# *Summary*

# Decadal Survey of Civil Aeronautics: Foundation for the Future 2006

**ASEB Meeting**
**Irvine, CA**
**October 2011**

# Process for Integration and Prioritization

- The steering committee developed:
  - Framework for the study
  - Strategic Objectives
  - Guidelines for the panels
  - QFD to be used
  - Identified, defined, and weighted the Strategic Objectives as well as the Why NASA? Criteria
  - Outlined some basic rules and conventions for completing the prioritization process

# Strategic Objectives for Civil Aero R&T

- Increase capacity
- Improve safety and reliability
- Increase efficiency and performance
- Reduce energy consumption and environmental impact

- *Take advantage of synergies with national and homeland security.*
- *Support the space program.*

# Aeronautics R&T Areas

- Area A: Aerodynamics and aeroacoustics
- Area B: Propulsion and power
- Area C: Materials and structures
- Area D: Dynamics, navigation, and control, and avionics
- Area E: Intelligent and autonomous systems, operations and decision making, human integrated systems, and networking and communications

# QFD

| | | Strategic Objective | | | | | | | Why NASA? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R&T Challenge | Weight | Capacity | Safety and Reliability | Efficiency and Performance | Energy and the Environment | Synergies with Security | Support to Space | National Priority | Supporting Infrastructure | Mission Alignment | Lack of Alternative Sponsors | Appropriate Level of Risk | Why NASA Composite Score | NASA Priority Score |
| | | 5 | | 3 | | 1 | | | 1/4 each | | | | | |
| X1 | R&T Challenge 1 | 9 | 9 | 3 | 3 | 1 | 1 | 110 | 3 | 9 | 3 | 9 | 6.0 | 660 |
| X2 | R&T Challenge 2 | 3 | 9 | 3 | 9 | 1 | 1 | 98 | 1 | 9 | 3 | 9 | 5.5 | 539 |
| X3 | R&T Challenge 3 | 1 | 1 | 1 | 3 | 9 | 9 | 40 | 9 | 9 | 9 | 9 | 9.0 | 360 |

# Area A: Aerodynamics and Aeroacoustics

1. Integrated system performance through novel propulsion-airframe integration
2. Aerodynamic performance improvement through transition, boundary layer, and separation control
3. Novel aerodynamic configurations that enable high performance and/or flexible multimission aircraft
4. Aerodynamic designs and flow control schemes to reduce aircraft and rotor noise
5. Accuracy of prediction of aerodynamic performance of complex 3D configurations, including improved boundary layer transition and turbulence models and associated design tools
6. Aerodynamics robust to atmospheric disturbances and adverse weather conditions, including icing
7. Aerodynamic configurations to leverage advantages of formation flying
8. Accuracy of wake vortex prediction, and vortex detection and mitigation techniques
9. Aerodynamic performance for V/STOL and ESTOL, including adequate control power
10. Techniques for reducing/mitigating sonic boom through novel aircraft shaping
11. Robust and efficient multidisciplinary design tools

# Area B: Propulsion and power

1. Quiet propulsion systems
2. Ultraclean gas turbine combustors to reduce gaseous and particulate emissions in all flight segments
3. Intelligent engines and mechanical power systems capable of self-diagnosis and reconfiguration between shop visits
4. Improved propulsion system fuel economy
5. Propulsion systems for short takeoff and vertical lift
6. Variable-cycle engines to expand the operating envelope
7. Integrated power and thermal management systems
8. Propulsion systems for supersonic flight
9. High-reliability, high-performance, and high-power density aircraft electric power systems
10. Combined-cycle hypersonic propulsion systems with mode transition

# Area C: Materials and structures

1. Integrated vehicle health management
2. Adaptive materials and morphing structures
3. Multidisciplinary analysis, design, and optimization
4. Next-generation polymers and composites
5. Noise prediction and suppression
6. Innovative high-temperature metals and environmental coatings
7. Innovative load suppression, and vibration and aeromechanical stability control
8. Structural innovations for high-speed rotorcraft
9. High-temperature ceramics and coatings
10. Multifunctional materials

# Area D: Dynamics, navigation, and control, and avionics

1. Advanced guidance systems
2. Distributed decision making, decision making under uncertainty, and flight path planning and prediction
3. Aerodynamics and vehicle dynamics via closed-loop flow control
4. Intelligent and adaptive flight control techniques
5. Fault-tolerant and integrated vehicle health management systems
6. Improved onboard weather systems and tools
7. Advanced communication, navigation, and surveillance (CNS) technology
8. Human–machine integration
9. Synthetic and enhanced vision systems
10. Safe operation of unmanned air vehicles in the national airspace

# Area E: Intelligent and autonomous systems, operations and decision making, human integrated systems, and networking and communications

1. Methodologies, tools, and simulation and modeling capabilities to design and evaluate complex interactive systems
2. New concepts and methods of separating, spacing, and sequencing aircraft
3. Appropriate roles of humans and automated systems for separation assurance, including the feasibility and merits of highly automated separation assurance systems
4. Affordable new sensors, system technologies, and procedures to improve the prediction and measurement of wake turbulence
5. Interfaces that ensure effective information sharing and coordination among ground-based and airborne human and machine agents
6. Vulnerability analysis as an integral element in the architecture design and simulations of the air transportation system
7. Adaptive ATM techniques to minimize the impact of weather by taking better advantage of improved probabilistic forecasts
8. Transparent and collaborative decision support systems
9. Using operational and maintenance data to assess leading indicators of safety
10. Interfaces and procedures that support human operators in effective task and attention management

# Common Themes

- ***Physics-based analysis tools*** to enable analytical capabilities that go far beyond existing modeling and simulation capabilities and reduce the use of empirical approaches
- ***Multidisciplinary design tools*** to integrate high-fidelity analyses with efficient design methods and to accommodate uncertainty, multiple objectives, and large-scale systems
- ***Advanced configurations*** to go beyond the ability of conventional technologies and aircraft to achieve the Strategic Objectives
- ***Intelligent and adaptive systems*** to significantly improve the performance and robustness of aircraft and the air transportation system as a whole
- ***Complex interactive systems*** to better understand the nature of and options for improving the performance of the air transportation system, which is itself a complex interactive system

# Recommendations 1/2

1. NASA should use the 51 Challenges listed in Table ES-1 as the foundation for the future of NASA's civil aeronautics research program during the next decade
2. The U.S. government should place a high priority on establishing a stable aeronautics R&T plan, with the expectation that the plan will receive sustained funding for a decade or more, as necessary, for activities that are demonstrating satisfactory progress
3. NASA should use five Common Themes to make the most efficient use of civil aeronautics R&T resources
4. NASA should support fundamental research to create the foundations for practical certification standards for new technologies
5. The U.S. government should align organizational responsibilities as well as develop and implement techniques to improve change management for federal agencies and to assure a safe and cost-effective transition to the air transportation system of the future

# Recommendations 2/2

6. NASA should ensure that its civil aeronautics R&T plan features the substantive involvement of universities and industry, including a more balanced allocation of funding between in-house and external organizations than currently exists.
7. NASA should consult with non-NASA researchers to identify the most effective facilities and tools applicable to key aeronautics R&T projects and should facilitate collaborative research to ensure that each project has access to the most appropriate research capabilities, including test facilities; computational models and facilities; and intellectual capital, available from NASA, the Federal Aviation Administration, the Department of Defense, and other interested research organizations in government, industry, and academia.
8. The U.S. government should conduct a high-level review of organizational options for ensuring U.S. leadership in civil aeronautics

# Backup

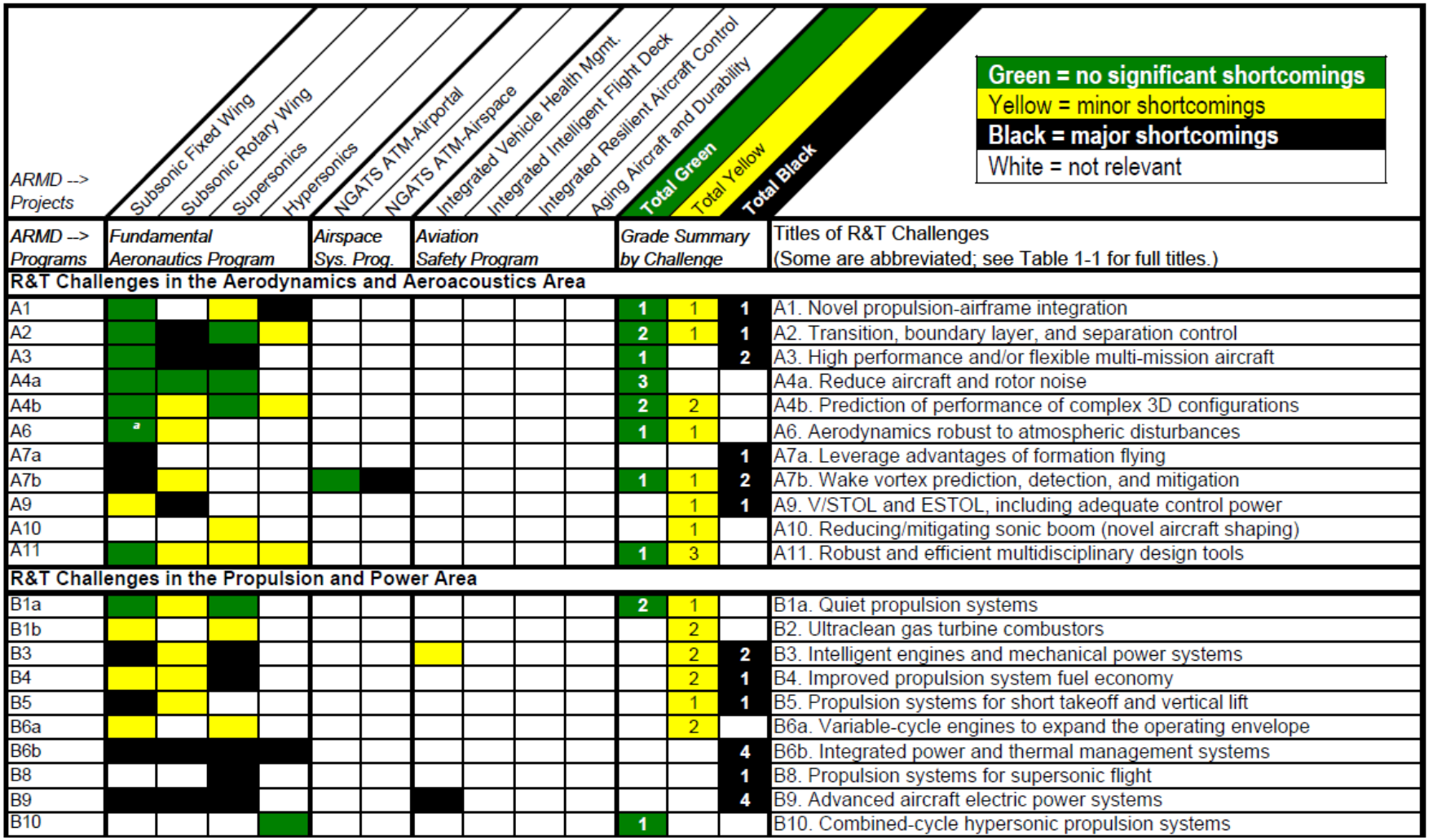
# NASA Aeronautics Research: An Assessment - 2008

1. How well does NASA's research portfolio implement appropriate recommendations and address relevant highest-priority research and technology (R&T) challenges identified in the NRC *Decadal Survey of Civil Aeronautics?* If gaps are found, what steps should be taken by the federal government to eliminate them?

2. How well does NASA's aeronautics research portfolio address the aeronautics research requirements of NASA, particularly for robotic and human space exploration? How well does NASA's aeronautics research portfolio address other federal government department/agency non-civil aeronautics research needs? If gaps are found, what steps should be taken by NASA and/or other parts of the federal government to eliminate them? In order to answer this question the committee will identify and prioritize requirements for such research that fall within the scope of NASA's Aeronautics Research Program. To assist in the identification of such research requirements, NASA will provide the NRC with a list of its current research activities that contribute to these areas no later than March 12, 2007. It is likely that much of this research will be "dual use" or even "triple use," meaning that the research may provide benefit to the civil aeronautics community, and/or the space exploration community, and/or departments and agencies with non-civil aeronautics research needs.

3. Will the nation have a skilled research workforce and research facilities commensurate with the requirements in (1) and (2) above? What critical improvements in workforce expertise and research facilities, if any, should NASA and the nation make to achieve the goals of NASA's research program?

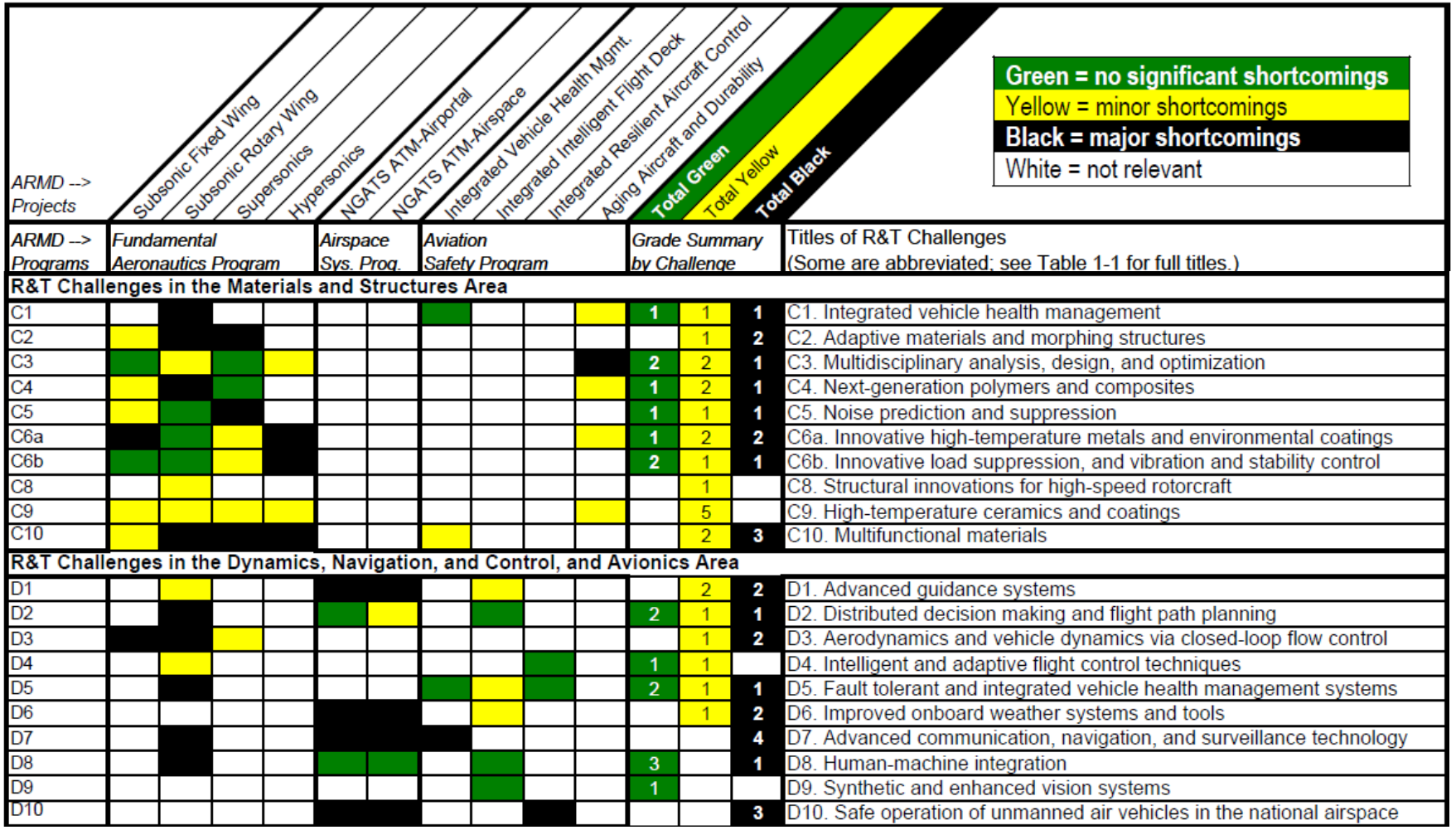
# How well does NASA's research portfolio implement NRC *Decadal Survey of Civil Aeronautics? 1/3*



Green = no significant shortcomings
Yellow = minor shortcomings
Black = major shortcomings
White = not relevant

| ARMD --> Projects | Subsonic Fixed Wing | Subsonic Rotary Wing | Supersonics | Hypersonics | NGATS ATM-Airportal | NGATS ATM-Airspace | Integrated Vehicle Health Mgmt. | Integrated Intelligent Flight Deck | Integrated Resilient Aircraft Control | Aging Aircraft and Durability | Total Green | Total Yellow | Total Black | Titles of R&T Challenges (Some are abbreviated; see Table 1-1 for full titles.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ARMD --> Programs | Fundamental Aeronautics Program | | | | Airspace Sys. Prog. | | Aviation Safety Program | | | | Grade Summary by Challenge | | | |
| **R&T Challenges in the Aerodynamics and Aeroacoustics Area** | | | | | | | | | | | | | | |
| A1 | | | | | | | | | | | 1 | 1 | 1 | A1. Novel propulsion-airframe integration |
| A2 | | | | | | | | | | | 2 | 1 | 1 | A2. Transition, boundary layer, and separation control |
| A3 | | | | | | | | | | | 1 | | 2 | A3. High performance and/or flexible multi-mission aircraft |
| A4a | | | | | | | | | | | 3 | | | A4a. Reduce aircraft and rotor noise |
| A4b | | | | | | | | | | | 2 | 2 | | A4b. Prediction of performance of complex 3D configurations |
| A6 | [a] | | | | | | | | | | 1 | 1 | | A6. Aerodynamics robust to atmospheric disturbances |
| A7a | | | | | | | | | | | | | 1 | A7a. Leverage advantages of formation flying |
| A7b | | | | | | | | | | | 1 | 1 | 2 | A7b. Wake vortex prediction, detection, and mitigation |
| A9 | | | | | | | | | | | | 1 | 1 | A9. V/STOL and ESTOL, including adequate control power |
| A10 | | | | | | | | | | | | 1 | | A10. Reducing/mitigating sonic boom (novel aircraft shaping) |
| A11 | | | | | | | | | | | 1 | 3 | | A11. Robust and efficient multidisciplinary design tools |
| **R&T Challenges in the Propulsion and Power Area** | | | | | | | | | | | | | | |
| B1a | | | | | | | | | | | 2 | 1 | | B1a. Quiet propulsion systems |
| B1b | | | | | | | | | | | | 2 | | B2. Ultraclean gas turbine combustors |
| B3 | | | | | | | | | | | | 2 | 2 | B3. Intelligent engines and mechanical power systems |
| B4 | | | | | | | | | | | | 2 | 1 | B4. Improved propulsion system fuel economy |
| B5 | | | | | | | | | | | | 1 | 1 | B5. Propulsion systems for short takeoff and vertical lift |
| B6a | | | | | | | | | | | | 2 | | B6a. Variable-cycle engines to expand the operating envelope |
| B6b | | | | | | | | | | | | | 4 | B6b. Integrated power and thermal management systems |
| B8 | | | | | | | | | | | | | 1 | B8. Propulsion systems for supersonic flight |
| B9 | | | | | | | | | | | | | 4 | B9. Advanced aircraft electric power systems |
| B10 | | | | | | | | | | | 1 | | | B10. Combined-cycle hypersonic propulsion systems |

# How well does NASA's research portfolio implement NRC *Decadal Survey of Civil Aeronautics? 2/3*



| ARMD --> Projects | Subsonic Fixed Wing | Subsonic Rotary Wing | Supersonics | Hypersonics | NGATS ATM-Airportal | NGATS ATM-Airspace | Integrated Vehicle Health Mgmt. | Integrated Intelligent Flight Deck | Integrated Resilient Aircraft Control | Aging Aircraft and Durability | Total Green | Total Yellow | Total Black | Titles of R&T Challenges (Some are abbreviated; see Table 1-1 for full titles.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ARMD --> Programs | Fundamental Aeronautics Program | | | | Airspace Sys. Prog. | | Aviation Safety Program | | | | Grade Summary by Challenge | | | |
| **R&T Challenges in the Materials and Structures Area** | | | | | | | | | | | | | | |
| C1 | | | | | | | | | | | 1 | 1 | 1 | C1. Integrated vehicle health management |
| C2 | | | | | | | | | | | | 1 | 2 | C2. Adaptive materials and morphing structures |
| C3 | | | | | | | | | | | 2 | 2 | 1 | C3. Multidisciplinary analysis, design, and optimization |
| C4 | | | | | | | | | | | 1 | 2 | 1 | C4. Next-generation polymers and composites |
| C5 | | | | | | | | | | | 1 | 1 | 1 | C5. Noise prediction and suppression |
| C6a | | | | | | | | | | | 1 | 2 | 2 | C6a. Innovative high-temperature metals and environmental coatings |
| C6b | | | | | | | | | | | 2 | 1 | 1 | C6b. Innovative load suppression, and vibration and stability control |
| C8 | | | | | | | | | | | | 1 | | C8. Structural innovations for high-speed rotorcraft |
| C9 | | | | | | | | | | | | 5 | | C9. High-temperature ceramics and coatings |
| C10 | | | | | | | | | | | | 2 | 3 | C10. Multifunctional materials |
| **R&T Challenges in the Dynamics, Navigation, and Control, and Avionics Area** | | | | | | | | | | | | | | |
| D1 | | | | | | | | | | | | 2 | 2 | D1. Advanced guidance systems |
| D2 | | | | | | | | | | | 2 | 1 | 1 | D2. Distributed decision making and flight path planning |
| D3 | | | | | | | | | | | | 1 | 2 | D3. Aerodynamics and vehicle dynamics via closed-loop flow control |
| D4 | | | | | | | | | | | 1 | 1 | | D4. Intelligent and adaptive flight control techniques |
| D5 | | | | | | | | | | | 2 | 1 | 1 | D5. Fault tolerant and integrated vehicle health management systems |
| D6 | | | | | | | | | | | | 1 | 2 | D6. Improved onboard weather systems and tools |
| D7 | | | | | | | | | | | | | 4 | D7. Advanced communication, navigation, and surveillance technology |
| D8 | | | | | | | | | | | 3 | | 1 | D8. Human-machine integration |
| D9 | | | | | | | | | | | 1 | | | D9. Synthetic and enhanced vision systems |
| D10 | | | | | | | | | | | | | 3 | D10. Safe operation of unmanned air vehicles in the national airspace |

Green = no significant shortcomings
Yellow = minor shortcomings
Black = major shortcomings
White = not relevant

# How well does NASA's research portfolio implement NRC *Decadal Survey of Civil Aeronautics? 3/3*

| ARMD --> Projects | Subsonic Fixed Wing | Subsonic Rotary Wing | Supersonics | Hypersonics | NGATS ATM-Airportal | NGATS ATM-Airspace | Integrated Vehicle Health Mgmt. | Integrated Intelligent Flight Deck | Integrated Resilient Aircraft Control | Aging Aircraft and Durability | Total Green | Total Yellow | Total Black | Titles of R&T Challenges (Some are abbreviated: see Table 1-1 for full titles.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ARMD --> Programs | Fundamental Aeronautics Program | | | | Airspace Sys. Prog. | | Aviation Safety Program | | | | Grade Summary by Challenge | | | |
| **R&T Challenges in the Intelligent and Autonomous Systems, Operations and Decision Making, Human Integrated Systems, Networking and Communications Area** | | | | | | | | | | | | | | |
| E1 | | | | | | | | | | | 1 | 3 | | E1. Design and evaluate complex interactive systems |
| E2 | | | | | | | | | | | | 2 | | E2. Separating, spacing, and sequencing aircraft |
| E3 | | | | | | | | | | | | 2 | | E3. Roles of humans and automated systems for separation assurance |
| E4 | | | | | | | | | | | | | 2 | E4. Sensors, etc. to predict and measure wake turbulence |
| E5 | | | | | | | | | | | 1 | 1 | | E5. Information sharing among human and machine agents |
| E6 | | | | | | | | | | | | 1 | 1 | E6. Vulnerability analysis in the design of the air transportation system |
| E7 | | | | | | | | | | | | 2 | | E7. Adaptive ATM techniques to minimize the impact of weather |
| E8a | | | | | | | | | | | 2 | | | E8a. Transparent and collaborative decision support systems |
| E8b | | | | | | | | | | | 1 | 1 | | E8b. Operational and maintenance data to assess safety |
| E8c | | | | | | | | | | | 1 | | 1 | E8c. Human operators in effective task and attention management |
| Totals for All 51 R&T Challenges from the Decadal Survey | | | | | | | | | | | | | | |
| **Green** | 10 | 4 | 6 | 1 | 7 | 2 | 3 | 3 | 2 | 0 | 38 | | | |
| Yellow | 9 | 13 | 9 | 5 | 3 | 7 | 3 | 3 | 1 | 5 | | 58 | | |
| **Black** | 8 | 14 | 9 | 5 | 6 | 7 | 2 | 0 | 1 | 1 | | | 53 | |

**Green = no significant shortcomings**
Yellow = minor shortcomings
**Black = major shortcomings**
White = not relevant

[a] Work on R&T Challenge A6 related to subsonic fixed wing aircraft is being done by the NASA Office of Safety.

# Recommendations

1. ARMD should ensure that its research program substantively advances the state of the art and makes a significant difference in a time frame of interest to users of the research results

2. ARMD should bridge the gap between research and application—and thereby increase the likelihood that this research will be of value to the intended users

3. As reference documents and project plans are revised and updated, NASA should continue to improve the correlation between (1) the reference documents that describe project rationale and scope and (2) the project plans and actual implementation of each project

4. To ensure that the NASA aeronautics program has and will continue to have an adequate supply of trained employees, ARMD should develop a vision describing the role of its research staff as well as a comprehensive, centralized strategic plan for workforce integration and implementation specific to ARMD

5. Absent a substantial increase in facility maintenance and investment funds, NASA should reduce the impact of facility shortcomings by continuing to assess facilities and mothball or decommission facilities of lesser importance so that the most important facilities can be properly sustained

# Area A: Aerodynamics and Aeroacoustics

| | | Strategic Objective | | | | | | | Why NASA? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Capacity | Safety and Reliability | Efficiency and Performance | Energy and the Environment | Synergies with Security | Support to Space | National Priority | Supporting Infrastructure | Mission Alignment | Lack of Alternative Sponsors | Appropriate Level of Risk | Why NASA Composite Score | NASA Priority Score |
| R&T Challenge | Weight | 5 | | 3 | | 1 | | | 1/4 each | | | | | |
| A1 | Integrated system performance through novel propulsion–airframe integration | 9 | 3 | 9 | 9 | 9 | 9 | 132 | 3 | 9 | 3 | 9 | 6.0 | 792 |
| A2 | Aerodynamic performance improvement through transition, boundary layer, and separation control | 9 | 3 | 9 | 9 | 3 | 3 | 120 | 3 | 9 | 3 | 9 | 6.0 | 720 |
| A3 | Novel aerodynamic configurations that enable high performance and/or flexible multimission aircraft | 9 | 3 | 9 | 9 | 3 | 1 | 118 | 3 | 9 | 3 | 9 | 6.0 | 708 |
| A4a | Aerodynamic designs and flow control schemes to reduce aircraft and rotor noise | 9 | 1 | 3 | 9 | 3 | 1 | 90 | 3 | 9 | 3 | 9 | 6.0 | 540 |
| A4b | Accuracy of prediction of aerodynamic performance of complex 3-D configurations, including improved boundary layer transition and turbulence models and associated design tools | 3 | 3 | 9 | 3 | 3 | 3 | 72 | 9 | 9 | 3 | 9 | 7.5 | 540 |
| A6 | Aerodynamics robust to atmospheric disturbances and adverse weather conditions, including icing | 9 | 9 | 3 | 1 | 9 | 1 | 112 | 3 | 9 | 3 | 3 | 4.5 | 504 |
| A7a | Aerodynamic configurations to leverage advantages of formation flying | 3 | 1 | 9 | 9 | 3 | 1 | 78 | 3 | 9 | 9 | 3 | 6.0 | 468 |
| A7b | Accuracy of wake vortex prediction, and vortex detection and mitigation techniques | 9 | 9 | 3 | 1 | 1 | 1 | 104 | 3 | 9 | 3 | 3 | 4.5 | 468 |
| A9 | Aerodynamic performance for V/STOL and ESTOL, including adequate control power | 9 | 3 | 3 | 1 | 3 | 1 | 76 | 3 | 9 | 3 | 9 | 6.0 | 456 |
| A10 | Techniques for reducing/mitigating sonic boom through novel aircraft shaping | 3 | 1 | 3 | 9 | 3 | 1 | 60 | 9 | 9 | 3 | 9 | 7.5 | 450 |
| A11 | Robust and efficient multidisciplinary design tools | 3 | 3 | 9 | 9 | 3 | 3 | 90 | 3 | 9 | 3 | 3 | 4.5 | 405 |
| A12 | Accurate predictions of thermal balance and techniques for the reduction of heat transfer to hypersonic vehicles | 1 | 1 | 3 | 1 | 9 | 9 | 40 | 9 | 9 | 3 | 9 | 7.5 | 300 |
| A13 | Low-speed takeoff and landing flight characteristics for access-to-space vehicles | 1 | 3 | 1 | 1 | 3 | 9 | 38 | 3 | 9 | 9 | 9 | 7.5 | 285 |
| A14 | Efficient control authority of advanced configurations to permit robust operations at hypersonic speeds and for access-to-space vehicles | 1 | 1 | 3 | 1 | 9 | 9 | 40 | 3 | 9 | 3 | 9 | 6.0 | 240 |
| A15 | Decelerator technology for planetary entry | 1 | 1 | 1 | 1 | 3 | 9 | 28 | 3 | 9 | 9 | 9 | 7.5 | 210 |
| A16 | Low-Reynolds-number and unsteady aerodynamics for small UAVs | 1 | 1 | 3 | 1 | 9 | 3 | 34 | 3 | 9 | 3 | 9 | 6.0 | 204 |
| A17 | Low-drag airship designs to enable long-duration stratospheric flight | 1 | 3 | 1 | 3 | 9 | 1 | 42 | 3 | 3 | 3 | 9 | 4.5 | 189 |
| A18 | Prediction of communication capability through reentry trajectory and techniques to mitigate impact of communication blackouts | 1 | 1 | 1 | 1 | 9 | 9 | 34 | 3 | 9 | 3 | 3 | 4.5 | 153 |
| A19 | Aircraft protective countermeasures based on a range of small deployed air vehicles | 1 | 3 | 1 | 1 | 9 | 1 | 36 | 3 | 3 | 3 | 3 | 3.0 | 108 |

# Area B: Propulsion and power

| | | Strategic Objective | | | | | | | Why NASA? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Capacity | Safety and Reliability | Efficiency and Performance | Energy and the Environment | Synergies with Security | Support to Space | National Priority | Supporting Infrastructure | Mission Alignment | Lack of Alternative Sponsors | Appropriate Level of Risk | Why NASA Composite Score | NASA Priority Score |
| R&T Challenge | Weight | 5 | | 3 | | 1 | | | 1/4 each | | | | | |
| B1a | Quiet propulsion systems | 9 | 1 | 3 | 9 | 3 | 1 | 90 | 3 | 9 | 3 | 9 | 6.0 | 540 |
| B1b | Ultraclean gas turbine combustors to reduce gaseous and particulate emissions in all flight segments | 9 | 1 | 3 | 9 | 3 | 1 | 90 | 3 | 9 | 3 | 9 | 6.0 | 540 |
| B3 | Intelligent engines and mechanical power systems capable of self-diagnosis and reconfiguration between shop visits | 3 | 9 | 3 | 3 | 3 | 1 | 82 | 3 | 9 | 3 | 9 | 6.0 | 492 |
| B4 | Improved propulsion system fuel economy | 3 | 1 | 9 | 9 | 3 | 1 | 78 | 3 | 9 | 3 | 9 | 6.0 | 468 |
| B5 | Propulsion systems for short takeoff and vertical lift | 9 | 1 | 3 | 3 | 3 | 1 | 72 | 3 | 9 | 3 | 9 | 6.0 | 432 |
| B6a | Variable-cycle engines to expand the operating envelope | 3 | 1 | 9 | 3 | 3 | 9 | 68 | 3 | 9 | 3 | 9 | 6.0 | 408 |
| B6b | Integrated power and thermal management systems | 3 | 1 | 9 | 3 | 3 | 9 | 68 | 3 | 9 | 3 | 9 | 6.0 | 408 |
| B8 | Propulsion systems for supersonic flight | 3 | 1 | 3 | 1 | 9 | 9 | 50 | 9 | 9 | 3 | 9 | 7.5 | 375 |
| B9 | High-reliability, high-performance, and high-power-density aircraft electric power systems | 1 | 3 | 9 | 3 | 3 | 3 | 62 | 1 | 9 | 3 | 9 | 5.5 | 341 |
| B10 | Combined-cycle hypersonic propulsion systems with mode transition | 1 | 1 | 3 | 1 | 9 | 9 | 40 | 9 | 9 | 3 | 9 | 7.5 | 300 |
| B11 | Alternative fuels and additives for propulsion that could broaden fuel sources and/or lessen environmental impact | 3 | 1 | 3 | 9 | 3 | 1 | 60 | 3 | 3 | 3 | 9 | 4.5 | 270 |
| B12 | Hypersonic hydrocarbon-fueled scramjet | 1 | 1 | 3 | 1 | 9 | 9 | 40 | 9 | 3 | 3 | 9 | 6.0 | 240 |
| B13 | Improved propulsion system tolerance to weather, inlet distortion, wake ingestion, bird strike, and foreign object damage | 3 | 9 | 3 | 1 | 3 | 1 | 76 | 3 | 3 | 3 | 3 | 3.0 | 228 |
| B14 | Propulsion approaches employing specific planetary atmospheres in thrust-producing chemical reactions | 1 | 1 | 1 | 1 | 1 | 9 | 26 | 3 | 9 | 9 | 9 | 7.5 | 195 |
| B15 | Environmentally benign propulsion systems, structural components, and chemicals | 1 | 1 | 1 | 9 | 3 | 1 | 44 | 3 | 3 | 3 | 3 | 3.0 | 132 |
| B16 | Reduced engine manufacturing and maintenance costs | 3 | 3 | 3 | 3 | 3 | 1 | 52 | 3 | 1 | 1 | 3 | 2.0 | 104 |

# Area C: Materials and structures

| | | Strategic Objective | | | | | | | Why NASA? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Capacity | Safety and Reliability | Efficiency and Performance | Energy and the Environment | Synergies with Security | Support to Space | National Priority | Supporting Infrastructure | Mission Alignment | Lack of Alternative Sponsors | Appropriate Level of Risk | Why NASA Composite Score | NASA Priority Score |
| R&T Challenge | Weight | 5 | | 3 | | 1 | | | 1/4 each | | | | | |
| C1 | Integrated vehicle health management | 9 | 9 | 3 | 1 | 9 | 3 | 114 | 9 | 9 | 1 | 9 | 7.0 | 798 |
| C2 | Adaptive materials and morphing structures | 9 | 3 | 9 | 3 | 9 | 3 | 108 | 9 | 9 | 1 | 9 | 7.0 | 756 |
| C3 | Multidisciplinary analysis, design, and optimization | 9 | 3 | 9 | 1 | 3 | 3 | 96 | 9 | 9 | 3 | 9 | 7.5 | 720 |
| C4 | Next-generation polymers and composites | 9 | 3 | 9 | 1 | 9 | 3 | 102 | 9 | 9 | 1 | 9 | 7.0 | 714 |
| C5 | Noise prediction and suppression | 9 | 1 | 3 | 9 | 3 | 1 | 90 | 9 | 9 | 3 | 9 | 7.5 | 677 |
| C6a | Innovative high-temperature metals and environmental coatings | 3 | 9 | 3 | 1 | 9 | 3 | 84 | 9 | 9 | 3 | 9 | 7.5 | 630 |
| C6b | Innovative load suppression, and vibration and aeromechanical stability control | 3 | 9 | 3 | 1 | 9 | 3 | 84 | 9 | 9 | 3 | 9 | 7.5 | 630 |
| C8 | Structural innovations for high-speed rotorcraft | 9 | 1 | 3 | 1 | 9 | 1 | 72 | 9 | 9 | 3 | 9 | 7.5 | 540 |
| C9 | High-temperature ceramics and coatings | 3 | 1 | 9 | 3 | 3 | 9 | 68 | 9 | 9 | 3 | 9 | 7.5 | 510 |
| C10 | Multifunctional materials | 3 | 3 | 9 | 3 | 9 | 9 | 84 | 3 | 9 | 3 | 9 | 6.0 | 504 |
| C11 | Novel coatings | 3 | 9 | 3 | 3 | 1 | 1 | 80 | 3 | 9 | 3 | 9 | 6.0 | 480 |
| C12 | Innovations in structural joining | 3 | 3 | 9 | 1 | 3 | 3 | 66 | 3 | 9 | 3 | 9 | 6.0 | 396 |
| C13 | Advanced airframe alloys | 9 | 1 | 9 | 1 | 3 | 1 | 84 | 1 | 3 | 1 | 9 | 3.5 | 294 |
| C14 | Next-generation nondestructive evaluation | 3 | 9 | 1 | 1 | 3 | 1 | 70 | 3 | 9 | 1 | 3 | 4.0 | 280 |
| C15 | Aircraft hardening | 1 | 9 | 1 | 1 | 9 | 1 | 66 | 3 | 3 | 1 | 9 | 4.0 | 264 |
| C16 | Multiphysics and multiscale modeling and simulation | 3 | 3 | 3 | 3 | 3 | 1 | 52 | 3 | 3 | 3 | 3 | 3.0 | 156 |
| C17 | Ultralight structures | 3 | 1 | 3 | 1 | 3 | 3 | 38 | 3 | 9 | 1 | 3 | 4.0 | 152 |
| C18 | Advanced functional polymers | 1 | 3 | 1 | 1 | 3 | 1 | 30 | 9 | 3 | 3 | 3 | 4.5 | 135 |
| C19 | Advanced engine nacelle structures | 3 | 1 | 3 | 1 | 1 | 1 | 34 | 1 | 9 | 1 | 3 | 3.5 | 119 |
| C20 | Repairability of structures | 3 | 3 | 3 | 1 | 1 | 1 | 44 | 3 | 3 | 1 | 3 | 2.5 | 110 |

# Area D: Dynamics, navigation, and control, and avionics

| R&T Challenge | | Weight | Strategic Objective: Capacity | Strategic Objective: Safety and Reliability | Strategic Objective: Efficiency and Performance | Strategic Objective: Energy and the Environment | Strategic Objective: Synergies with Security | Strategic Objective: Support to Space | National Priority | Why NASA?: Supporting Infrastructure | Why NASA?: Mission Alignment | Why NASA?: Lack of Alternative Sponsors | Why NASA?: Appropriate Level of Risk | Why NASA Composite Score | NASA Priority Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 | | 3 | | 1 | | | 1/4 each | | | | | |
| D1 | Advanced guidance systems | | 9 | 9 | 9 | 3 | 3 | 3 | 132 | 9 | 9 | 3 | 9 | 7.5 | 990 |
| D2 | Distributed decision making, decision making under uncertainty, and flight-path planning and prediction | | 9 | 9 | 9 | 3 | 3 | 3 | 132 | 3 | 9 | 3 | 9 | 6.0 | 792 |
| D3 | Aerodynamics and vehicle dynamics via closed-loop flow control | | 1 | 9 | 9 | 3 | 3 | 3 | 92 | 9 | 9 | 3 | 9 | 7.5 | 690 |
| D4 | Intelligent and adaptive flight control techniques | | 3 | 9 | 9 | 3 | 3 | 9 | 108 | 3 | 9 | 3 | 9 | 6.0 | 648 |
| D5 | Fault-tolerant and integrated vehicle health management systems | | 3 | 9 | 3 | 1 | 3 | 9 | 84 | 9 | 9 | 3 | 9 | 7.5 | 630 |
| D6 | Improved onboard weather systems and tools | | 9 | 9 | 3 | 1 | 1 | 1 | 104 | 9 | 9 | 3 | 3 | 6.0 | 624 |
| D7 | Advanced communication, navigation, and surveillance technology | | 9 | 9 | 9 | 3 | 3 | 3 | 132 | 3 | 9 | 3 | 3 | 4.5 | 594 |
| D8 | Human–machine integration | | 3 | 9 | 9 | 1 | 3 | 3 | 96 | 3 | 9 | 3 | 9 | 6.0 | 576 |
| D9 | Synthetic and enhanced vision systems | | 3 | 9 | 3 | 1 | 1 | 3 | 76 | 9 | 9 | 3 | 3 | 6.0 | 456 |
| D10 | Safe operation of unmanned air vehicles in the national airspace | | 3 | 9 | 3 | 1 | 9 | 1 | 82 | 3 | 9 | 3 | 3 | 4.5 | 369 |
| D11 | Secure network-centric avionics architectures and systems to provide low-cost, efficient, fault-tolerant, onboard communications systems for data link and data transfer | | 9 | 9 | 9 | 1 | 9 | 3 | 132 | 3 | 3 | 1 | 3 | 2.5 | 330 |
| D12 | Smaller, lighter, and less expensive avionics | | 1 | 3 | 9 | 3 | 3 | 9 | 68 | 3 | 3 | 3 | 3 | 3.0 | 204 |
| D13 | More efficient certification processes for complex systems | | 3 | 9 | 9 | 1 | 1 | 3 | 94 | 3 | 1 | 1 | 3 | 2.0 | 188 |
| D14 | Design, development, and upgrade processes for complex, software-intensive systems, including tools for design, development, and validation and verification | | 3 | 9 | 3 | 1 | 1 | 3 | 76 | 1 | 3 | 1 | 1 | 1.5 | 114 |

# Area E: Intelligent and autonomous systems, operations and decision making, human integrated systems, and networking and communications

| R&T Challenge | Weight | Strategic Objective: Capacity (5) | Safety and Reliability (5) | Efficiency and Performance (3) | Energy and the Environment (3) | Synergies with Security (1) | Support to Space (1) | National Priority | Why NASA? Supporting Infrastructure (1/4 each) | Mission Alignment (1/4 each) | Lack of Alternative Sponsors (1/4 each) | Appropriate Level of Risk (1/4 each) | Why NASA Composite Score | NASA Priority Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E1 | Methodologies, tools, and simulation and modeling capabilities to design and evaluate complex interactive systems | 9 | 9 | 9 | 9 | 9 | 3 | 156 | 3 | 9 | 3 | 9 | 6.0 | 936 |
| E2 | New concepts and methods of separating, spacing, and sequencing aircraft | 9 | 9 | 9 | 3 | 3 | 1 | 130 | 3 | 9 | 3 | 9 | 6.0 | 780 |
| E3 | Appropriate roles of humans and automated systems for separation assurance, including the feasibility and merits of highly automated separation assurance systems | 9 | 9 | 9 | 1 | 3 | 1 | 124 | 3 | 9 | 3 | 9 | 6.0 | 744 |
| E4 | Affordable new sensors, system technologies, and procedures to improve the prediction and measurement of wake turbulence | 9 | 9 | 3 | 1 | 1 | 1 | 104 | 3 | 9 | 3 | 9 | 6.0 | 624 |
| E5 | Interfaces that ensure effective information sharing and coordination among ground-based and airborne human and machine agents | 3 | 9 | 9 | 1 | 9 | 3 | 102 | 3 | 9 | 3 | 9 | 6.0 | 612 |
| E6 | Vulnerability analysis as an integral element in the architecture design and simulations of the air transportation system | 3 | 9 | 9 | 1 | 9 | 1 | 100 | 3 | 9 | 3 | 9 | 6.0 | 600 |
| E7 | Adaptive ATM techniques to minimize the impact of weather by taking better advantage of improved probabilistic forecasts | 9 | 3 | 9 | 3 | 1 | 1 | 98 | 3 | 9 | 3 | 9 | 6.0 | 588 |
| E8a | Transparent and collaborative decision support systems | 3 | 9 | 9 | 1 | 3 | 3 | 96 | 3 | 9 | 3 | 9 | 6.0 | 576 |
| E8b | Using operational and maintenance data to assess leading indicators of safety | 3 | 9 | 9 | 1 | 3 | 3 | 96 | 3 | 9 | 3 | 9 | 6.0 | 576 |
| E8c | Interfaces and procedures that support human operators in effective task and attention management | 3 | 9 | 9 | 1 | 3 | 3 | 96 | 3 | 9 | 3 | 9 | 6.0 | 576 |
| E11 | Automated systems and dynamic strategies to facilitate allocation of airspace and airport resources | 9 | 3 | 9 | 3 | 3 | 1 | 100 | 3 | 9 | 1 | 9 | 5.5 | 550 |
| E12 | Autonomous flight monitoring of manned and unmanned aircraft | 3 | 9 | 3 | 1 | 9 | 1 | 82 | 3 | 9 | 3 | 9 | 6.0 | 492 |
| E13 | Feasibility of deploying an affordable broad-area, precision-navigation capability compatible with international standards | 9 | 9 | 3 | 1 | 3 | 1 | 106 | 3 | 3 | 3 | 9 | 4.5 | 477 |
| E14 | Advanced spacecraft weather imagery and aircraft data for more accurate forecasts | 3 | 3 | 9 | 3 | 1 | 1 | 68 | 3 | 9 | 3 | 9 | 6.0 | 408 |
| E15 | Technologies to enable refuse-to-crash and emergency autoland systems | 1 | 9 | 1 | 1 | 3 | 1 | 60 | 3 | 9 | 3 | 9 | 6.0 | 360 |
| E16 | Appropriate metrics to facilitate analysis and design of the current and future air transportation system and operating concepts | 3 | 3 | 9 | 3 | 3 | 1 | 70 | 3 | 9 | 3 | 3 | 4.5 | 315 |
| E17 | Change management techniques applicable to the U.S. air transportation system | 9 | 9 | 9 | 1 | 3 | 1 | 124 | 1 | 3 | 3 | 3 | 2.5 | 310 |
| E18 | Certifiable information-sharing protocols that enable exchange of contextual information and coordination of intent and activity among automated systems | 3 | 1 | 9 | 1 | 9 | 1 | 60 | 3 | 9 | 3 | 3 | 4.5 | 270 |
| E19 | Provably correct protocols for fault-tolerant aviation communications systems | 3 | 9 | 3 | 1 | 3 | 1 | 76 | 3 | 3 | 1 | 1 | 2.0 | 152 |
| E20 | Comprehensive models and standards for designing and certifying aviation networking and communications systems | 3 | 9 | 3 | 1 | 1 | 1 | 74 | 3 | 3 | 1 | 1 | 2.0 | 148 |