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A New Way to Justify Test and Evaluation Infrastructure Investments

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Abstract

In 2013, the Congress directed that a study be conducted on the ability of the national test and evaluation infrastructure to effectively and efficiently mature technologies for defense-related hypersonic systems development through 2030. It further required that a report be submitted to the Congress on the study results, along with a plan identifying the capability needs and proposed defense-related investments. The Institute for Defense Analyses (IDA) supported both congressionally directed efforts and was subsequently tasked with providing a business case analysis for the proposed investments. This article describes the IDA-developed methodology used to successfully justify and secure full funding for the proposed five-year, $350 million Department of Defense Test and Evaluation infrastructure investment augmentation.

Introduction

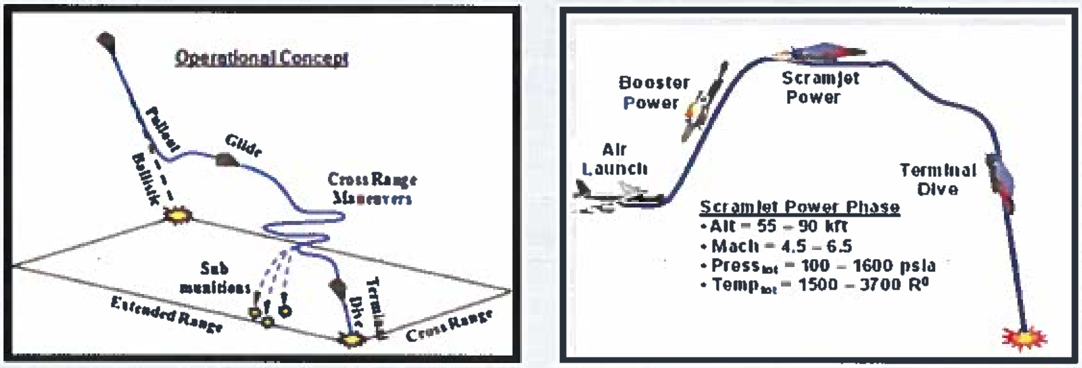
State-of-the-art test and evaluation (T&E) capabilities are essential for successful development of new aerospace products, as well as for the upgrading of currently fielded products. Despite the unarguable fact that system development programs require a robust and continuing investment in research, development, test and evaluation (RDT&E), including the T&E infrastructure, the Department of Defense (DoD) still must justify additional test infrastructure investments needed to effectively and efficiently develop and field future aerospace systems. This has proven to be a major challenge for facility owners and operators.

The Hypersonic T&E Infrastructure Working Group (IWG), established to respond to congressional direction regarding adequacy of the DoD's T&E infrastructure for the development of hypersonic missiles, found capability gaps in the DoD's wind tunnel infrastructure. Their analysis established the need for $350 million in improvements at several facilities. The Institute for Defense Analyses (IDA) was asked to develop a Business Case Analysis (BCA) to support the investment.

IDA proposed using an approach that values the potential programmatic cost savings that could reasonably be expected to accrue during system development from funding proposed T&E capability enhancements.

Background

Figure 1 shows an operational concept for notional hypersonic boost glide vehicles (left) and a scramjet-powered cruise missile (right). Both the strategic and tactical boost glide vehicles share an operational concept for delivering a payload. The Strategic Boost Glide (SBG) vehicle is delivered by a multi-stage ballistic missile, has an extended glide phase inside the atmosphere, and ends in a terminal dive. The Tactical Boost Glide (TBG) vehicle is launched from an aircraft, employs a rocket engine to boost it to hypersonic speeds, has an extended glide phase inside the atmosphere, and ends in a terminal dive.



Schematic of a Notional Boost-Glide Flight Profile

Schematic of a Notional Hypersonic Scramjet Powered Cruise Missile

Figure 1. **Conceptual Hypersonic Weapons**

Methodology

First, the research team described a generic hypersonic development program that assumed the capability gaps in the hypersonic T&E infrastructure associated with that design were closed before the program started. Three successful missile Major Defense Acquisition Programs (MDAPs) were used to develop a generic resource-loaded schedule model. Second, the team estimated schedule delays the three conceptual programs might encounter if the capability gaps were not closed. The T&E Infrastructure subject matter experts (SMEs) identified the value of closing the capability gaps in terms of additional flight tests needed during development, based upon flight test failures in their experience. Third, the research team introduced random schedule delays and added resources to the resource-loaded schedule to estimate the final state of the programs. Estimated savings were taken as the difference between the initial and final states. The team created a computer model to simulate the growth over a range of initial conditions. The results reported are the average of 1,000 runs.

Results

Joint Air-to-Surface Standoff Missile (JASSM), Phased Array Track Radar Intercept of Target (PATRIOT) Advanced Capability 3 (PAC-3), and Terminal High Altitude Area Defense (THAAD) were chosen as reference programs. As a group, they bracketed the expected development challenges (each faced a technology readiness challenge) and costs the conceptual hypersonic missile system programs would likely face.

- JASSM is a subsonic stealthy cruise missile that is used to attack surface targets. It is powered by an air-breathing turbojet engine that provides sustained flight in the atmosphere and accomplishes target recognition and terminal homing via infrared (IR) imaging.

- PAC-3 is a tactical, hypersonic, ballistic missile that can achieve speeds of Mach 5+ and intercepts at altitudes of approximately 20 kilometers (km). It was the first MDAP that delivered hit-to-kill technology.

- THAAD is a hypersonic hit-to-kill ballistic missile that employs divert and attitude control technology and an advanced guidance, navigation, and control (GN&C) system to achieve its end-game mission. THAAD pushed the range (approximately 200 km) and altitude (150 km) envelopes beyond the PAC-3 missile.

Table 1 compares the developmental challenges of the reference programs to the three conceptual conventional hypersonic programs.

Table 6. Characteristics of Analogous MDAPs and Conceptual Hypersonic Programs

MDAP	MDAP Attributes	Parallel Conceptual Programs Analogy
JASSM	• Stealthy cruise missile • Sustained subsonic flight in the atmosphere • Air-breathing turbojet engine • Target recognition/homing via IR imaging • Designed to hit surface targets	• Sustained hypersonic flight in the atmosphere • Air breathing scramjet engine • Target recognition and terminal homing • Designed to hit surface targets
PAC-3	• Tactical missile (Mach 5+) • Powered by a solid propellant rocket • Hit-to-kill technology • GN&C/Divert and attitude control	• Tactical missile (hypersonic) • GN&C/autonomous end-game
THAAD	• Hypersonic ballistic missile interceptor • Hit-to-kill technology • GN&C/Divert and attitude control • Extensive flight path (THAAD has an estimated range of 200 km and can reach an altitude of 150 km)	• Hypersonic vehicle • GN&C/autonomous end-game • Extensive flight path/similar altitudes

Figure 2 shows a breakout of development costs for the JASSM, PAC-3, and THAAD programs in billions of dollars ($B) adjusted to FY 2014. (All cost values in this study were in FY 2014 dollars unless otherwise stated.) The cost values were derived from each program's Selected Acquisition Reports (SARs) and Contractor Cost Data Reports (CCDRs). The THAAD system program comprised two major development efforts: the ground radar and the THAAD missile. Only the portion associated with the missile development was used to inform this cost estimate. Cost Estimating Relationships (CERs) were derived from these cost data. Spacing on the horizontal axis is the average Munition Recurring Unit Cost (MRUC) reported during the development phase.

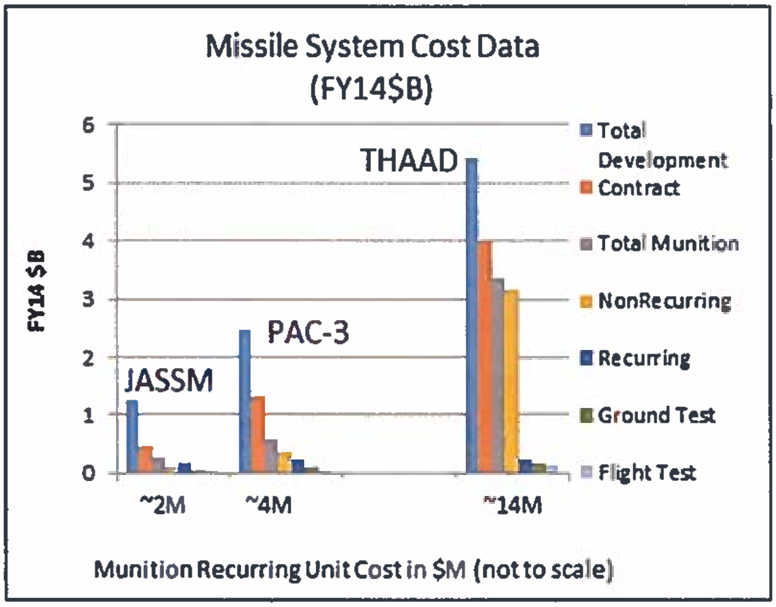


Figure 2. **Actual JASSM, PAC-3, and THAAD Development Costs**

Figure 3 shows the initial estimated and final actual time intervals between Milestone (MS) A and MS C for JASSM, PAC-3, and THAAD as a function of MRUC. These data show initial schedules ranging from five to 10 years and final (as executed) schedules ranging from eight to 17 years. They also show actual schedule delays ranging from two to seven years. The straight lines suggest empirical relationships between development time for MDAPs and the MRUC.

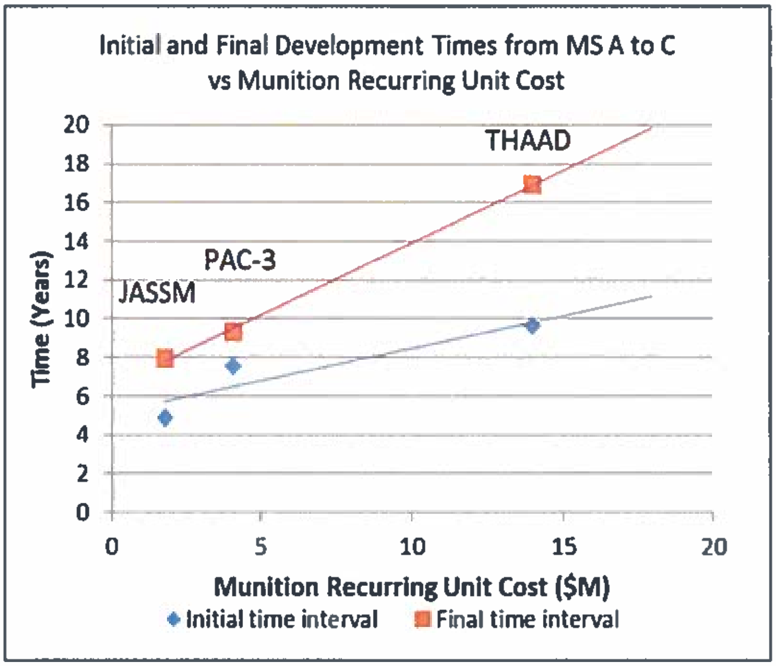


Figure 3. **Actual Initial/Final MS A-to-C Time Intervals**

Figure 4 shows the actual number of flight tests flown as a function of MRUC (calculated from the development CCDR). The number of flight tests displayed in this chart was compiled from actual data gathered from the JASSM Risk Reduction and EMD phases, PAC 3 and its predecessor Flexible Lightweight Agile Guided Experiment and Extended Range Interceptor programs, and the THAAD Program Definition and Risk Reduction (PDRR) and Engineering and Manufacturing Development (EMD) phases. The straight line represents an empirical relationship between the number of flight tests executed on MDAPs and the MRUC.

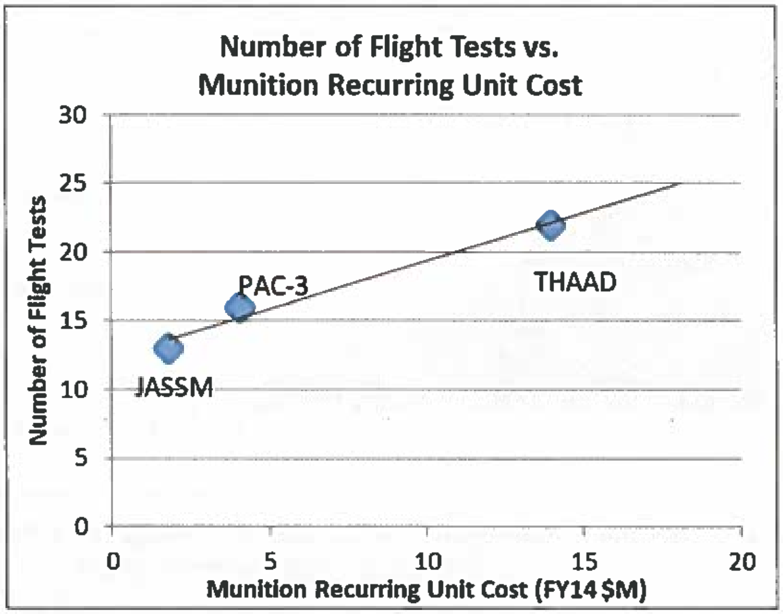


Figure 4. **Actual Number of Fight Tests on JASSM, PAC-3, and THAAD**

Figure 5 presents a frequency histogram of the time between flight tests (known as test centers) for the JASSM, JASSM Extended Range (JASSM-ER), PAC-3, PAC-3 Missile Segment Enhancement (PAC-3 MSE), and THAAD programs, as executed. The IDA research team used these data to inform its flight test schedules. According to these data, 90% of all flight test centers were below 12 months (with design flaws and schedule delays included).

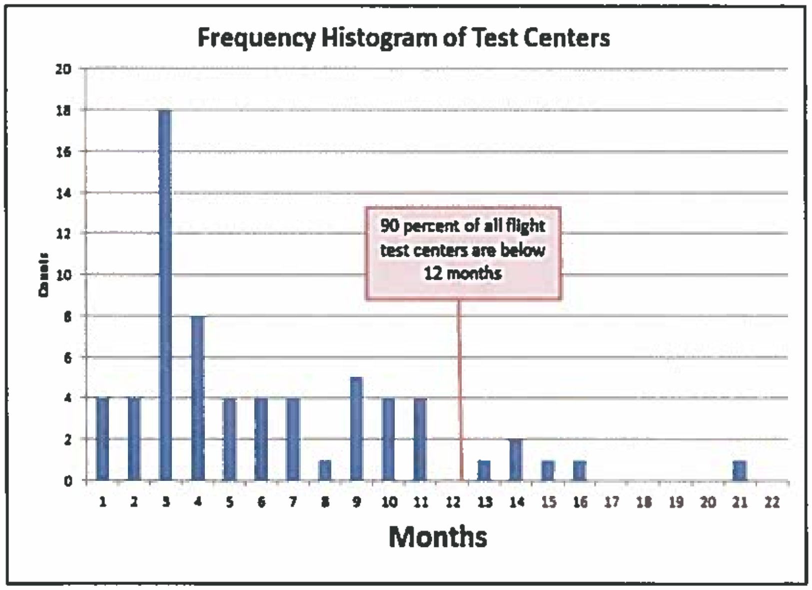


Figure 5. **Actual Flight Test Centers**

Figure 6 depicts a sample resource-loaded schedule for a program executing with adequate T&E infrastructure. The different color bands represent the various elements of cost (as shown in Figure 2). The program depicted has three years of development and ground testing after MS A approval and prior to the first flight test. The flight test program executes with an average of four months between flight test centers. Since this schedule is populated with cost data from a model built with JASSM, PAC-3, and THAAD program data, it includes any design flaws, flight test failures, redesign efforts, and schedule delays inherent in those programs.

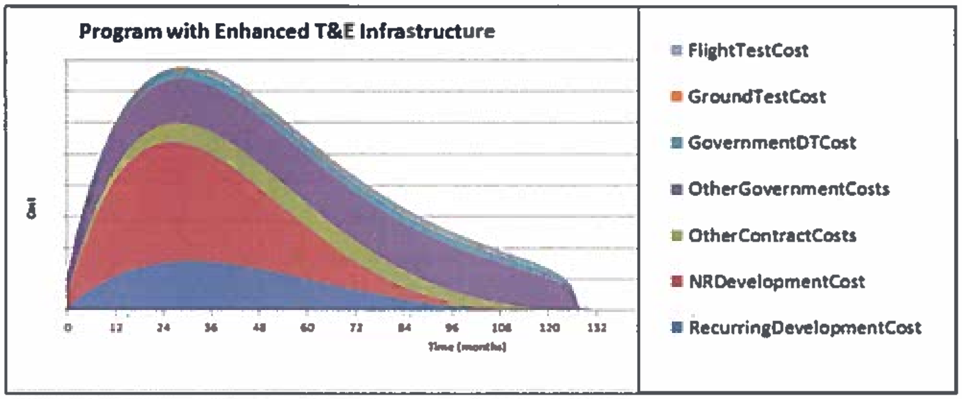


Figure 6. **Sample Initial Resource-Loaded Schedule for a Program With an Enhanced T&E Infrastructure**

The T&E SMEs characterized the design and development problems each of the development programs might expect to encounter if the hypersonic T&E infrastructure were not enhanced prior to MS A, and translated them into an estimated number of additional unanticipated design flaws that would persist past the critical design review. Table 2 shows the SME-generated analysis for the conceptual TBG program; it shows five undetected design flaws in the lower right two columns.

Table 2. SME-Generated Analysis of Estimated Undetected Design Flaws for the Conceptual Boost Glide Program

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				

Table 3 shows the SME-generated estimates of the capability gaps and design flaws for the three conceptual programs.

Table 3. Resulting Additional Major Design Flaws Resulting From Infrastructure Capability Gaps

Hypersonic Weapon System Type	Number of T&E Infrastructure Capability Gaps	Estimate of the Number of Additional Major Design Flaws
Scramjet Cruise Missile (CM)	10	9
Tactical Boost Glide (TBG)	7	3
Strategic Boost Glide (SBG)	9	5

Figure 7 shows the resource-loaded schedule (from Figure 6) with schedule delays due to the number of design flaws.

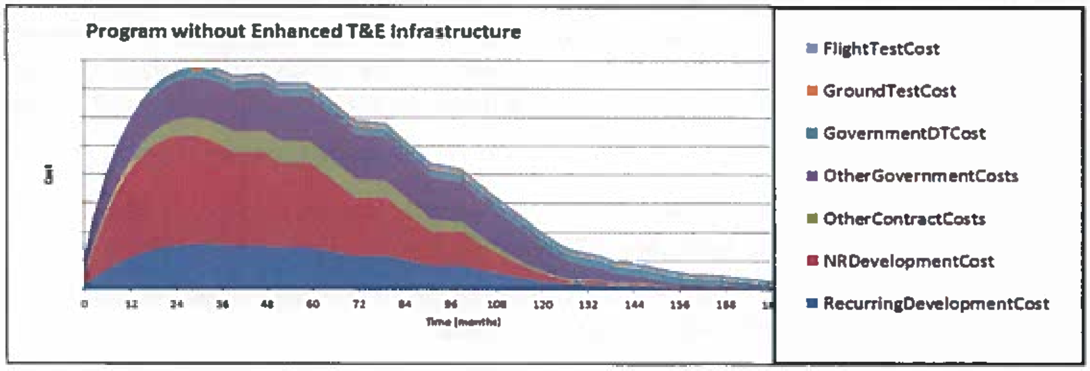


Figure 7. **Sample Resource-Loaded Schedule With Added Schedule Delays**

Table 4 shows the estimated savings for the range of development program costs from $1.3 to $2.9 billion. For reference, the IDA team included the initial RDT&E schedule in years (line 2), the number of flight tests (line 3), and the savings to the three conceptual programs if the unanticipated design flaws are avoided (lower right quadrant).

Table 4. Study Results: Estimated Savings Over a Range of Development Costs

Estimated Savings Over a Range of Development Costs					
Range of Development Costs ($M)		1,300	1.800	2,400	2,900
Initial RDT&E Schedule (Years)		9	10	10	10
Number of Flight Tests		18	21	23	23
	Number of Additional Design Flaws	**Savings if the Design Flaws are Avoided ($M)**			
TBG	3	100	150	200	270
SBG	5	150	240	310	400
CM	9	240	380	530	690

Table 5 shows the calculated (discounted) net savings over the range of estimated development costs from $1.3 billion to $2.9 billion analyzed for the three conceptual systems: Scramjet CM, SBG, and TBG. Each entry in Table 5 is the amount of the cost avoided by making the investment (i.e., the numbers from Table 4 less the $350 million investment). While there was no compelling evidence to make the investment based on the costs avoided for either the TBG or SBG programs, should the DoD decide to pursue both (Table 5, bottom line), the investment option became more attractive.

Table 5. Study Results: Net Savings With Enhanced Hypersonic T&E Infrastructure

Net Discounted Savings				
	Range of Development Costs ($M)			
	1,300	*1,800*	*2,400*	*2,900*
	Savings ($M)			
TBG	-250	-200	-150	-75
SBG	-200	-125	-50	50
Scramjet CM	-125	25	175	325
Both TBG and SBG	-100	25	150	300

Conclusion

The IDA-developed methodology was used successfully to justify and secure a five-year, $350 million T&E infrastructure investment augmentation for the DoD. Potential users of this process, however, are reminded again that it takes substantial time and effort—and success is not guaranteed. In the hypersonic missile arena, preparing the pathway and developing the plan took over three years to complete and required substantial effort not only by the core IDA research 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.

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