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A Value-Based Justification Process for Aerospace RDT&E Capability Investments

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Abstract

Section 1071 of the *National Defense Authorization Act for Fiscal Year 2013* required the Director of the White House Office of Science and Technology Policy (OSTP), working with the Secretary of Defense and the Administrator of the National Aeronautics and Space Administration (NASA), to conduct a study on the ability of the national test and evaluation (T&E) infrastructure to effectively and efficiently mature hypersonic technologies for defense-related systems development in the short and long term. It further required the Secretary of Defense to submit a report to the appropriate congressional committees containing the results of this study, together with a plan for requirements and proposed investments to meet Department of Defense (DoD) needs through 2030. The Institute for Defense Analyses (IDA) supported both the OSTP and DoD efforts, and was subsequently tasked to quantify the projected savings that could accrue to each of three conceptual conventional hypersonic system development programs if the proposed T&E capability enhancements presented in the DoD plan submitted to Congress were available at the beginning of Milestone (MS) A. As part of its analysis, IDA utilized an IDA-developed approach for valuing the closure of critical T&E capability gaps based on the potential programmatic cost and schedule savings that could reasonably be expected to accrue from the start of MS A through the end of MS C by funding the five-year, $350 million T&E infrastructure investment proposed in the DoD plan. This expansion of the cost-benefit "control volume" to include projected system development savings proved successful in justifying and securing full funding for the proposed DoD plan. This paper summarizes the IDA approach and its application to making the business case for closing capability gaps in other aerospace research, development, test, and evaluation areas.

I. Introduction

A. Problem Statement

State-of-the-art ground and flight test facilities, computational techniques, testing tools and technologies, and a skilled workforce are the "tools of the trade" for the aerospace research, development, test, and evaluation (RDT&E) community—much like hammers, nails, screwdrivers, and saws are for the building and construction industry. But despite the unarguable fact that the development of new aerospace products requires a robust and continuing commitment to foundational research and development (R&D)—which, in turn, requires having available the computational and experimental capabilities essential for managing risk during both initial system development and subsequent upgrades—justifying investments to enhance the test and evaluation (T&E) capabilities needed to

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effectively and efficiently field future military and commercial systems has historically proven to be a daunting task for facility owners and operators. If the requirement is so clear, why is the justification so daunting?

One reason is that the management of United States (U.S.) test capabilities—whether owned by government, industry, or academia—is largely stove-piped and subject to organizational budget pressures and constraints. This is further compounded by the fact that test facilities and test capabilities have historically been treated as cost centers, with their current and future existence determined by a return-on-investment (ROI) largely predicated on capacity utilization metrics (such as occupancy rate or billable test hours per year) or anticipated demand (projected usage rates associated with existing or new systems). That the test community has struggled for decades to garner support for increased RDT&E infrastructure investments is proof these metrics do not generate a compelling business case.

In the annual head-to-head competition for funds between R&D programs and T&E infrastructure enhancements, R&D programs almost always win the battle. The large number of T&E facilities that have either been mothballed or closed over the past three decades because their business cases failed provides testimony to this reality. If the justification could be successfully made for T&E infrastructure investments based on utilization metrics alone, the aerospace RDT&E infrastructure would be owned and operated by industry as a profit center. Absent a new and more compelling methodology for justifying RDT&E infrastructure investments, the United States is at risk of not having the required computational and experimentation capabilities it needs for future aerospace product development.

B. Historical Perspective

Because test facilities are often unique, as well as expensive to construct and sustain, the U.S. government has traditionally owned and operated the nation’s RDT&E infrastructure (wind tunnels, test cells, laboratories, ranges, etc.)—with a majority of the larger Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) facilities having been built during the period from the 1940s through the 1960s. The years from post-World War II through the late 1970s were the boom years for experimental testing, with the focus being largely on applied research, product development, and system acquisition. As the number of system development programs continued to decline during the subsequent three decades, the focus on RDT&E infrastructure shifted to reducing expenditures—a dynamic that was largely fueled by near-term budgetary constraints and funding instabilities, as well as by the belief that emerging computational fluid dynamics (CFD) capabilities would obviate the need for “brick and mortar” test facilities in the not-too-distant future. As a result, the government focused its scarce resources on preserving an outdated test infrastructure rather than investing in an updated infrastructure capable of supporting future U.S. aerospace needs.

The test community tried to advise senior leadership that rapidly increasing system complexity, declining workforce “hands-on experience” (resulting from both attrition and the reduced number of new system developments), and the unrealized promise that CFD would obviate the need for test facilities were creating a “perfect storm” for the national RDT&E infrastructure, but that advice went largely unheeded, particularly in the high-speed flight regime. Within the last decade, however, the T&E community began sounding an alarm more loudly to senior decision-makers in DoD and NASA that infrastructure investment shortfalls of the prior three decades were contributing to unintended system development cost and schedule consequences, as measured by the increased number of undetected defects being discovered during flight testing, Nunn-McCurdy breaches,[4] and program schedule slippages. An awareness subsequently began to emerge that facilities and test capabilities being reduced to minimum (or below-minimum) levels, elimination of redundancies (test capacity), and the willful elimination of often-infrequently-used (but unique) government test capabilities—including their associated T&E workforces—were pre-allowing these unintended consequences to occur. Thus, the realization began to grow within senior leadership that something needed to be done, and soon, to improve risk management across the developmental T&E (DT&E) process used to support aerospace product development to reverse these detrimental trends in system development cost and schedule. This was especially true in the hypersonic flight regime, where facility demand has historically been cyclic and unpredictable.

But the daunting challenge facing the T&E community regarding the successful justification of increased investments mentioned earlier remained—how does one win the head-to-head competition for funding between R&D programs and T&E infrastructure enhancements? In 2013, Congress inserted itself into the process.

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[4] A *significant* breach is when the Program Acquisition Unit Cost (the total cost of development, procurement, and construction divided by the number of units procured) or the Procurement Unit Cost (the total procurement cost divided by the number of units to be procured) increases 15 percent or more over the current baseline estimate or 30 percent or more over the original baseline estimate. A *critical* breach occurs when the cost increases 25 percent or more over the current baseline estimate or 50 percent or more over the original baseline estimate.

C. A New Approach for Justifying Infrastructure Investments – Expand the Cost Savings “Control Volume”

The Fiscal Year 2013 *National Defense Authorization Act (*hereafter referred to as *The Act)* [1] required the Director of the White House Office of Science and Technology Policy (OSTP), working with the Secretary of Defense (SECDEF) and the NASA Administrator, to conduct a study on the ability of the national T&E infrastructure to effectively and efficiently mature hypersonic technologies for defense systems development in the short and long term. For purposes of this study, the national hypersonic T&E infrastructure was defined as the ground test facilities and open-air ranges owned and operated by DoD and NASA, as well as those relevant ground test facilities owned and operated by the private sector (industry and academia).[5] *The Act* further required the SECDEF to submit a report to the appropriate congressional committees containing the results of the OSTP study, an assessment of current facility condition and adequacy, and an assessment of non-DoD test capabilities that could be leveraged to support defense-related system development—along with a plan that provides the test capabilities and investments needed to satisfy DoD hypersonic T&E requirements through 2030. Based on the OSTP-sponsored study findings, conclusions, and recommendations, DoD determined that an additional $350 million investment would be needed to close the identified test capability gaps. [2]

In addition to supporting both the OSTP study and DoD report efforts directed by Congress, in 2015, the Institute for Defense Analyses (IDA) was tasked by the DoD Test Resource Management Center (TRMC) to quantify the projected savings that could accrue to each of three conceptual hypersonic system development programs if the T&E capability enhancements proposed in the DoD plan were available at the beginning of Milestone (MS) A. As part of its analysis, IDA utilized an IDA-developed approach for valuing the closure of the critical T&E capability gaps, not based on traditional capacity utilization metrics, but on the potential programmatic cost savings that could reasonably be expected from the start of MS A through the end of MS C if the five-year, $350 million T&E infrastructure investment proposed in the DoD plan were funded. The rationale behind the use of an investment justification process that treats test capabilities as part of the larger system development programs they support is that the cost of infrastructure sustainment, improvement, and modernization is far less than the cost of the negative consequences that result from going forward with higher development risk created by not having the requisite test tools and capabilities to better understand the underlying physics associated with the concept(s) under development.

This expansion of the cost-benefit “control volume” to include projected system development savings, as described in Ref. [3], proved successful in justifying and securing full funding for the proposed DoD plan. This paper summarizes the approach used and notes its potential application to closing identified capability gaps in other military and commercial aerospace RDT&E arenas across the subsonic, transonic, supersonic, and hypersonic flight regimes.

II. A Value-Based Justification Process for Increased RDT&E Capability Investments

A. Justification Process Overview

The IDA value-based justification process involves expanding the analysis “control volume” for valuing capability investments (as depicted in Fig. 1) and then developing a cost model for the MS A through MS C phases of a system development program based on actual cost, schedule, and flight test frequency data compiled from previously successful major defense acquisition programs (MDAPs) of similar operational capability and/or system complexity. This model is then tailored to each conceptual system-specific model to assess the resulting cost and schedule growth for future conceptual development programs *if the proposed T&E capability enhancements are not made.*

Before describing the justification process in more detail, potential users are advised that this is an extremely information-, time-, and analysis-intensive effort requiring substantial involvement and preparatory work by a variety of study team members with experience in both strategic planning and large-scale program development; test capability owners; investment stakeholders; and subject matter experts (SMEs) having specific detailed knowledge and expertise in technology development and demonstration, DT&E, and the allocation of costs across the various elements of system development. Thus, because of the magnitude of the effort required, application of this process has its greatest value and benefit when used to justify larger-scale ($100+ million) investment augmentations having substantial national military and/or economic impacts.

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[5] In this study, the T&E infrastructure was defined as including not only the ground and flight test facilities themselves, but also the testing tools, test technologies, computational capabilities, and supporting T&E workforce.

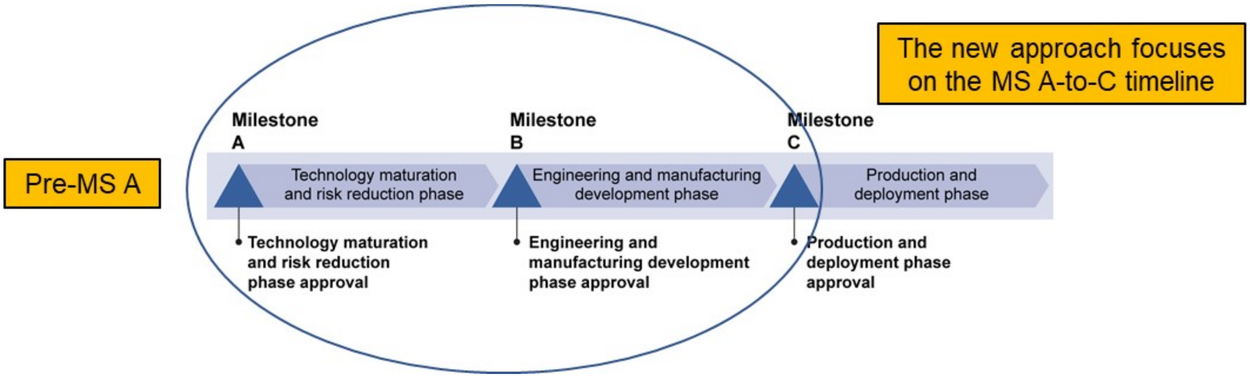


Fig. 1 The Expanded Cost-Benefit Analysis Control Volume.

It is also worth noting that this process has the greatest potential for success when the investment stakeholder funding the proposed enhancements owns both the RDT&E infrastructure being enhanced and the system development programs ultimately utilizing it—since the requisite expenditures and accrued savings typically fall into different organizational budget accounts (as in DoD). However, this process might also be used effectively for internal investment justifications by industry RDT&E infrastructure owners who develop military and/or commercial systems as well as for investment justifications in research facilities owned by academia, provided an analysis “control volume” can be constructed that affords potentially significant financial benefit to the academic institution (such as increased revenues derived from expanded student enrollment or successful competition for larger research grants).

B. Preparing the Analysis Pathway

Since the potential accrued savings are derived from reduced system development time and cost, the aerospace RDT&E community needs to first define what it takes to develop the conceptual systems affected by the capability enhancements being proposed. In many ways, this is a more difficult and time-consuming effort than performing the business case analysis (BCA) itself. Preparing the pathway for the BCA involves three critical steps. The first step is getting the attention of the decision-makers by making a compelling argument as to why the proposed capability being advanced is important to our nation, because if the decision-makers do not agree that there is a compelling argument, the effort required to develop the value-based justification will be a waste of time and energy. The second step is to define the proposed vision, goals, and key capability needs for the capabilities being advanced. The third step is to identify the capability gaps and evaluate the impacts of not closing those gaps on the system development process. The activities associated with each of these three critical steps are discussed in greater detail below.

1.   Step 1 – Get the Attention of the Decision-Makers

The first step in preparing the analysis pathway is to clearly articulate why the capabilities being proposed for enhancement are critically important to the nation and/or the aerospace RDT&E community. Benefits (or negative consequences) are typically characterized in terms of their military and/or economic impacts. Military impacts are typically framed in terms of how the proposed activity can (1) quantitatively improve U.S. offensive or defensive operational capabilities in a timely manner; (2) qualitatively alter the dynamics of regional conflicts; and/or (3) directly respond to national security policies, strategies, and/or guidance. Economic impacts are typically framed in terms of how the capabilities being advanced can (1) quantitatively improve commercial aircraft capabilities—possibly opening new routes and/or global markets; (2) reduce product development time/time-to-market; (3) increase global market share in specific arenas (e.g., single-aisle, narrow-body aircraft); (4) reduce individual vehicle operational cost or overall fleet life cycle cost; and/or (5) (from a national perspective) improve the balance of trade for the U.S. aerospace sector.

It is important to emphasize that, although articulating the military and/or economic impacts is a necessary first step in making a compelling argument to the decision-makers, experience has shown it is seldom sufficient (on its own merits) to justify increased investment. Nonetheless, explaining why the capabilities being advanced are critical, and providing the data to support that position, are essential to getting senior leadership’s attention, because when it comes to winning the battle for funding, *you don’t have to outrun the bear, you only have to outrun the person next to you* (i.e., the other competing efforts being considered by the decision-makers for additional investment)!

2. *Step 2 – Define the Proposed Vision, Goals, and Key Capability Needs*

Defining the desired end-state (and what is needed to achieve it) is the next step in the process of preparing the analysis pathway. Many times, this is more difficult and time-consuming than initially anticipated because it involves more than just identifying a vision, the target goals, and the capabilities needed to get there. It also involves gaining consensus on the desired end-state among the various participants and stakeholders—often referred to as *socializing* the proposed vision, goals, and key capabilities.

The visioning process may include developing sub-visions for the primary constituent parts of the overall vision, depending on the nature and extent of the capabilities being advanced. For example, if the vision is at the enterprise level in a specific flight regime, there could be sub-visions associated with ground testing, flight testing, test execution, and workforce development in that flight regime, which collectively contribute in substantive ways to the achievement of the overall vision. However, if the vision is associated with a new capability that cross-cuts multiple flight regimes (such as the integration of computational and experimentation capabilities), there could be an overall capability vision as well as sub-visions for computation, experimentation, and integration in each of the individual flight regimes. Socializing the vision is vital because *"if you don't know where you are going, any road will get you there."* [4]

In developing the target goals, two questions should be answered in quantitative terms: (1) What are you trying to accomplish? and (2) By when? It is safe to say that most organizations involved in aerospace RDT&E—whether within government, industry, or academia—have planning documents that contain a set of quantitative goals they are pursuing and a projected time for their achievement. It is also safe to say that many organizations fail to achieve their stated RDT&E goals on schedule (if at all) for one of three reasons: (1) their target goals are unreasonable or unachievable, (2) their plan is inadequately resourced to meet their projected timelines (thus making them late-to-need), or (3) changes in organizational priorities or focus render the plan no longer relevant to future organizational strategies or directions. In the value-based justification process, knowing the "by when" and *delivering the promised outcomes on schedule* is vitally important, because capability enhancements delivered late-to-need to a system development program (i.e., after the start of MS A) cannot use that program in the investment justification. Therefore, being aware of conceptual systems in the development pipeline that constitute the capability drivers, and when they will potentially reach MS A, is essential to both developing the proposed plan and performing the investment justification.

Once the vision, target goals, and timeline have been defined, the next step is to determine the key capabilities needed for successful development of the conceptual systems being used for the value-based justification. This involves conducting analyses to define (1) the key developmental test capability areas, (2) the requisite test objectives that need to be successfully demonstrated in each capability area, and (3) those requisite objectives affected by the proposed enhancements. Identifying the requisite test objectives includes describing the parameters that need to be measured, the test approach and facilities that would be employed, the test conditions and test variables, the test articles required (including their scale), any specialized equipment required (such as specialized instrumentation, measurement devices, or test fixtures) or specific testing technologies needed (such as CFD and other modeling capabilities), the required flight conditions, and the amount of testing needed (the number of test runs/test hours/total time at conditions), as well as any special workforce skills needed to support the broad spectrum of activities performed during conceptual system development. Conducting these analyses typically involves significant and active participation by SMEs with specific knowledge and experience in system development and DT&E. The product of these analyses is a set of tables (like the one depicted in Table 1) that are populated with information and data identifying the test capability areas and describing the test objectives that should be satisfied for each of the conceptual systems. These tables are used to help identify the current capability area gaps that need to be closed.

Table 1 Key Capability Needs.

T/O #	Test Capability Area	Req'd Perf Parameter	Approach/ Facilities	Test Conditions	Test Variables	Test Articles	Special Equip	# Flt Conditions	Test Hrs/Runs	Tot Time
1.0	**Aerodynamics**									
1.1	*Stability & Control Effects*									
1.2	*Boundary Layer Transition*									
1.3	*Inlet Performance*									
2.0	**Aerothermodynamics**									
3.0	**Materials Characterization**									
4.0	**Propulsion**									
5.0	**Stage / Stores Separation**									
6.0	**Weather / Erosion**									
7.0	**Guidance / Nav / Control**									
8.0	**System Lethality**									
9.0	**Survivability / Vulnerability**									
10.0	**Flight Testing**									

3. *Step 3 – Identify the Capability Gaps – And the Impacts of Not Closing Them*

After the DT&E capability requirements for each of the conceptual system applications included in the justification analysis have been determined using the process described in Step 2 above, the next step is to determine if capability gaps exist by assessing the ability of the existing RDT&E infrastructure to satisfy the identified facility, test tools, testing technologies, and workforce capability needs in Table 1. Those capability needs that cannot be satisfied by the current RDT&E infrastructure constitute the capability gaps.

The process of assessing which capability gaps need to be closed begins by taking each identified gap and quantifying the first-order effects of not closing that gap on (1) technical risk, (2) system design and development during full-scale development (FSD) and DT&E, and (3) system operation and sustainment (O&S) in the field, as shown in Table 2. This analysis typically involves the same group of SMEs that supported the key capability needs analysis. Each SME is also asked to provide a high/medium/low assessment as to the importance of closing the identified capability gaps.

Table 2 Impact and Importance of Not Closing the Identified Capability Gaps.

Gap No.	Capability Gap	Technical Risk (1st Order Effect on Technology Development)	System Design/Development Impacts (1st Order Effect on FSD/DT&E)	O&S Impacts (1st Order Effect on O&S Capabilities)	Importance
C-1	Lack of … Inability to …	• Inconsistencies between… • Inability to predict… • No knowledge of …	• Reduced confidence in the ability to… • Greater operability margins would be required, thereby increasing weight and/or reducing performance • Resolution could require many tens of flight tests to establish the required confidence for initial fielding	• Reduced system range would… • Reduced system effectiveness would…	High
C-2	Lack of … Inability to …	• Inconsistencies between… • Inability to predict… • No knowledge of …	• Reduced confidence in the ability to… • Greater operability margins would be required, thereby increasing weight and/or reducing performance • Resolution could require many tens of flight tests to establish the required confidence for initial fielding	• Reduced system range would… • Reduced system effectiveness would…	Medium

Based on the assessments provided by the SMEs for each conceptual system application, numeric values ranging from 1 to 10 can be assigned to the gaps and a Pareto chart (depicted in Fig. 2) can then be constructed to determine which gaps, if closed, would have the greatest overall importance to each specific conceptual system application. This analysis is repeated for each of the conceptual systems and a collective set of capability gaps is then compiled for all the conceptual system applications included in the BCA, as shown in Table 3. (As highlighted in Table 3, a given capability gap may be relevant to multiple conceptual system applications, but how the gap would be closed may differ from application to application.) This collective set of capability gaps forms the basis for the proposed plan that is evaluated using the value-based justification process.

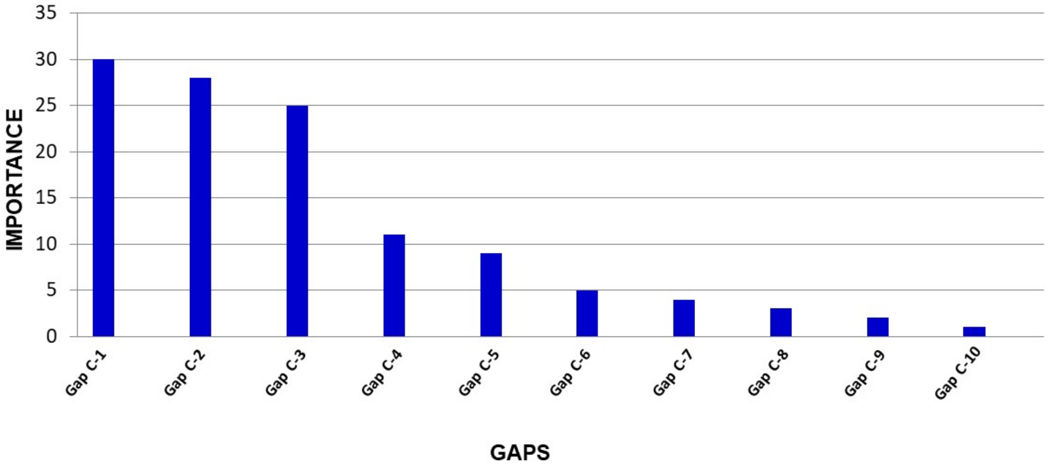


Fig. 2 Importance of Not Closing the Gaps for Conceptual System C.

Table 3 Collective Set of Capability Gaps (All Conceptual System Applications).

System/ Gap No.	**Capability Gap**	**System/ Gap No.**	**Capability Gap**	**System/ Gap No.**	**Capability Gap**
A-1	Lack of ….	B-1	Lack of ….	C-1	Lack of ….
A-2	Inability to …	B-2	Inability to …	C-2	Inability to …
…	…	…	…	…	…
A-i	Inefficient CFD tools	B-i	Inefficient CFD tools	C-i	Inefficient CFD tools
		B-j	Lack of ….	…	…
				C-k	Lack of ….

C. Developing a Plan for Closing the Identified Capability Gaps

Once all the data needed to prepare the pathway have been compiled and analyzed, the next steps in the process are to (1) develop a detailed plan that closes the defined capability gaps (including an estimate of its cost), and (2) socialize the plan with the broader community of capability owners and stakeholders.

1. Step 1 – Develop the Plan

The first task in developing the plan is to formulate a set of projects that must be executed to close the gaps identified in Table 3. Each project must be defined in sufficient detail (typically one to three pages each) to describe its goal(s), how it will be executed (i.e., the tasks and sub-tasks that must be conducted to successfully complete the project), its execution timeline, any interrelationship it has with other projects in the list (i.e., does it receive input from, or provide input to, any other projects), and its estimated cost, by fiscal year. From this, a project listing can be constructed of all the projects included in the overall execution plan, as shown in Table 4.

Table 4 Project Listing by Conceptual System Application.

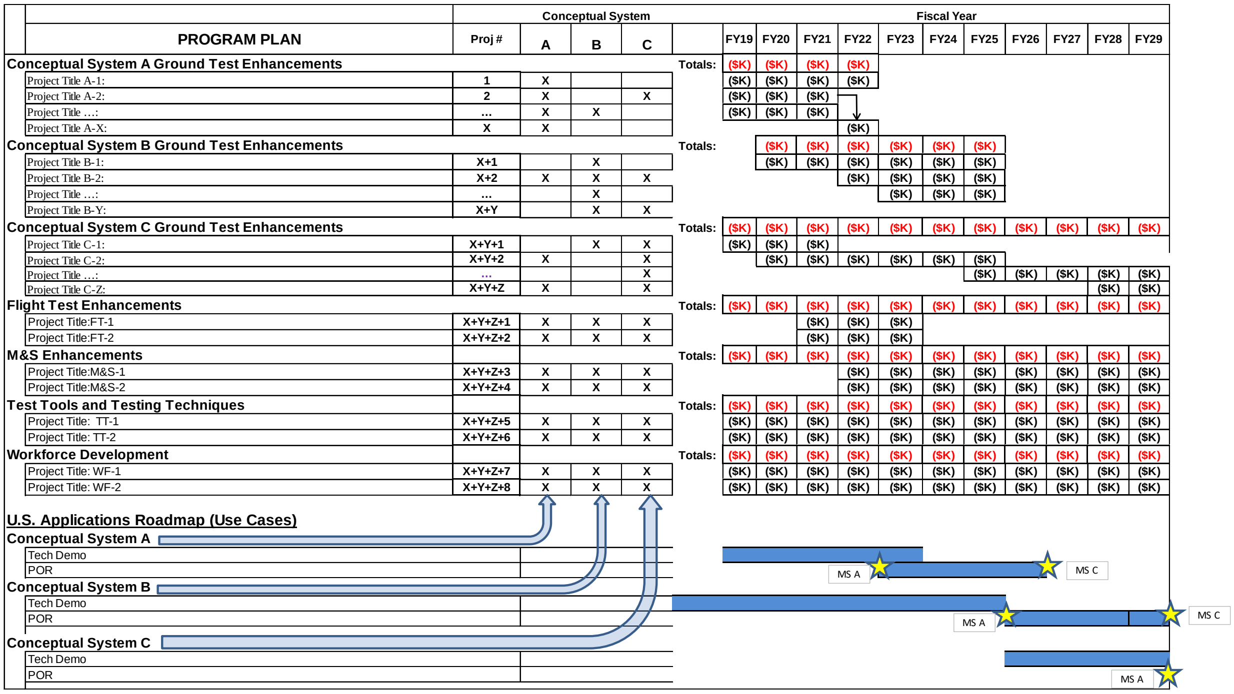
Project Listing	Project No.
Conceptual System A	
Project Title A-1:	1
Project Title A-2:	2
Project Title …:	…
Project Title A-X:	X
Conceptual System B	
Project Title B-1:	X+1
Project Title B-2:	X+2
Project Title …:	…
Project Title B-Y:	X+Y
Conceptual System C	
Project Title C-1:	X+Y+1
Project Title C-2:	X+Y+2
Project Title …:	…
Project Title C-Z:	X+Y+Z

Once the various projects have been identified and defined in sufficient detail, a cross-walk can then be performed between the projects and the gaps to evaluate and assess their interrelationships, as shown in Table 5. Multiple projects may support an individual gap, and multiple gaps may be supported by an individual project (as highlighted in yellow). Performing this cross-walk not only reveals the "robustness" of each project in terms of its relevance to multiple gaps (as demonstrated by Project 2 in Table 5), but it also reveals the criticality of individual projects to the resolution of a specific gap (as demonstrated by Project 7, which is the only project supporting Capability Gap A-2). Knowing these interrelationships can assist the Program Manager in assessing and managing risk during plan execution.

Table 5 Projects/Capability Gaps Cross-Walk.

Gap #	Capability Gap	Projects												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**…**	**…**	**…**	**…**	**…**	**X**
A-1	Lack of ….	X	X				X				X	X		X
A-2	Inability to …							X						
…	…	X			X		X							
…	…	X	X	X		X			X		X		X	
…	…		X	X					X	X			X	X
…	…		X					X				X		
A-i	Inefficient CFD tools		X		X	X				X			X	X

The end-product of the plan development effort is an executable roadmap (as depicted in Fig. 3) showing the projects that are being proposed for funding, their relevance to the conceptual systems used in the value-based justification, their time-phased connectivity to the MS A development "off-ramps" for the various conceptual systems, and the funding both currently programmed and required for each year of the program execution schedule. The difference between what is programmed and what is required is the funding augmentation that is being justified using the value-based process.



PROGRAM PLAN	Proj #	Conceptual System				Fiscal Year										
		A	B	C		FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29
Conceptual System A Ground Test Enhancements					Totals:	($K)	($K)	($K)	($K)							
Project Title A-1:	1	X				($K)	($K)	($K)	($K)							
Project Title A-2:	2	X		X		($K)	($K)	($K)								
Project Title …:	...	X	X			($K)	($K)	($K)								
Project Title A-X:	X	X							($K)							
Conceptual System B Ground Test Enhancements					Totals:		($K)	($K)	($K)	($K)	($K)	($K)				
Project Title B-1:	X+1		X				($K)	($K)	($K)	($K)	($K)	($K)				
Project Title B-2:	X+2	X	X	X					($K)	($K)	($K)	($K)				
Project Title …:	...		X							($K)	($K)	($K)				
Project Title B-Y:	X+Y		X	X												
Conceptual System C Ground Test Enhancements					Totals:	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title C-1:	X+Y+1		X	X		($K)	($K)	($K)								
Project Title C-2:	X+Y+2	X		X			($K)	($K)	($K)	($K)	($K)	($K)				
Project Title …:	...			X								($K)	($K)	($K)	($K)	($K)
Project Title C-Z:	X+Y+Z	X		X											($K)	($K)
Flight Test Enhancements					Totals:	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title:FT-1	X+Y+Z+1	X	X	X				($K)	($K)	($K)						
Project Title:FT-2	X+Y+Z+2	X	X	X				($K)	($K)	($K)						
M&S Enhancements					Totals:	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title:M&S-1	X+Y+Z+3	X	X	X					($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title:M&S-2	X+Y+Z+4	X	X	X					($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Test Tools and Testing Techniques					Totals:	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title: TT-1	X+Y+Z+5	X	X	X		($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title: TT-2	X+Y+Z+6	X	X	X		($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Workforce Development					Totals:	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title: WF-1	X+Y+Z+7	X	X	X		($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)
Project Title: WF-2	X+Y+Z+8	X	X	X		($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)	($K)

Fig. 3 Plan Roadmap.

2.   *Step 2 – Socialize the Plan*

The first thing to remember about the socialization process is that an individual *somewhere* in the senior leadership chain has the authority to budget the funding augmentation being proposed—the challenge is to identify that person. That's the good news. The bad news is that there are potentially dozens of mid-level managers along the path to that outcome who will present a litany of reasons why any effort expended to justify and seek a funding augmentation is destined to be fruitless—those are the people on whom the socialization effort focuses. They will say things like "budgets are tight this year" (News-Flash #1: budgets are tight *every* year), or "this is not on the list of top priorities for our organization" (News-Flash #2: RDT&E infrastructure investments seldom are), or "there is no Program of Record (POR) stating it requires the proposed enhanced capabilities" (News-Flash #3: if a POR already exists, significant infrastructure-related capability enhancements are already late-to-need). But hang in there and do not become discouraged. Nobody said this was going to be easy—that is just the bureaucracy at work.

The second thing to remember is that the socialization process is a marathon, not a sprint. If the capability enhancements being proposed are critically important to the nation and/or the aerospace RDT&E community, visionary leaders will recognize it and become supportive advocates. In the case of hypersonics, those advocates were Congress and the White House!

Since the initial legwork is already done (Preparing the Pathway, Steps 1 through 3), an advocacy briefing package should then be constructed and meetings scheduled with potential stakeholders and mid-level managers, starting at the bottom of the organization and working up the leadership chain. So this would be the time to begin targeting those individuals and getting on their calendars. The purpose of these meetings is to gather information that can be useful in refining the proposed investment augmentation justification (both technically and from a national importance perspective). To that end, the briefing package should clearly articulate the military and/or economic benefits and importance, the vision, the goal(s), the capability needs, and the plan for overcoming the identified gaps. During these meetings, capture the views and perspectives offered by the various participants, as these will undoubtedly reveal potential roadblocks to success (at least from their vantage points) that need to be addressed as progress is made up the management chain. Remember, the goal of socialization is to generate advocates, so listen attentively and adjust accordingly! As a point of reference, for the hypersonic effort, socializing the plan at the various levels took over eight months!

After these meeting have been completed, and (to the extent feasible) stakeholder and senior management issues and concerns have been addressed, it is now time to quantify the cost and schedule impacts associated with not closing the capability gaps that have been identified for each of the conceptual system development programs being used in the justification analysis. The reason all the up-front planning and socialization efforts are necessary is because (as stated earlier) the value-based justification process is extremely data-, time-, and analysis-intensive, so “getting all your ducks in line” before starting will help to minimize the probability of having to do it a second time.

D. Quantifying the Programmatic Impacts of Not Closing the Identified Capability Gaps

With the pathway prepared and the proposed plan developed and socialized, the process of quantifying the programmatic cost and schedule impacts caused by not closing the identified capability gaps can commence. This involves (1) establishing the set of baseline assumptions to be used; (2) identifying representative comparative programs that have actual system development cost and schedule data available that can be used; (3) gathering the requisite cost, schedule, and test frequency data from the comparative development programs chosen, and creating the requisite cost estimating relationships (CERs); (4) constructing a cost model; (5) determining the nature and extent of the impact caused by not having the capability enhancements; and (6) using the cost model to assess the programmatic cost and schedule impacts with and without the proposed capability enhancements. These six steps are discussed in greater detail below.

1. Step 1 – Establish the Baseline Analysis Assumptions

As with any study, establishing the baseline assumptions is a critical first step, as the assumptions strongly influence the outcomes. In conducting the hypersonic study, the following assumptions were made:

(1) The additional investment for the proposed capability enhancements (contained in the plan) is a given—the value-based justification process estimates the return on that investment;

(2) The cost of development programs increases with the complexity of the requirements;

(3) Experimentation is critical to the development of more accurate computational capabilities;

(4) More accurate computational capabilities provide greater understanding of the underlying physics, thus enabling a more compressed, lower-risk system development schedule;

(5) Experimentation capabilities must be enhanced to improve understanding of the underlying physics;

(6) Failure to provide the requisite T&E facility and capability enhancements will increase the number of undetected design flaws that occur during system development;

(7) All proposed enhancements will be available at MS A for the conceptual programs being evaluated;

(8) Relevant past programs (used to construct the cost model) had an adequate T&E infrastructure available, so actual experience from these programs can be used to inform the baseline conceptual system development programs used (and executed with the equivalent of an enhanced T&E infrastructure) in the analysis;

(9) Actual experience from relevant past programs can be used to inform certain programmatic cost elements for future programs, such as the

   a. Number of flight tests,
   b. Time between flight tests (test phases),
   c. Development time from MS A through MS C,
   d. Schedule growth, and
   e. Costs for the prime development contract (including recurring and non-recurring costs, DT&E, and flight testing); and

(10) Design flaws encountered by using unenhanced experimentation and computational capabilities will cause program delays, adding cost at the time they are discovered.

The assumptions above would be relevant to most value-based justification analyses; nonetheless, any study assumptions must be tailored to each new capability enhancement being proposed for a BCA.

2. Step 2 – Identify Representative Comparative Programs

Identifying representative comparative development programs starts with determining which programs most closely align with the operational capabilities afforded by the conceptual systems being used in the analysis. For example, representative programs could include development of the Boeing 767 and 777 in the civil arena, or development of the F-22 and Joint Air-to-Surface Standoff Missile (JASSM) in the military arena. Some of the criteria that need to be critically assessed for the comparative development programs include (1) whether they were successfully developed and fielded, (2) whether they have similar operational capabilities or capability attributes (including similar technology reach) to the conceptual development systems being used, and (3) whether they have similarly reported cost and schedule data. It is worth emphasizing that this third criterion can pose several problems for your study team. If actual cost data are not available, an accurate cost estimate cannot be developed. Further, the assistance and counsel of SMEs with access to such information and data is essential. This is vital to the successful conduct of a value-based justification analysis.

3. Step 3 – Gather the Requisite Data and Create the Requisite CERs

To evaluate the programmatic cost and schedule impacts on the conceptual systems being used in the analysis (Step 6), the cost and schedule driver(s) first need to be identified. In the high-speed missile analysis, the driver was undetected flaws encountered during flight test, which would result in program delays and added cost at the time encountered.

Cost and schedule data for the representative comparative development programs must span the spectrum of potential system applications that would be affected by the new capabilities in the proposed plan. Schedule data must include the initially proposed schedule that preceded the start of system development as well as the actual final schedule after successful completion of system development. These schedule data are used to evaluate the reasonableness of any projected program slippages calculated by the cost model used in the evaluation of the MS A through MS C conceptual system development programs.

In addition to the recurring unit cost for each representative system, cost allocation data should include both the recurring and non-recurring development costs, other contract costs, other government costs (for government-funded programs), developmental test costs, and the cost of ground and flight testing. We show examples of the requisite development cost allocation and schedule CERs needed to construct the cost model in Fig. 4 and Fig. 5, respectively.

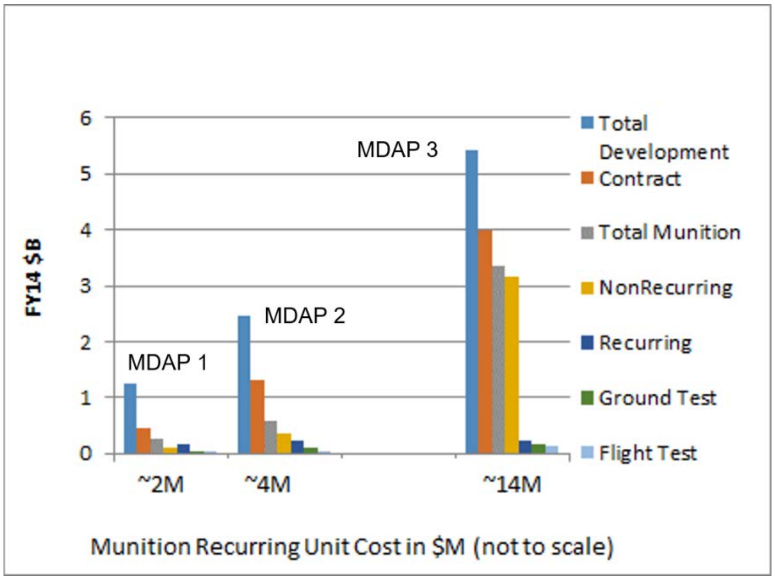


Fig. 4 Allocation of Development Costs.

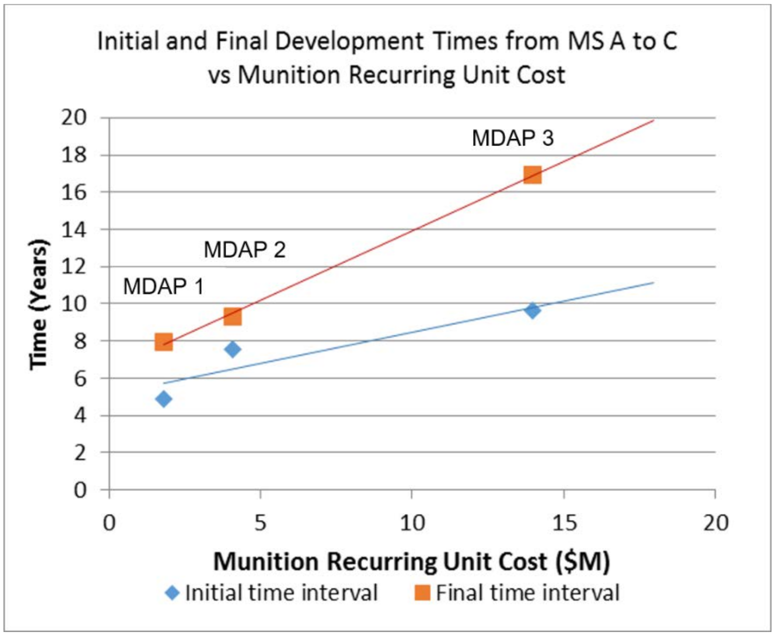


Fig. 5 Initial/Final Development Times.

In addition to these CERs, actual data are needed on the number of flight tests that were conducted between MS A and MS C for the representative successful system development programs selected (including any preceding unsuccessful programs that contributed materially to the system design or were instrumental in the program's ultimate success) as well as the frequency of flight tests across the spectrum of *all* representative comparative programs used in the analysis. These data are used to not only predict the number of flight tests conducted in the cost model, but also to estimate the characteristic times between flight test centers, so estimates of projected program delays can be determined using actual historic flight test data. Examples of the estimating relationship for the number of flight tests required and the flight test frequency histogram are shown in Fig. 6 and Fig. 7, respectively.

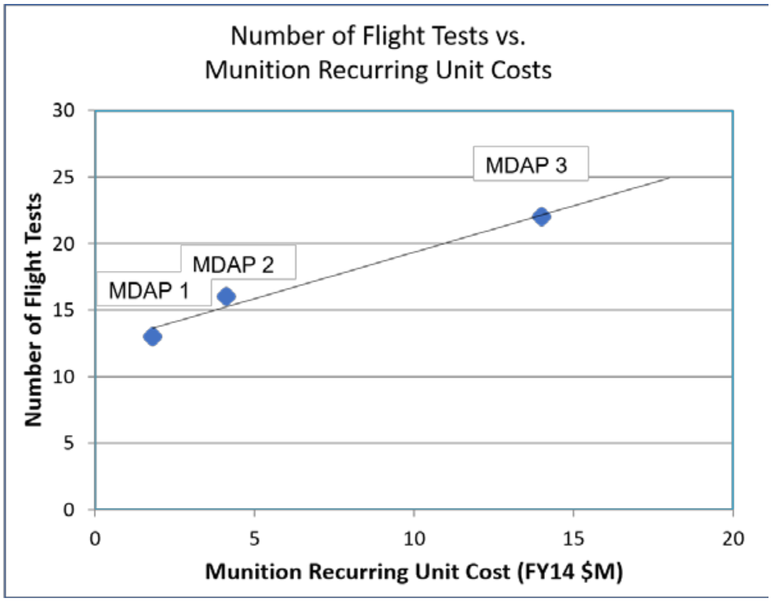


Fig. 6 Number of Flight Tests (MS A through MS C).

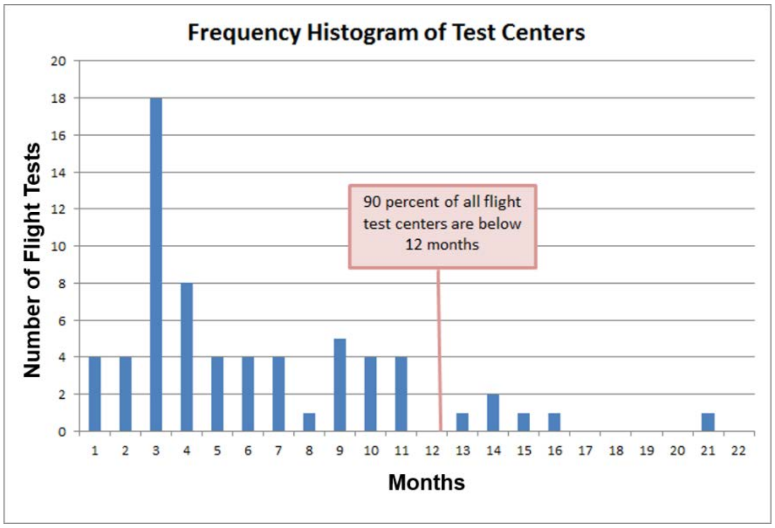


Fig. 7 Flight Test Frequency Histogram.

4. *Step 4 – Construct the Cost Model*

Construction of the cost model involves incorporating all the information and data gathered during Steps 2 and 3 (above) into a probabilistic model that can be used to generate a cost-schedule profile based on the collective representative comparative program data. Fig. 8 shows an example cost-schedule profile.

Because constructing and exercising models of this type requires substantial expertise and experience in both the formulation and execution of system development programs, as well as in cost analysis data and methods, seeking the counsel and assistance of SMEs knowledgeable in this field is *highly* recommended. Once the model has been developed and validated, one can then tailor it to each conceptual development program used in the value-based justification analysis to determine the cost-schedule impacts of unanticipated design flaws resulting from not closing the identified capability gaps being addressed in the plan. First, however, some additional counsel is needed from the SMEs who helped to construct Table 1, Table 2, and Table 5 with regard to the nature and extent of the impact caused by not having the requisite T&E infrastructure.

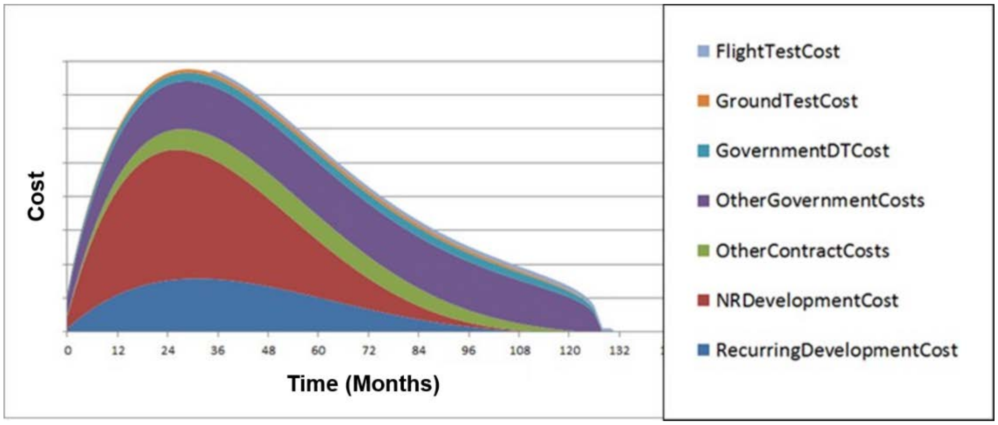


Fig. 8 Example Cost/Schedule Profile.

5. *Step 5 – Determine the Nature and Extent of the Impact Caused by Not Having the Capability Enhancements*

As noted earlier, in the high-speed missile arena, the nature of the impact that drove program cost and schedule was the occurrence of undetected flaws during flight test. Determining the extent of the impact (i.e., the number of undetected flaws encountered during flight test) due to not having available the requisite RDT&E capabilities (once again) required input from SMEs with specific knowledge and experience in system development and DT&E. These SMEs provided informed determinations, based on their best engineering judgment, regarding the ability of currently available capabilities to satisfy the developmental test objectives identified in Table 1. For each test objective (or group of test objectives), the SMEs provided informed judgments on which test objectives would be affected, and in what ways (test times/test costs/ frequency of test campaigns), by not having available the proposed capability enhancements. They also provided informed judgments on which capability shortfalls would potentially result in the existence—and number—of undetected flaws. We present an example of this analysis in Table 6.

Table 6 Example Analysis of Estimated Undetected Design Flaws.

Conceptual System A (with Enhancements)											
Test Type	**Test Objectives Addressed**	**Est Test Cost ($K)**	**Est Test Time (weeks)**	**Number of Ground Tests**			**Total Cost ($K)**	**Experimental (Supplements Data)**		**Undetected Design Flaws (Possible F/T Failures)**	
				Pre-MS A	**MS A-B**	**Post MS B**		**MS A-B**	**MS B-C**	**MS A-B**	**MS B-C**
Aero	1.1-to-1.5	4,000	8	2	2	0	16,000	baseline	baseline	baseline	baseline
Aerotherm	2.1-to-2.7	1,000	4	1	1	0	2,000	baseline	baseline	baseline	baseline
Materials	3.4-to-3.11	2,000	26	2	1	0	6,000	baseline	baseline	baseline	baseline
Propulsion	4.2-to-4.3	5,000	12	2	2	0	20,000	baseline	baseline	baseline	baseline
Stage/Store	5.1	500	2	0	2	8	5,000	baseline	baseline	baseline	baseline
Weather	6.1-to-6.3	2,500	12	0	2	2	10,000	baseline	baseline	baseline	baseline
GNC	7.5-to-7.7	2,000	8	0	2	2	8,000	baseline	baseline	baseline	baseline
Lethality	8.1	1,000	8	0	1	2	3,000	baseline	baseline	baseline	baseline

Conceptual System A (without Enhancements)											
Test Type	**Test Objectives Addressed**	**Est Test Cost ($K)**	**Est Test Time (weeks)**	**Number of Ground Tests**			**Total Cost ($K)**	**Experimental (Supplements Data)**		**Undetected Design Flaws (Possible F/T Failures)**	
				Pre-MS A	**MS A-B**	**Post MS B**		**MS A-B**	**MS B-C**	**MS A-B**	**MS B-C**
Aero	1.1-to-1.5	5,000	10	3	2	1	30,000			1	1
Aerotherm	2.1-to-2.7	2,000	8	2	1	0	6,000				
Materials	3.4-to-3.11	2,500	34	2	1	0	7,500			1	
Propulsion	4.2-to-4.3	7,000	18	2	2	1	35,000			1	
Stage/Store	5.1	500	2	0	2	12	7,000				1
Weather	6.1-to-6.3	2,500	12	0	3	3	15,000	2	4		
GNC	7.5-to-7.7	2,000	8	0	2	3	10,000				
Lethality	8.1	1,000	8	0	1	3	4,000				

Identifying and quantifying the nature and extent of the impacts caused by not having the requisite RDT&E capabilities available varies from application to application, so Step 5 will have to be tailored to the specific capability enhancements being proposed and assessed.

6. Step 6 – Assess the Programmatic Impacts with and without the Proposed Capability Enhancements

The IDA study team tailored the cost model developed in Step 4 to create probabilistic models for each conceptual system by incorporating system-specific estimates (based on engineering judgment) of the time interval between flight test centers and the length of the delays that would result from encountering the undetected flaws projected in Table 6. In analyzing the potential cost and schedule impacts in the high-speed missile analysis, the IDA study team assumed that past successful development programs had an adequate infrastructure available to them from MS A through MS C of system development. Therefore, the baseline tailored model for each conceptual system was called the "enhanced" model.

The IDA team then probabilistically introduced the estimated number of undetected flaws (and the projected delays the flaws would cause) into the enhanced model and ran the model again to evaluate the "unenhanced" cost-schedule profile. The team made multiple computer runs (numbering in the hundreds) to generate average outcomes for both the enhanced and unenhanced cases. The difference in cost and schedule between the enhanced and unenhanced model runs, depicted in Fig. 9, represents the projected savings that would accrue from having the proposed capability enhancements available for each conceptual system at the beginning of MS A. (In the Fig. 9 conceptual example, the time savings were three years and the cost savings were $235 million.) The flight test events for the enhanced and unenhanced cases are depicted as triangular “hats” along the top of each cost-schedule profile. The composite total cost savings for all the conceptual systems used in the analysis, minus the estimated up-front cost of the plan, represent the total net savings that would accrue from making the capability enhancement investments.

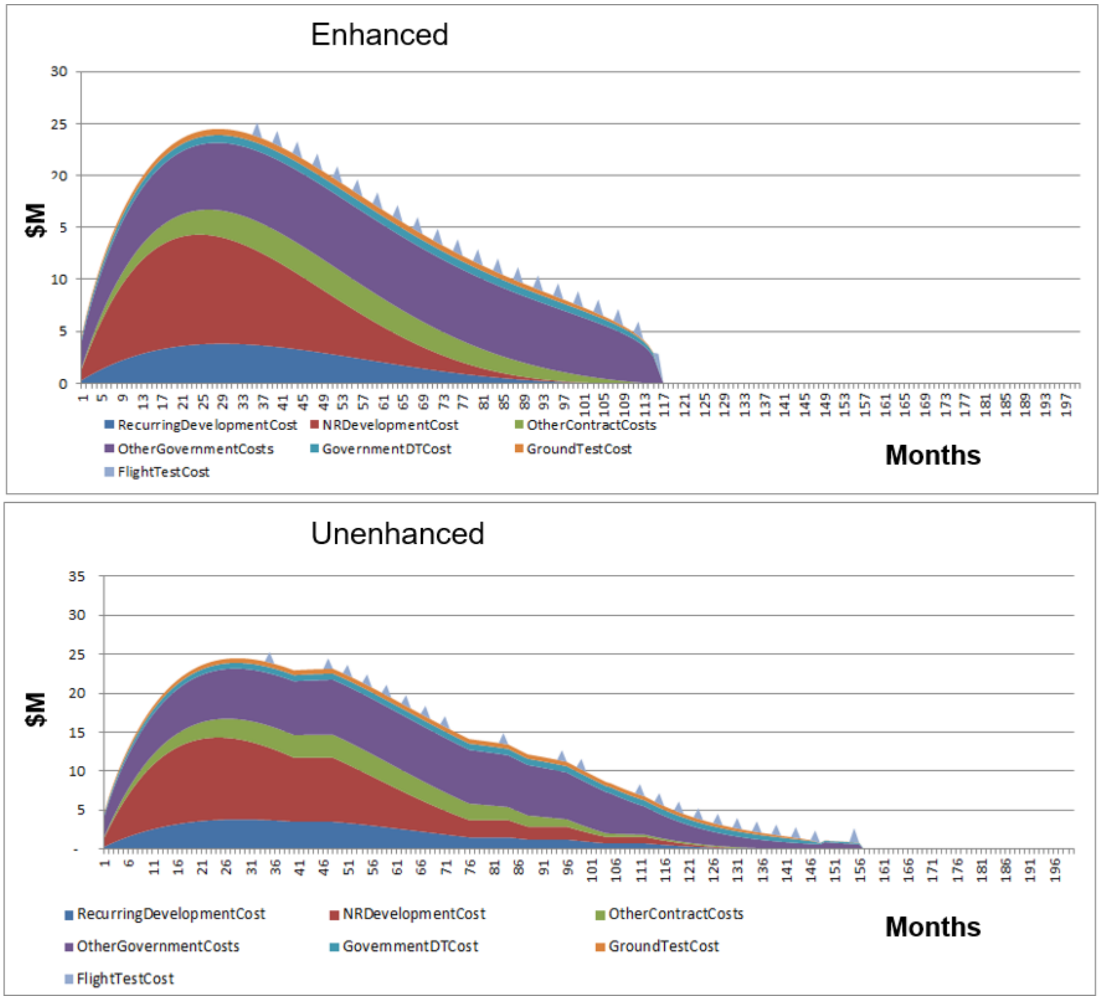


Fig. 9 Development Cost/Schedule Growth Resulting from Not Closing the Capability Gaps.

The example analysis described above was tailored to a high-speed missile application. Since each application will be somewhat different, the cost drivers associated with the specific conceptual systems being evaluated will have to be determined to ensure that the model constructed has the capability to respond to changes in those drivers.

III. Summary

The purpose of this paper is to share this successful process for justifying proposed capability investments with the broader aerospace RDT&E community, so that it can be employed in other RDT&E capability areas to support both sustainment and capital investment decisions. Potential users of this process, however, need to realize that the process takes substantial time and effort—and that success is not guaranteed. In the high-speed missile case study, for example, the process described in Sections II.A through II.C took over three years to complete (about one-quarter of which was associated with the socialization process), and it required substantial effort not only by the core IDA study team, but also by an extensive support team of government and industry SMEs who provided information and counsel on the key capability needs, the capability gaps, the impacts of not closing the gaps, and the proposed investment plan.

In addition, the process described in Section II.D took another nine months to complete and required substantial archival research on the cost, schedule, and test frequency of comparative development programs. It then took an additional year to develop the Issue Paper seeking the budget augmentation, coordinate it up to the Under Secretary of Defense level for inclusion in the President's Budget Request, shepherd the requested augmentation through the various congressional authorization and appropriation committees, and finally get the funds appropriated. Thus, the overall time-period from the beginning of the initial study effort to get the attention of the decision-makers, until the first dollar of new funding was received, was five calendar years. It suffices to say that the application of this process to other capability areas will require the investment of substantial time, cost, commitment, and perseverance—but the fruits of a successful justification can be significant!

IV. Acknowledgments

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V. References

[1] National Defense Authorization Act (NDAA) for Fiscal Year 2013 (Public Law 112-239). Section 1071. United States Congress, January 2013.

[2] West, Tim (Col., U.S. Air Force), US Air Force Initiative to Enhance Hypersonic Test Capabilities, presented at the 32nd Annual National Defense Industrial Association (NDIA) T&E Conference, San Diego, CA, March 8, 2017.

[3] Piscopo, Paul F., Bronson, Patricia F., Hong, John S. et al., "2015 Hypersonic T&E Investment Planning Study Phase II Final Report," Institute for Defense Analyses (IDA) Paper P-5313, April 2016.

[4] Quote from Lewis Carroll, noted English writer, mathematician, logician, Anglican deacon, and photographer; author of Alice's Adventures in Wonderland.

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14. ABSTRACT

Section 1071 of the National Defense Authorization Act for Fiscal Year 2013 required the Director of the White House Office of Science and Technology Policy (OSTP), working with the Secretary of Defense and the Administrator of the National Aeronautics and Space Administration (NASA), to conduct a study on the ability of the national test and evaluation (T&E) infrastructure to effectively and efficiently mature hypersonic technologies for defense-related systems development in the short and long term. It further required the Secretary of Defense to submit a report to the appropriate congressional committees containing the results of this study, together with a plan for requirements and proposed investments to meet Department of Defense (DoD) needs through 2030. The Institute for Defense Analyses (IDA) supported both the OSTP and DoD efforts, and was subsequently tasked to quantify the projected savings that could accrue to each of three conceptual conventional hypersonic system development programs if the proposed T&E capability enhancements presented in the DoD plan submitted to Congress were available at the beginning of Milestone (MS) A. As part of its analysis, IDA utilized an IDA-developed approach for valuing the closure of critical T&E capability gaps based on the potential programmatic cost and schedule savings that could reasonably be expected to accrue from the start of MS A through the end of MS C by funding the 5-year, $350M T&E infrastructure investment proposed in the DoD plan. This expansion of the cost-benefit “control volume” to include projected system development savings proved successful in justifying and securing full funding for the proposed DoD plan. This paper summarizes the IDA approach and its application to making the business case for closing capability gaps in other aerospace research, development, test and evaluation (RDT&E) areas.

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