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# Advancing Aeronautics

## A Decision Framework for Selecting Research Agendas

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## Summary

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Publicly funded research has long played a role in the development of aeronautics, ranging from foundational research on airfoils to development of the air-traffic control system. Yet more than a century after the research and development of successful controlled, sustained, heavier-than-air flight vehicles, there are questions over the future of aeronautics research. The field of aeronautics is relatively mature, technological developments within it have become more evolutionary, and funding decisions are sometimes motivated by the continued pursuit of these evolutionary research tracks rather than by larger factors. These developments raise questions over whether public funding of aeronautics research continues to be appropriate or necessary and at what levels. Tightened federal budgets and increasing calls to address other public demands make these questions sharper still.

To help it address the questions of appropriate directions for publicly funded aeronautics research, the National Aeronautics and Space Administration's (NASA's) Aeronautics Research Mission Directorate (ARMD) asked the RAND Corporation to assess the elements required to develop a strategic view of aeronautics research opportunities; identify candidate aeronautic grand challenges, paradigms, and concepts; outline a framework for evaluating them; and exercise the framework as an example of how to use it. Accordingly, this research seeks to address these questions:

- What aeronautics research should be supported by the U.S. government?
- What compelling and desirable benefits drive government-supported research?
- How should the government—especially NASA—make decisions about which research to support?

Advancing aeronautics involves broad policy and decisionmaking challenges. Decisions involve tradeoffs among competing perspectives, uncertainties, and informed judgment. We examine these challenges and develop a unifying decision-making approach that balances perspectives, simplifies decisionmaking processes, and enables strategic thinking and explanation of the resulting decisions. Our research also provides some aeronautics research options and opportunities for the United States

along with underlying data and analysis to show how decisionmakers could use this approach to create and refine research-investment portfolios.

## **What Aeronautics Research Should Be Supported by the U.S. Government?**

Publicly supported research should focus on areas of public good that lack incentives for private-sector investors. In economic terms, it should focus on areas where the net present value (NPV) or benefit-cost ratio (BCR) is high and positive, yet where the NPV would be negative for private investors. Government research should provide a public good, not subsidize private-sector activity.

Policymakers can use available data to estimate the monetized benefits and costs for possible research projects. Such estimates should consider the demands for the benefits of research and the technical and other challenges to conducting it. They should consider not only the costs and benefits of a given research project but also of anticipated subsequent projects. Figure S.1 provides an overview of how to consider whether a research project should receive public or private funding, from identifying uses of the project to estimating the NPV of the research.

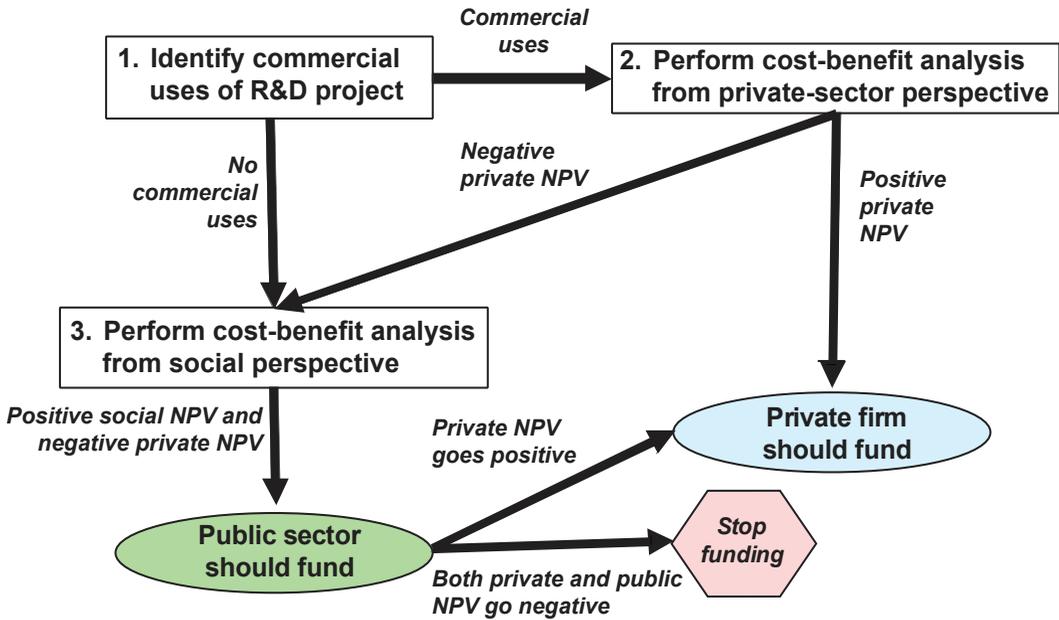
Estimates of the costs and benefits of research might be only rough approximations. Nevertheless, they can convey a sense of the magnitude of the possible benefits from research as well as of the full range of costs over time that may be required to reap those benefits. We emphasize not precision but gathering and conveying a sense of the magnitude of research costs and benefits, with benefits and costs distributed over time discounted to a common unit of measurement.

## **What Compelling and Desirable Benefits Drive Government-Supported Research?**

Appropriate topics for publicly supported research may number in the hundreds and cut across multiple broad national goals such as safety, efficiency, capacity, flexibility, comfort, competitiveness, reducing environmental effects and travel time, and supporting space exploration and national defense. Integrating such multiple dimensions is key to research decisionmaking.

Figure S.2 illustrates key dimensions that can inform identification and prioritization of aeronautics research options. These are national policies and plans, grand challenges or “visions” for aeronautics, technology, and social benefits or “drivers,” which can act independently or reinforce each other. For example, technology can enable new visions and application concepts that, in turn, generate social demands for such applications. Policies and plans can set new directions as goals and visions or

**Figure S.1**  
**Langford-GRA Model of Public Sector Research and Development Prioritization**



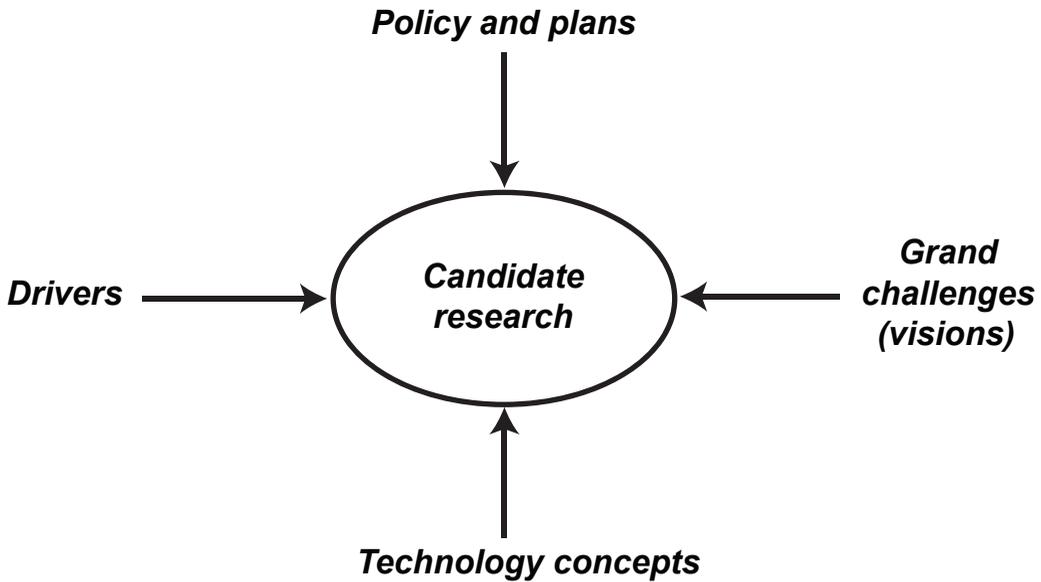
SOURCE: Vonortas and Hertzfeld (1998).  
 RAND MG997-2.2

can reinforce the importance of competing social demands resulting from technology-enabled application concepts. Many proposals have considered only one or two of these dimensions, resulting in less-than-compelling arguments for the proposals specifically and aeronautics research generally. In particular, analysis and discussion of social and economic drivers for aeronautics research has been lacking.

### Policy and Plans

U.S. policy for aeronautics research is evolving and does not dictate specific directions. It limits aeronautics research to areas that do not support a single company or to areas that industry cannot fund. The policy frames the research portfolio, reaffirming, for example, the broad role NASA should play, rather than specifying it. Periodic national research and development plans are more detailed than the policy but do not direct activities for specific agencies and do not preclude other research activities. Government agencies and departments still conduct their own research planning according to their specific missions in combination with the national policy and plans. In sum, the policy and plans serve a useful coordinating and communication function but, by themselves, do not direct research or dictate research investment decisions and tradeoffs.

**Figure S.2**  
**Dimensions That May Inform Aeronautics Research Options**



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### **Social and Economic Drivers for Research**

Existing data indicate several social and economic challenges that aeronautics research can address—as well as areas where aeronautics research needs may need to be traded off against others. These include

- airspace throughput demands that are forecast to increase 50 percent by 2025, overwhelming current capacity
- flying remotely piloted vehicles in U.S. airspace for military and civil purposes
- airline delays, primarily from weather and airport terminal congestion, costing U.S. society about \$40 billion annually
- commercial air carrier fatalities resulting in an annual cost from loss of life of \$90 million in commercial aviation—and of \$3 billion in general aviation (or all aviation excepting military and scheduled commercial)
- life-cycle safety of new composite materials and structures
- social cost of carbon dioxide emissions totaling \$3 billion annually—a substantial sum but a level only about one-fifth that for automobiles, which policymakers might prefer to address as an alternative to aeronautics research<sup>1</sup>

<sup>1</sup> When considering investments in aeronautics research, comparisons with similar social demands in other domains help provide perspective on the relative importance of that research. Thus, examining the relative magnitude of a problem such as emissions in aeronautics and other domains (such as automobiles) can help decision-

- nitrogen oxide emissions, which, while also substantial, are, on a per-passenger mile level, only one-tenth that of automobiles—another topic that policymakers may prefer to address.

In short, although there are several areas of aeronautics challenges worthy of public investment, some, such as emissions, may not be as pressing in aeronautics as they are in other fields, such as automobile travel, and others, such as fatalities, may be more pressing in some areas of aeronautics than others.

### **Grand Challenges**

To help identify appropriate directions for future research and possible projects to support them, we suggest grand challenges to unify different research goals and inspire research. Table S.1 illustrates several possible grand challenges by principal policy areas.

Grand challenges can help identify multiple research possibilities addressing a broad, common goal. Consider, for example, research to reduce travel time. Travelers are willing to spend only about \$20 to \$40 per hour to recoup time otherwise lost to travel. It also appears that non-aeronautics-related delays (e.g., traffic delays in driving to airports, security check-in delays at airports) are much larger concerns than trying to increase travel speed to supersonic levels. A grand challenge related to supersonic travel, therefore, would do well to reflect practical realities by targeting prices comparable to current transonic jet flights while mitigating noise and emission concerns.

Grand challenges should reflect needs, costs, and technical reality. The magnitude of a need, its value, competing social and economic drivers, technical realities, and those benefiting from resulting research should all be considered in considering these visions.

### **Technology**

Policies and plans, grand challenges or visions, and social and economic drivers of research must be tempered by technical realities. Decisionmakers should align research ideas and opportunities with available or feasible technologies. This can ensure practical results, sufficient budgets, complementary advances, and justifiable programs. Otherwise, research may be conducted for its own sake or toward applications with diminishing returns.

**Table S.1**  
**Illustrative Aeronautics Grand Challenges and Themes**

Policy Principal Areas	Possible Grand Challenge
Safety	Maintain passenger safety levels as the industry moves from aluminum to composite airplanes
	Make general aviation as safe as commercial passenger air travel
Environment	Planes as fuel efficient as trains
	“Silent” airplane
	Zero greenhouse-gas emission plane (hydrogen plane?)
Airspace	Triple passenger air transport system throughput
	Unmanned vehicles in U.S. civil airspace
Reduced travel time	Green, quiet, supersonic flight at transonic prices
Increased travel comfort	<i>(none—problem not dominated by technology)</i>
Convenience	Safe personal air vehicles
Space access	Practical air-breathing space-access vehicles
National security	Month-long (or even year-long) loitering surveillance aircraft
	Automated unmanned aircraft
	Hypersonic global-strike vehicle
	Unmanned vehicles in U.S. civil airspace
	Cost-effective military vertical envelopment transport vehicles

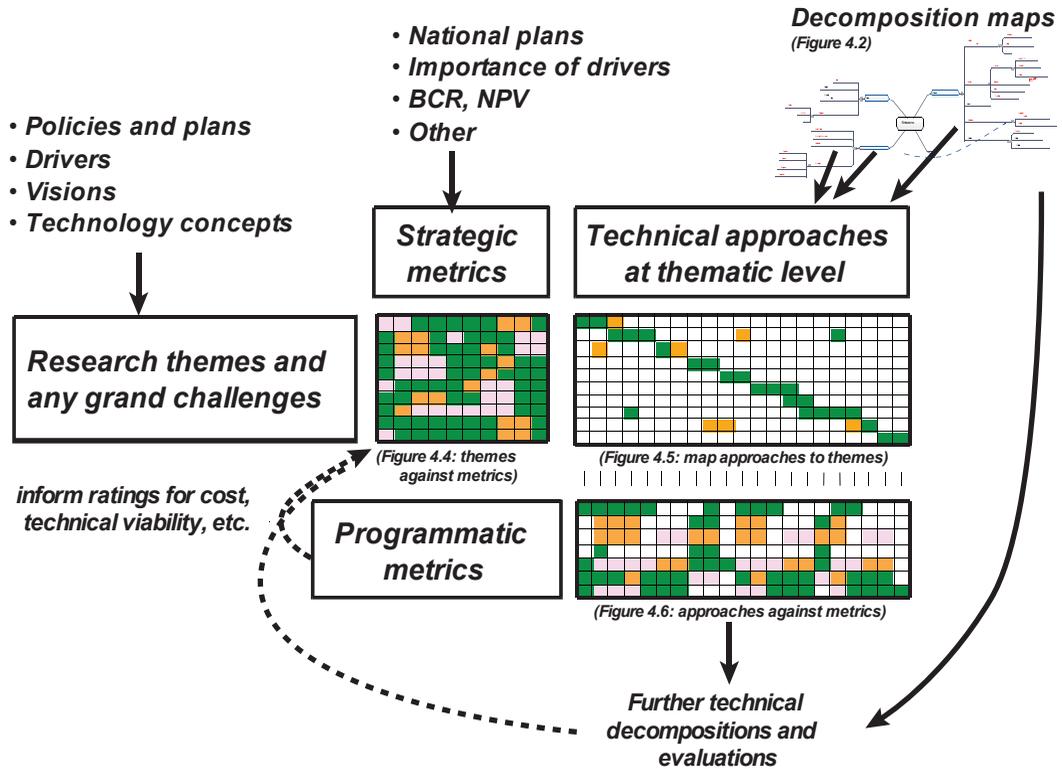
NOTES: Vertical envelopment is a “tactical maneuver in which troops, either air-dropped or air-landed, attack the rear and flanks of a force, in effect cutting off or encircling the force” (DoD, 2010). See, for example, Grossman et al. (2003) for a discussion of this concept and its technical and logistical challenges.

## How Should the Government—Especially NASA—Make Decisions About Which Research to Support?

Our decision framework, illustrated in Figure S.3, integrates multiple perspectives in a process that uses groups of objective metrics to set priorities among competing research options. To illustrate how to use the framework, we provide in the monograph specific examples of our analysis and data collection along each of the following steps in exercising the framework.

It begins in the upper left corner of the figure, with a grouping of candidate research ideas we extract or develop from policy and plans, social and economic drivers, technology, and grand challenges. Such grouping will require many steps. The resulting broader research themes will facilitate debate and consideration of research

**Figure S.3**  
**Hierarchical Decision Framework Components for Prioritizing Research Themes, Grand Challenges, and Technical Approaches**



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directions. The scope and number of research themes is key to the effectiveness of the decision framework. Too narrow and many, and the process becomes unwieldy. Too broad and few, and it becomes difficult to identify lower-priority areas. The research themes also need to be understandable to non-technical policymakers and the public to facilitate prioritization discussions and transparency.

These research themes should then be evaluated against strategic metrics (top center of Figure S.3; see also Figure 4.4). Using metrics allows decisionmakers to rate options objectively against varying interests and to see the tradeoffs between them. In the monograph, we review priorities in national plans, measures of the value of drivers (e.g., the economic cost of pollution), economic metrics such as BCR and NPV, and other measures to generate a list of potential strategic metrics for evaluating the research themes. A matrix showing the ratings of options against strategic metrics allows the decisionmaker to easily see how each project compares with metrics reflecting their priorities. Metrics should not only reflect policies and plans, social and economic drivers, visions for aeronautics research, and technology but also cost, benefit, and value metrics such as NPV and BCR. For illustration purposes, we show in the

monograph notional values in the matrices to demonstrate how the framework would work. More specific values should be informed by an exercise that obtains evaluations and judgments by domain experts in the relevant research fields.

The process also evaluates technical approaches to addressing research themes and grand challenges (upper-right corner of Figure S.3; see also Figure 4.5). Many of these may emanate from our decomposition of grand challenges into technical approaches (upper-right corner of Figure S.3; see also Figure 4.2), employing our decompositional maps that show the logical approaches that could be taken to address different research themes at the thematic and programmatic levels. Such decompositions also help identify technical approaches that can address multiple grand challenges.

The framework also includes a step for assessing technical approaches against program metrics (bottom right of Figure S.3; see also Figure 4.6). This prioritization provides more detail on the viability of pursuing a research theme and therefore informs the evaluation of research themes and grand challenges against strategic metrics. Again, the monograph includes notional values for such matrices to illustrate how the framework would work, but domain experts should be consulted in an exercise to obtain evaluations and judgments.

The goal of this process is to explain research decisions to oversight bodies, Congress, and the public. Showing all options, and the processes used to choose among them, helps others better understand the decisions made while also conveying information, such as the sufficiency of budgets relative to needs, and enables dialogue on priorities. Showing matrices as well, although more complicated than merely listing research to be funded, allows others to understand whether there is valuable research that cannot be funded under current budgets or whether research is approaching diminishing returns.

## Conclusions

Aeronautics is a relatively mature field struggling to find revolutionary yet practical designs and concepts. Still, social and economic “drivers” for aeronautics research remain. Our framework can inform the creation of new programs and the refinement of existing ones.

In our initial exercise of reviewing and analyzing relevant inputs and pilot-testing the framework, we found that such a decision framework can lead to large, compelling rationales and technical ideas for advancing aeronautics. Our exercises found some interesting candidates as well as some objectives and concepts that are less compelling when compared with practical realities, alternative problems with easier solutions, and the benefits of the research. More analysis and participation in the framework process by the relevant stakeholders is needed. However, our initial work shows that the application of this model in government decisionmaking is likely to lead to further refinement in which new questions and preferences will emerge.

NASA's ARMD should consider adopting and adapting these approaches both in planning and explaining its research program. These approaches can give decisionmakers and the public a better understanding of the challenges facing aeronautics and how well the government's budget can address them.

Policymakers—rather than merely choosing among a list of technical ideas and opportunities proposed by researchers—should explicitly analyze social and economic drivers of research; the full extent of research, development, and implementation costs; and the resulting benefits—all tempered by technical realities. The integration of these multiple perspectives will result in more persuasive research plans. Without it, aeronautics research may become exploratory endeavors with unclear ties to results and drivers—or, worse yet, a collection of insufficiently funded activities that is unlikely to benefit society.