of Automotive Engineers (SAE) Aerospace Control and Guidance Systems Committee, and a member of the National Aeronautics and Space Administration (NASA) Advisory Council. He is a fellow of the Institute of Electrical and Electronic Engineers (IEEE), the Society of Automotive Engineers, and the Human Factors and Ergonomics Society, an honorary fellow of the AIAA, and a member of the National Academy of Engineering. Other honors include the Caltech Distinguished Alumni Award, the NASA Distinguished Public Service Medal, the AIAA Mechanics and Control of Flight Award, the Franklin Institute's Levy Medal, the Human Factors and Ergonomics Society's Alexander Williams Award, and SAE's Aerospace Engineering Leadership Award.

THEODORE H. OKIISHI (see biography above)

TOD PALM (see biography above)

ALFRED G. STRIZ (see biography above)

MAHLON WILSON received his Ph.D. in chemical engineering from the University of California at Santa Barbara. His thesis research was in heterogeneous catalysis, with particular emphasis in adsorbate-surface interactions on nanoscale catalyst particles. Subsequently, he became a postdoctoral research fellow at Los Alamos National Laboratory, working in the Core Research Program on polymer electrolyte fuel cells (PEFCs). He pioneered the catalyzed membrane concept, which has since become the standard technology used by the PEFC community. In 1991, Dr. Wilson became a technical staff member at Los Alamos, and he continues to work primarily in the PEFC area. Dr. Wilson has more than a dozen patents in fuel cell technology, the majority of which have been licensed to the fuel cell industry.

J. MITCHELL WOLFF is an associate professor at Wright State University. He is the author of over 45 technical papers and journal articles in the areas of propulsion, computational methods, MEMS instrumentation, unsteady aerodynamics, and forced response. Dr. Wolff is a member of the American Institute of Aeronautics and Astronautics (AIAA) Air-Breathing Propulsion Technical Committee and the turbine engine and education subcommittees. He also represents the United States as a scientific committee member for both the International Society of Air Breathing Engines (ISOABE) and the International Symposium of Transport Phenomena and Dynamics of Rotating Machinery (ISROMAC). He has received several awards, including the SAE Ralph R. Teetor Educational Award and the ASEE Dow Outstanding New Educator Award. Dr. Wolff received a Ph.D. in mechanical engineering from Purdue University.

MICHAEL ZYDA is the director of the Modeling, Virtual Environments and Simulation (MOVES) Institute, located at the Naval Postgraduate School (NPS), Monterey, California. He is also a professor in the Department of Computer Science at NPS. Since 1986, he has been the director of the NPSNET Research Group. Dr. Zyda's research interests include computer graphics, large-scale, networked 3D virtual environments, computer-generated characters, video production, entertainment/defense collaboration, and modeling and simulation. He is known for his work on software architectures for networked virtual environments. Dr. Zyda was a member of the National Research Council's Committee on Virtual Reality Research and Development and was the chair of the National Research Council's Computer Science and Telecommunications Board Committee on Modeling and Simulation: Linking Entertainment and Defense. From that report, for the Deputy Assistant Secretary of the Army for Research and Technology, Dr. Zyda drafted the operating plan and research agenda for the University of Southern California's Institute for Creative Technologies. He began his career in computer graphics in 1973 as part of an undergraduate research group, the Senses Bureau, at the University of California, San Diego. Dr. Zyda received a B.A. in bioengineering from the University of California, San Diego, in 1976, an M.S. in computer science-neurocybernetics from the University of Massachusetts, Amherst, in 1978, and a D.Sc. in computer science from Washington University, St. Louis, in 1984.

AIRSPACE SYSTEMS PANEL MEMBERS

FRANK F. TUNG, *Panel Chair* (see biography above)

CHARLES AALFS is a retired air traffic control specialist for the FAA. He has over 30 years of experience as an air traffic controller for both the U.S. Navy and the FAA. While with the FAA, he served as an air traffic controller, air traffic automation specialist, air traffic facility officer, air traffic facility manager, air traffic regional office automation specialist and branch manager, and division manager of resource management. When he retired, he was the manager of the new Southern California TRACON in San Diego, California. As an automation specialist, he was responsible for the software maintenance of the terminal automated radar system called ARTS III and IIIA. He is also the author of many design changes to the ARTS III program, one of which was the design to allow automated handoffs from one ARTS III site to another. Since retiring from the FAA, Mr. Aalfs has been a consultant to the FAA on air traffic training, airspace studies for the New England and Seattle areas, and the FAA's air traffic facility management structure. He has also consulted for the Boeing Company in establishing its new air traffic management business and currently is a consultant and program manager for an airspace study of Southern California. Mr. Aalfs has also served on two NRC study groups: the Panel on Human Factors in Air Traffic Control Automation and the Committee to Study the FAA's Methodologies for Estimating Air Traffic Controller Staffing Standards.

YAAKOV BAR-SHALOM is currently a Board of Trustees Distinguished Professor of Electrical and Computer Engineering at the University of Connecticut, where he has been a professor since 1976. Previously he was a research engineer with Systems Control, Inc. Dr. Bar-Shalom received a B.S. and an M.S. in electrical engineering from Technion (Israel) in 1963 and 1967, respectively, and a Ph.D. from Princeton University in 1970. His research interests include target tracking with radar, sonar, or infrared sensors; air traffic control; and surveillance systems with multiple sensors. Dr. Bar-Shalom is the author of seven books and over 260 publications on estimation and tracking. He is a fellow of the IEEE and a member of Eta Kappa Nu and Sigma Xi. He is also a licensed single-engine pilot. He served as president of the International Society of Information Fusion in 2000 and 2002.

BARRY BERSON is currently a technical fellow at Lockheed Martin Skunk Works, where he is responsible for the planning, conduct, and documentation of human factors activities directed toward supporting Lockheed Martin aeronautics programs. Previously, Mr. Berson served as a research engineer in human factors and crew systems with Lockheed, Hughes Aircraft

Company, Perceptronics, Integrated Sciences, and Dunlap and Associates. He has authored or coauthored over 100 human factors technical reports and is a fellow of the Human Factors and Ergonomics Society. He is currently a part-time instructor at California State University, Northridge (CSUN), teaching graduate-level human factors courses. Mr. Berson received his B.A. in psychology from UCLA in 1969 and his M.A. in human factors psychology from CSUN in 1974.

WALTER COLEMAN (see biography above)

WILLIAM DUNLAY is currently a principal with Leigh Fisher Associates (LFA), a consulting firm that specializes in aviation. He has been with LFA since 1978, where, as leader of LFA's airfield and airspace practice, he directed analyses of more than 40 airports in the United States and overseas. He recently managed delay reduction strategy studies for the LaGuardia and John F. Kennedy International airports, an airfield simulation study (using the Total Airspace and Airport Modeler TAAM) for Seattle-Tacoma International Airport, and analyses of redesigned flight procedures for the New York-New Jersey Metroplex airspace. Dr. Dunlay is currently a visiting lecturer and research engineer at the University of California, Berkeley, where he is teaching an airport design course and working on FAA-sponsored research at the National Center of Excellence for Aviation Operations Research. He previously was an assistant professor of civil engineering at the University of Pennsylvania (1976-1978) and the University of Texas at Austin (1974-1976). Dr. Dunlay received a B.S. in civil engineering from Penn State in 1965 and an M.S. in 1970. He obtained a Ph.D. in civil engineering from the University of California at Berkeley in 1974.

ANGELA GITTENS is director of the Miami-Dade Aviation Department. In this position, she is responsible for the operations and management of Miami International Airport and five general aviation airports. Before that, Ms. Gittens was vice president of TBI Airport Management, a company that manages airport facilities under contract. Prior to that, she directed Hartsfield Atlanta International Airport. She began her aviation career as deputy director for business and finance at San Francisco International Airport. She was previously deputy administrator at San Francisco General Hospital and assistant vice president of the New York City Health and Hospitals Corporation. Ms. Gittens earned a bachelor's degree from Fairleigh Dickinson University.

ROBERT HILB (see biography above)

R. BOWEN LOFTIN holds a B.S. in physics from Texas A&M University and an M.A. and a Ph.D. in physics from Rice University. In August 2000 he joined Old Dominion University in Norfolk, Virginia as professor of electrical and computer engineering and professor of computer science. In addition, Dr. Loftin is executive director of the Virginia Modeling, Analysis and Simulation Center and the university's director of simulation programs with responsibility for the university's graduate programs in modeling and simulation. Before coming to Old Dominion University, Dr. Loftin was a professor in the Department of Computer Science and its chair and the director of the NASA Virtual Environments Research Institute at the University of Houston. Since 1983, Dr. Loftin and his students and coworkers have been exploring the application of advanced software technologies, such as artificial intelligence and interactive, three-dimensional computer graphics, to the development of training and visualization systems. He is a frequent consultant to both industry and government in the area of advanced training technologies and scientific and engineering data visualization. Awards received by Dr. Loftin include the University of Houston-Downtown Awards for Excellence in Teaching and Service, the American Association of Artificial Intelligence Award for an innovative application of artificial intelligence, NASA's Space Act Award, the NASA Public Service Medal, and the 1995 NASA Invention of the Year award. He is the author or coauthor of more than a hundred technical publications.

J. DAVID POWELL is emeritus faculty in the Aeronautics and Astronautics Department at Stanford University. Dr. Powell received a B.S. in mechanical engineering from MIT in 1960 and M.S. and Ph.D. degrees from the Department of Aeronautics and Astronautics at Stanford University in 1966 and 1970, respectively. Dr. Powell has been on the Stanford faculty since 1971. He continues to be active in research since becoming emeritus in 1998. His research interests included space tether dynamics and control, internal combustion engine control, and the design of aerospace digital flight control systems. More recently, GPS-based attitude determination augmented with inertial sensors, the use of GPS for air and land vehicle surveillance and navigation, and the design of GPS-aided flight displays have become his research focus. He is the author of more than a hundred research papers and two of the leading control textbooks. Dr. Powell is a fellow of AIAA and ASME and is an aircraft owner and instrument-rated pilot.

EDUARDO SALAS (see biography above)

DEBRA WINCHESTER (see biography above)

AVIATION SAFETY PANEL MEMBERS

THOMAS SHERIDAN, *NAE*, *Panel Chair* (see biography above)

RICHARD ABBOTT (see biography above)

JAMES DANAHER retired in 1998 as chief of the Operational Factors Division of the Office of Aviation Safety, National Transportation Safety Board (NTSB). He has more than 35 years of government and industry experience in the human factors and safety fields. After joining NTSB in 1970, he served in various management positions, with a special emphasis on human performance in flight operations and air traffic control. He has participated in the on-scene investigation of numerous accident investigations, public hearings, and the development of NTSB recommendations. He is a former naval aviator and holds a commercial pilot's license with single-engine, multiengine, and instrument ratings. Among other NRC assignments, he served on the Panel on Human Factors in Air Traffic Control Automation for the Commission on Behavioral and Social Sciences and Education. Mr. Danaher earned a master's degree in experimental psychology from Ohio State University.

VALERIE GAWRON is the chief scientist, Human Factors, at Veridian. Her experience in engineering psychology and human factors covers the areas of design, research, simulation, and training. She has produced numerous simulation programs and training manuals and conducted many experiments to improve aviation. She has over 250 publications including a handbook on human performance measurement. She is an associate fellow of the American Institute of Aeronautics and Astronautics, a fellow of the Human Factors and Ergonomics Society, and a member of the Army Science Board. Dr. Gawron received the A.R. Lauer Safety Award from the Human Factors and Ergonomics Society in 2002 and the Decoration for Exceptional Civilian Service in 2000. She has earned degrees from the State University of New York at Buffalo (B.A., psychology; M.S., industrial engineering; M.B.A., business administration), State University College at Geneseo (M.A., psychology), and the University of Illinois (Ph.D., engineering psychology).

RONALD HESS is a professor in the Department of Mechanical and Aeronautical Engineering at the University of California, Davis (UCD). He has been a member of the UCD faculty since 1982. Before that, Dr. Hess was a research scientist at NASA Ames Research Center, where he conducted research in the flight control and handling qualities of vertical and short takeoff and landing aircraft and rotorcraft. He is an associate fellow of the AIAA, a senior member of the IEEE, and a member of the American Helicopter Society, Tau Beta Pi, and Sigma Xi. Dr. Hess is an associate editor of the *Journal of Aircraft*, the IEEE *Transactions on Systems, Man, and Cybernetics*, and the *Journal of Aerospace Engineering*. He is also a registered engineer in the state of California. Dr. Hess received a Ph.D. in aerospace engineering from the University of Cincinnati in 1970.

ADIB KANAFANI, *NAE*, is Edward G. and John R. Cahill Professor of Civil Engineering, Department of Civil and Environmental Engineering at the University of California, Berkeley. Since joining the faculty at Berkeley in 1970, he has taught and conducted research on transportation systems, transportation engineering, airport planning and design, and air transportation economics. He has made contributions to air transportation, including demand analysis, airport capacity analysis methods, and airline network analysis. In 1997 he was founding co-director of the National Center of Excellence for Aviation Operations Research (NEXTOR), a university/industry partnership funded by the FAA and headquartered at Berkeley. He served as director of UC Berkeley's Institute of Transportation Studies from 1983 to 1998 and as chairman of UC Berkeley's Department of Civil and Environmental Engineering from 1987 to 2002. He is a recipient of numerous awards, including the American Society of Civil Engineers' Walter Huber Research Prize in 1982, the Horonjeff Award in 1988, and the James Laurie Prize in 2000. He was elected to the National Academy of Engineering in 2002. Professor Kanafani earned his Ph.D. in transportation engineering from the University of California at Berkeley.

DAVID KOHLMAN is a principal engineer emeritus for Engineering Systems, Inc., a professional engineering consulting firm and laboratory. Dr. Kohlman holds B.S. and M.S. degrees in aeronautical engineering from the University of Kansas and received a Ph.D. degree in aeronautics and astronautics from MIT in 1963. His industrial experience included Sandia Corporation and the Boeing Company before his appointment to the faculty at the University of Kansas. Dr. Kohlman spent 18 years as professor of aerospace engineering at Kansas, where his research included airplane design, aerodynamics, stability and control, flight testing, and aircraft icing. In 1982, Dr. Kohlman became the president of Kohlman Systems Research, Inc., a flight testing and instrumentation company, and Kohlman Aviation Corporation, a consulting, research, and ice protection systems company. He joined Engineering Systems, Inc., in 1993. Dr. Kohlman teaches a short course at the University of Kansas on aircraft icing and has presented the course for major aircraft manufacturers and universities in Europe, Canada, and the United States. Dr. Kohlman is a licensed, instrument-rated pilot with over 3,200 hours of flight time and a licensed ground instructor. Dr. Kohlman has written a book on V/STOL airplanes, authored over 50 technical papers and reports, and assisted as an expert in more than 200 aircraft accident cases. Dr. Kohlman is a fellow of the American Institute of Aeronautics and Astronautics.

RAYMOND LaFREY (see biography above)

JOHN McCARTHY recently retired as manager for scientific and technical program development at the Naval Research Laboratory in Monterey, California, and currently is president of Aviation Weather Associates, Inc., a consulting company. Previously, Dr. McCarthy served as special assistant for program development to the director of the National Center for Atmospheric Research (NCAR), in Boulder, Colorado. Prior to that, he served as the director of the Research Applications Program (RAP) at NCAR. As director of RAP, he led research associated with aviation weather hazards, including NCAR activities associated with the FAA Aviation Weather Development Program, the FAA Terminal Doppler Weather Radar Program, and a national icing/winter storm research program. Previously, he directed NCAR activities associated with the Low-Level Windshear Alert System (LLWAS) project, which addressed the technical development of sensing systems to detect and warn of low-altitude windshear, the Joint Airport Weather Studies (JAWS), and the Classify, Locate and Avoid Wind Shear (CLAWS) project at NCAR. Additionally, Dr. McCarthy was the principal meteorologist associated with the development of the FAA Wind Shear Training Aid. In January 2000, Dr. McCarthy was named a fellow of the American Meteorological Society. Since the beginning of his tenure at NRL, Dr. McCarthy has developed programs in improving ceiling and visibility forecasting and flight operations risk assessment and a broad program effort to improve short-term weather information to navy battlegroups. Dr. McCarthy received a Ph.D. in geophysical sciences from the University of Chicago (1973).

EDMOND L. SOLIDAY (see biography above)

B

Statement of Task

The Aeronautics and Space Engineering Board of the National Research Council (NRC) will form a committee and three subordinate panels to assess the overall scientific and technical quality of the Revolutionize Aviation (RA) goal area of NASA's Aerospace Technology Enterprise. The committee's assessment will include findings and recommendations related to the quality and appropriateness of all NASA research in the RA goal area. This includes internal, collaborative and competitively sourced research, development, analysis, etc. While the primary objective is to conduct peer assessments that provide scientific and technical advice, the committee may offer programmatic advice when it follows naturally from technical considerations or is requested by the NASA Associate Administrator for Aerospace Technology.

The committee will be assisted by the three panels, each of which will assess the scientific and technical quality of one of the programs in the RA goal area. Each panel will provide inputs to the committee report via internal working documents to the committee.

Panels will meet as required during the study to receive technical presentations about the projects under review by their group and formulate final findings and recommendations. Panel members will also make site visits as deemed necessary in formulating the assessment. Portions of each meeting will be highly interactive with NASA personnel. After completion of its deliberations and investigation, the panels will report to the committee on findings via internal privileged correspondence and working papers.

The committee will meet as required during the review period to plan the review process, meet with the panel members, and discuss the charge to the committee and panels and to discuss panel working papers, findings, and recommendations. Meetings will involve interactive discussions with NASA personnel from the programs. The committee will develop a final report developed from panel inputs and discussions at the committee meetings.

The committee's observations will follow broad themes concerning technical and scientific quality and appropriateness of research, the research performers, and the research plan. The committee and panels will evaluate the following themes: research portfolio; formulation of the research plan; connections to the broader community; methodology; and overall capabilities. Examples of specific criteria for the panels to use as appropriate are found in the Appendix.

Neither the committee nor panels will make explicit budget recommendations to NASA, but will instead comment on program content, gaps in technology, and other issues outlined above.

APPENDIX

Where appropriate, the panel assessments should use specific criteria, such as the following:

Research Portfolio

- Is the balance between fundamental and user driven research proper?
- Is research being conducted in the proper areas?
- Are there plausible hypotheses supporting each of the research plans?
- Is far-term research at the forefront of science and determined to be a world-class endeavor?
- Is the proper amount of high-risk, high-payoff research being pursued?
- Is the application of fundamental science to solve real-world problems adequate?

Formulation of the Research Plan

- Are the program's goals and objectives clearly defined and consistent with relevant documents such as NASA's Strategic Plan?
- Is there evidence of a clear understanding of the need by NASA's enterprises, other organizations (i.e., the FAA, DoD, etc.), or the aerospace community at large for the R&D or analysis, and the potential benefits? Are the program's deliverables to those organizations clearly articulated and are those organizations adequately involved in the planning and review process?
- Can the expected benefits be accomplished by the proposed research? If not, is the path to adequately maturing the research clear? Is this planning well supported by sufficient decision points, downselects, customer agreements, and/or unallocated outyear funding?
- Are there sufficient near-term deliverables or progress metrics from which the program can be regularly assessed? Are there sufficient off-ramps or sunsets to ensure that funding is reallocated within the program or to other programs if the program does not make adequate progress towards one or more of its goals and objectives? Are the program's plans for independent and/or external reviews adequate and appropriate?
- Are appropriate scientific and technical objectives being posed, taking into consideration program goals, NASA's strengths, and the time horizon for the project? Are critical personnel and facilities required to support the program well defined?

Connections to the Broader Community

- Is the research being accomplished with a proper mix of personnel from NASA, academia, industry, and other government agencies? Is the program using high-quality research performers or is there untapped talent outside the program that can be brought to bear?
- Is there evidence that the research plan for the area under review reflects a broad understanding of the underlying science and technology and of comparable work within other NASA units as well as industry, academia, and other federal laboratories?
- Is there evidence that the research builds appropriately on work already done elsewhere? Does it leverage the work of leaders in the field? Is the strategy for out-of-house work (competitions, partnerships, etc.) well chosen and managed?

Methodology

- How well crafted are the research plans for the areas under review? In general, is the use of laboratory experiment, modeling, simulation, and/or field test appropriate? How well are these methods integrated?
- Have the appropriate supporting system-level assessments been conducted?
- Do both the researchers and managers understand and manage the risks involved to an appropriate level?
- Are the plans for further study reasonable and justifiable?

Overall Capabilities

- Is the scientific or engineering quality of the work (including work performed in academia and industry) comparable to similar world-class efforts at other institutions, and is it appropriate for the goal?
- Are the qualifications of the scientific and engineering staff (including researchers in aca-

demia and industry) sufficient to achieve program goals?
- Are the capabilities, quantity, and state of readiness of equipment and facilities sufficient to achieve program goals?
- Are personnel, equipment, and facilities supplied by support contractors used efficiently; do they fill gaps in government capabilities without duplication?

The selection of criteria for each assessment and the relative weights given to each criterion are within each panel's discretion and can vary from program to program.

C

Committee and Panel Activities

VEHICLE SYSTEMS PANEL

March 17-19, 2003	Overview meeting	Washington, D.C.
April 29-30, 2003	Site visit	Glenn Research Center
	Combustor Technologies task (7.4.5)	
	Crack-Resistant Materials task (7.7.2)	
	Propulsion Fundamentals Research subproject (7.2)	
	Materials and Structures for High Performance subproject (6.4)	
	Higher Operating Temperature Propulsion Components subproject (7.6)	
	Aeropropulsion and Power URETI subproject (7.3)	
	Compressor Flow Control task (7.4.2)	
	Multistage Compressor task (6.3.2)	
	Oil-Free Turbine Engine Technology subproject (7.5)	
May 21, 2003	Site visit	Langley Research Center
	Integrated Tailored Structures subproject (3.3)	
	Liner Technologies task (2.3.4)	
	Biologically Inspired Flight and Control Systems task (1.1.4)	
	Aviation Assessments task (1.5.1)	
	Vehicle Concept Teams task (4.1.5)	
May 27-29, 2003	Consensus meeting	El Segundo, California

AIRSPACE SYSTEMS PANEL

February 24-26, 2003	Overview meeting	Washington, D.C.
March 17, 2003	Site visit	Langley Research Center
	DAG-TM Airborne task	
	Advanced Communication for ATM task	
	SLIC/Wake Vortex Avoidance System task	
	SATS Project	
March 31-April 4, 2003	Site visit	Ames Research Center
	VAMS Project	
	AATT Project	
	AOS Project	
April 30-May 1, 2003	Consensus meeting	Irvine, California

AVIATION SAFETY PANEL

February 26-28, 2003	Overview meeting	Washington, D.C.
March 27, 2003	Site visit	Glenn Research Center
	Aircraft Icing subproject	
	WINCOMM task	
March 31-April 1, 2003	Site visit	Langley Research Center
	Vehicle Safety Project	
	AWIN task	
	TPAWS task	
May 6-7, 2003	Site visit	Ames Research Center
	System Safety Project	
May 27-29, 2003	Consensus meeting	Washington, D.C.

COMMITTEE

February 4, 2003	Chairs' meeting	Washington, D.C.
July 8-10, 2003	Consensus meeting	Washington, D.C.

D

National Research Council Questionnaire

The committee and panels asked the following questions of each principal investigator in NASA's Aeronautics Technology Programs:

Program Name:
Project Name:
Task Name:
PI Name and location:
PI email:
PI phone:

1. Briefly describe your research project's intent or goal, how it relates to NASA's missions, and what, in your opinion, constitutes success.

2. On what work does your work build (list key references as appropriate)?

3. What is the key progress to date? What are the milestones/measurables you have in place to track this progress?

4. What are the key technical issue/roadblocks you are facing?

5. Who else is trying to do similar research/development?

6. What is your plan to transition this research to NASA missions or other aerospace applications? Describe the status of that transition.

7. What products do you anticipate and who are your internal and external customers (provide names, affiliations, and phone numbers for no more than four)?

8. Give a full-time-equivalent (FTE) number of researchers on the effort per year: 0.0

9. List the approximate funding level for this task for FY 2003, followed by the anticipated funding level for FY 2004. If any funding comes from sources outside Revolutionize Aviation, please list the funding agency and program.

10. List the start date and anticipated end date.

11. List the additional tasks that are managed under your task, if any. Please include task title, PI name, affiliation, contact info, and approximate yearly funding level for each task.

12. List the three most important publications on your project in the last three years. If there were major invited talks or patents on the technology, please list those as well.

E

List of Tasks in NASA's Aeronautics Technology Research Portfolio

VEHICLE SYSTEMS PROGRAM

Project 1.0 Breakthrough Vehicle Technologies (BVT)

Subproject 1.1 Morphing

Task 1.1.1	Micro-Adaptive Control
Task 1.1.2	Smart Materials and Systems
Task 1.1.3	Adaptive Structural Morphing
Task 1.1.4	Biologically Inspired Flight and Control Systems

Subproject 1.2 Aerospace Systems Concept to Test

Task 1.2.1	Physics-Based Flow Modeling
Task 1.2.2	Fast, Adaptive Aerospace Tools
Task 1.2.3	Uncertainty-Based Methods
Task 1.2.4	Abrupt Wing Stall Research
Task 1.2.5	Computational Aeroelasticity, Modeling, and Scaling
Task 1.2.6	Dynamic Aero Modeling and Prediction

Subproject 1.3 Super Lightweight Multifunctional Systems Technologies (SLMFST)

Task 1.3.1	Biomimetics/Nanotechnology
Task 1.3.2	Revolutionary Metallic Materials and Structures
Task 1.3.3	Lightweight Multifunctional Structures

Subproject 1.4 Advances through Cooperative Efforts

Task 1.4.1	Fighter Aircraft Analysis and Simulation Technology
Task 1.4.2	Winter Runway Friction
Task 1.4.3	Tire Mechanics/Dynamics
Task 1.4.4	NASA/DoD Collaborative Activities

Subproject 1.5 Aerospace Systems Analysis Project

Task 1.5.1	Aviation Assessments

Subproject 1.6 Robust Aerospace Systems

Task 1.6.1	Electromagnetic Analysis and Design
Task 1.6.2	Robust Avionic Architectures
Task 1.6.3	Control of Complex Air Vehicles
Task 1.6.4	Highly Automated Air Vehicle Operations
Task 1.6.5	Sensors for Vehicle Health Management
Task 1.6.6	Ageless Structural Systems Technology

Project 2.0 Quiet Aircraft Technology (QAT)

Subproject 2.1 Airframe Systems Noise Reduction

Task 2.1.1	Airframe Noise Reduction
Task 2.1.2	Propulsion Airframe Aeroacoustics
Task 2.1.3	Passenger/Crew Environment

Subproject 2.2 Community Noise Impact Reduction

Task 2.2.1	Impact Modeling
Task 2.2.2	System Noise Prediction
Task 2.2.3	Low-Noise Flight Procedures

Subproject 2.3 Engine Systems Noise Reduction

Task 2.3.1	Fan Noise Reduction
Task 2.3.2	Jet Noise Reduction
Task 2.3.3	Core Noise Reduction
Task 2.3.4	Liner Technologies
Task 2.3.5	Engine Systems and Advanced Concepts

Project 3.0 Twenty-first Century Aircraft Technology (TCAT)

Subproject 3.1 Technology Integration and Assessment

Task 3.1.1	Technology Benefits Assessments

Subproject 3.2 Efficient Aerodynamic Shapes and Integration

Task 3.2.1	High-Speed Slotted Wing
Task 3.2.2	Simplified High-Lift System
Task 3.2.3	Ground-to-Flight Scaling
Task 3.2.4	Turbulence Modeling

Subproject 3.3 Integrated Tailored Structures

Task 3.3.1	Tailored Structures
Task 3.3.2	Tailored Materials/Processing Technology
Task 3.3.3	Design Technology for Tailored Structures
Task 3.3.4	Residual Strength/Damage Tolerance

Subproject 3.4 Green, Efficient Aircraft Power

Task 3.4.1	Hydrocarbon Fuels Processing and Fuel Characterization
Task 3.4.2	Power Management and Distribution Test Bed
Task 3.4.3	Configuration and Performance Evaluation

Project 4.0 Advanced Vehicle Concepts (AVC)

Subproject 4.1 Revolutionary Airframe Concepts Research

Task 4.1.1	Blended Wing Body
Task 4.1.2	Aeronautical Vehicle Technologies Demonstrator
Task 4.1.3	Personal Air Vehicles
Task 4.1.4	Active Vibration Suppression
Task 4.1.5	Vehicle Concept Teams

Subproject 4.2 Revolutionary Aircraft Flight Validation

Task 4.2.1	Intelligent Flight Control System: C-17
Task 4.2.2	Intelligent Flight Control System: NF-15

Subproject 4.3 Hyper-X

Task 4.3.1	Flight 2/Return to Flight

Project 5.0 Flight Research

Subproject 5.1 Flight Research Productivity

Task 5.1.1	Flight Research Productivity

Subproject 5.2 Advanced Systems Concepts

Task 5.2.1	Active Aeroelastic Wing
Task 5.2.2	Autonomous Aerial Refuling

Subproject 5.3 Integrated Transport and Testbed Experiment

Task 5.3.1	F-15B Space Flight Experiments

Subproject 5.4 Western Aeronautical Test Range

Task 5.4.1	Dryden Center Operation

Subproject 5.5 Environmental Research Aircraft and Sensor Technology

Task 5.5.1	Helios
Task 5.5.2	Altair
Task 5.5.3	Subsystems/National Air Space Operations

Project 6.0 Ultra-Efficient Engine Technology

Subproject 6.1 Propulsion Systems Integration and Assessment

Task 6.1.1	Systems Evaluation
Task 6.1.2	Environmental Assessment/ Atmospheric Modeling
Task 6.1.3	Environmental Assessment/FAA-EPA Collaboration
Task 6.1.4	Environmental Assessment/ Emissions Characterization
Task 6.1.5	Environmental Assessment/Turbine Modeling and Studies
Task 6.1.6	Environmental Assessment/ Particulate Measurements and Studies
Task 6.1.7	Environmental Assessment/Plume-Wake Studies
Task 6.1.8	Environmental Assessment/Engine Tests
Task 6.1.9	High Fidelity Systems Simulations
Task 6.1.10	GE High-Fidelity System Simulation Task Order

Subproject 6.2 Emissions Reduction

Task 6.2.1	Subsonic Large Engine NO_x Reduction
Task 6.2.2	GE Evandale Subsonic Research Contract
Task 6.2.3	P&W Subsonic Research Contract
Task 6.2.4	GE Testing in NASA Facilities
Task 6.2.5	P&W Testing in NASA Facilities
Task 6.2.6	Subsonic Large-Engine NO_x Reduction
Task 6.2.7	Honeywell Subsonic Research Contract
Task 6.2.8	Rolls Royce Subsonic Research Contract
Task 6.2.9	Honeywell Testing in NASA Facilities
Task 6.2.10	Rolls-Royce Testing in NASA Facilities
Task 6.2.11	NASA Combustion Facility General Maintenance
Task 6.2.12	In-house Diagnostics
Task 6.2.13	Quantitative Raman Diagnostics at High Pressure
Task 6.2.14	Benchmark Test with Liquid Spray Injector
Task 6.2.15	Combustor Code
Task 6.2.16	Large Eddy Simulation of a Gas-Turbine Model Combustor
Task 6.2.17	Lean Direct-Injection Low NO_x Combustor Concepts
Task 6.2.18	Concepts for Advanced Gas Turbine Combustors

Subproject 6.3 Highly Loaded Turbomachinery

Task 6.3.1	Fan Trailing Edge Ejection
Task 6.3.2	Multistage Compressor
Task 6.3.3	HP/LP Turbine System
Task 6.3.4	Heat Transfer Modeling
Task 6.3.5	Unsteady Modeling
Task 6.3.6	Average Passage Modeling
Task 6.3.7	Dual Spool Turbine Facility

Subproject 6.4 Materials and Structures for High Performance

Task 6.4.1	Materials and Structures Turbine Airfoil System
Task 6.4.2	Ceramic Matrix Composite Components
Task 6.4.3	Computational Materials Science
Task 6.4.4	3000°F Ceramic Matrix Composite System
Task 6.4.5	Ultra-High-Temperature Ceramics

Subproject 6.5 Propulsion-Airframe Integration

Task 6.5.1	Active Flow Control
Task 6.5.2	Active Shape Control
Task 6.5.3	Advanced Configurations

Subproject 6.6 Integrated Component Technology

Task 6.6.1	System Studies and Demonstration Plans
Task 6.6.2	2200°F Ceramic Matrix Composite Liner Demonstration
Task 6.6.3	Aspirating Seal Demonstration
Task 6.6.4	Mechanical Components
Task 6.6.5	Nozzle/Inlet Components for High Speed Flight

Subproject 6.7 Intelligent Propulsion Controls

Task 6.7.1	Rotating Machinery Clearance Management
Task 6.7.2	High-Temperature Wireless Data Communication Technology

Project 7.0 Propulsion and Power

Subproject 7.1 Revolutionary Aeropropulsion Concepts

Task 7.1.1	Constitutive Behavior Free Detection Schemes for Real-Time Condition Monitoring of Aero Propulsion Structures Leading to Minimum Safe Life Cycle Cost
Task 7.1.2	Hot/Smart Materials for Aeropropulsion
Task 7.1.3	Morphing Structures for Self-adaptive Aeropropulsion
Task 7.1.4	SOFC Stack Materials Development
Task 7.1.5	Miniature Autonomous Sensors and Actuators for Smart Propulsion Systems
Task 7.1.6	Advanced Tools for Revolutionary Architecture Design Space
Task 7.1.7	High Power Motor Control Inverter for Aeropropulsion
Task 7.1.8	Next Generation Fuel Cells
Task 7.1.9	High Power Density Electric Motors for Non-Polluting Aircraft Propulsion
Task 7.1.10	High Efficiency Carbon Nanotube Thermionic Power Supplies
Task 7.1.11	Nanotechnology Derived Materials
Task 7.1.12	NanoStar-Sonoluminescence
Task 7.1.13	Interstage Turbine Burner
Task 7.1.14	Levitated Ducted Fan Composite Rotor
Task 7.1.15	Gelled Cryogenic Fuels
Task 7.1.16	Distributed Propulsion
Task 7.1.17	Advanced Micromachining Technology for SiC Microengines
Task 7.1.18	Small Engine Health Monitoring
Task 7.1.19	Revolutionary Aeropropulsion Concepts NRA and Grants
Task 7.1.20	3D Turbo Machinery Analysis Tools

Subproject 7.2 Propulsion Fundamentals Research

Task 7.2.1	Future Propulsion Systems Research
Task 7.2.2	Nanotechnology
Task 7.2.3	Supersonic Propulsion
Task 7.2.4	Fundamental Noise
Task 7.2.5	Research Facility Investments

Subproject 7.3 Aeropropulsion and Power University Research and Engineering Technology Institute (URETI)

Task 7.3.1	Systems Analysis and Technical Integration
Task 7.3.2	Enabling Technologies
Task 7.3.3	Intelligent Engine Systems
Task 7.3.4	High-Performance Components
Task 7.3.5	Advanced Power Technology
Task 7.3.6	Education Program

Subproject 7.4 Smart Efficient Components

Task 7.4.1	Aspirating Flow Control
Task 7.4.2	Compressor Flow Control
Task 7.4.3	Intelligent Flutter Control
Task 7.4.4	Turbine Technologies
Task 7.4.5	Combustor Technologies
Task 7.4.6	Magnetic Bearing Development
Task 7.4.7	Aeroelastic/Structural Dynamics
Task 7.4.8	Seals Development
Task 7.4.9	Active Combustion Control
Task 7.4.10	Sensor Development

Subproject 7.5 Oil-Free Turbine Engine Technology

Task 7.5.1	Foil Bearing Development/Testing/Analysis

Subproject 7.6 Higher Operating Temperature Propulsion Components

Task 7.6.1	Ceramics
Task 7.6.2	Polymers
Task 7.6.3	Metallics
Task 7.6.4	Instrumentation

Subproject 7.7 Ultra-Safe Propulsion

Task 7.7.1	Engine Containment and Blade-Out Mitigation
Task 7.7.2	Crack-Resistant Materials

Subproject 7.8 Pulse Detonation Engine Technology

Task 7.8.1	Cycle Analysis
Task 7.8.2	Materials and Structures
Task 7.8.3	Instrumentation and Control
Task 7.8.4	Combustion/PDE Test Bed
Task 7.8.5	Inlets
Task 7.8.6	Nozzles
Task 7.8.7	Combined Cycles/Ejectors
Task 7.8.8	Hybrids
Task 7.8.9	Acoustics

AIRSPACE SYSTEMS PROGRAM

Project Advanced Air Transportation Technologies (AATT)

Subproject Terminal/Surface

Task	Multi-Center Traffic Management Advisor (McTMA)
Task	Expedite Departure Path
Task	Surface Management System

Subproject En Route

Task	En Route Descent Advisor
Task	Regional Metering
Task	Traffic Flow Management
Task	Direct-to-Controller Tool

Subproject Distributed Air-Ground Traffic Management

Task	DAG-TM Airborne
Task	DAG-TM Air Traffic Management
Task	DAG-TM Flight Deck and Cockpit Display of Traffic Information

Task Advanced Communications for Air Traffic Management

Project Small Aircraft Transportation System (SATS)

Task Systems Technology Development

Task Flight Infrastructure and Operations

Task Transportation Systems Analysis and Assessment

Project Virtual Airspace Modeling and Simulation (VAMS)

Subproject Systems Level Integrated Concepts

Task	Advanced Airspace Concept
Task	Automated Airport Surface Traffic Control
Task	Centralized Terminal Operation Control
Task	Massive Point-to-Point and On-Demand Air Transportation System
Task	Surface Operation Automation Research
Task	System Level Capacity Increasing Concept Research
Task	Systemwide Optimization of the National Airspace System
Task	Terminal Area Capacity Enhancement Concept

Subproject Virtual Airspace Simulation Technologies

Task	Communications, Navigation and Surveillance
Task	Non-Real-Time Modeling
Task	Real-Time Modeling

Task System Evaluation and Assessment

Task Wake Vortex Avoidance System

Project Airspace Operations Systems (AOS)

Subproject	*Human Automation Integration Research*
Task	Prototyping for Evaluation of Automation: Data Link Human Factors
Task	Human Automation Theory (Degani)
Task	Human Automation Theory (Meyer)
Task	State Awareness and Prediction
Task	Supervisory Control
Task	System Design and Analysis/Design of Displays and Procedures
Subproject	*Psychological and Physiological Stressors and Factors*
Task	Perceptual Models and Metrics
Task	Cognitive Models and Metrics
Task	Physiological Factors
Subproject	*Human Error Countermeasures*
Task	Fatigue Countermeasures
Task	Managing Risk and Uncertainty in Team Decision Making

AVIATION SAFETY PROGRAM

Project	**Technical Integration**
Project	**Vehicle Safety Technology**
Subproject	*Single Aircraft Accident Prevention*
Task	Vehicle Health Management and Flight Critical System Design
Task	Propulsion System Safety Technologies
Task	Control Upset Prevention and Recovery
Subproject	*Accident Mitigation*
Task	Fire Prevention
Subproject	*Synthetic Vision Systems*
Task	Commercial and Business Aircraft
Task	General Aviation
Task	Enabling Technologies
Project	**Weather Safety Technology**
Subproject	*Aircraft Icing*
Task	Design and Analysis Tools
Task	Aircraft Ice Protection
Task	Education and Training
Subproject	*Weather Accident Prevention*
Task	Aviation Weather Information
Task	Weather Information Communications
Task	Turbulence Prediction and Warning Systems
Project	**System Safety Technology**
Subproject	*Systemwide Accident Prevention*
Task	Human Performance Models
Task	Maintenance Human Factors
Task	Crew Training
Task	Program Human Factors
Subproject	*Aviation System Monitoring and Modeling*
Task	Data Analysis Tool Development
Task	Extramural Monitoring
Task	Modeling and Simulation
Task	Intramural Monitoring

F

Abbreviations and Acronyms

AATT	Advanced Air Transportation Technologies
ACT	Advanced Composites Technology
ALPA	Air Line Pilots Association
AOPA	Aircraft Owners and Pilots Association
AOS	Airspace Operations Systems
APMS	Aviation Performance Measuring System
ARTCC	Air Route Traffic Control Center
ASF	Air Safety Foundation
ASIST	Aviation Safety Investment Strategy Team
ASMM	Aviation System Monitoring and Modeling
ASP	Airspace Systems Program
ASRS	Aviation Safety Reporting System
ATC	air traffic control
ATM	air traffic management
ATP	airline transport pilot
AVC	Advanced Vehicle Concepts
AvSP	Aviation Safety Program
AWC	Aviation Weather Center
AWIN	Aviation Weather Information
BVT	Breakthrough Vehicle Technology
CAST	Commercial Aviation Safety Team
CFD	computational fluid dynamics
CO_2	carbon dioxide
CONOPS	Concept of Operations
COO	chief operating officer
CTAS	Center TRACON Automation System
CUPR	Control Upset Prevention and Recovery
D2	Direct-to-Controller
DAG-TM	Distributed Air-Ground Traffic Management
DNL	day-night level
DoD	Department of Defense
EDA	En Route Descent Advisor
EDP	Expedite Departure Path
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FACET	Future ATM Concepts Evaluation Tool
FCSD	Flight Critical Systems Design
FOSS	Fiber Optic Strain System
HAIR	Human Automation Integration Research
HEC	Human Error and Countermeasures
HLA	High Level Architecture
IAIPT	Interagency Integrated Product Team

IFR	instrument flight rules
IMC	instrument meteorological conditions
lidar	light detection and ranging
McTMA	Multi-Center Traffic Management Advisor
MEMS	microelectromechanical systems
NAOMS	National Aviation Operations Measurement Service
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEXRAD	Next Generation Weather Radar
NextNAS	NASA Exploratory Technologies for the NAS
NO_x	oxides of nitrogen
NRC	National Research Council
OMB	Office of Management and Budget
OO	object-oriented
PDARS	Performance Data Analysis and Reporting System
pFAST	Passive Final Approach Spacing Tool
PI	principal investigator
PPSF	Psychological and Physiological Stressors and Factors
QAT	Quiet Aircraft Technology
RMP	Research Management plan
RTP	Research Transition Plan
SAAP	Single Aircraft Accident Prevention
SATS	Small Aircraft Transportation System
SBIR	Small Business Innovation Research award
SLMFST	Super Lightweight Multifunctional Systems Technology
SMS	Surface Management System
SVS	Synthetic Vision Systems
SWAP	System-Wide Accident Prevention
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TCAT	Twenty-First Century Aircraft Technology
TMA	Traffic Management Advisor
TPAWS	Turbulence Prediction and Warning Systems
TRACON	Terminal Radar Approach Control
TRL	technology readiness level
UEET	Ultra-Efficient Engine Technology
URETI	University Research and Engineering Technology Institute
VAATE	Versatile Affordable Advanced Turbine Engine
VAMS	Virtual Airspace Modeling Systems
VARTM	vacuum-assisted resin transfer molding
VAST	Virtual Airspace Simulation Technologies
VDLM3	VHF Data Link Mode 3
VHF	very high frequency
VHM	vehicle health monitoring
VSP	Vehicle Systems Program
WINCOMM	Weather Information Communications
WxAP	Weather Accident Prevention