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An Approach to Establishing System Benefits for Technology in NASA's Hypersonics Investment Area

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An Approach to Establishing System Benefits for Technologies in NASA's Hypersonics Investment Area

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Abstract

NASA's has established long term goals for access-to-space. The third generation launch systems are to be fully reusable and operational around 2025. The goals for the third generation launch system are to significantly reduce cost and improve safety over current systems. The Advanced Space Transportation Program (ASTP) Office at the NASA's Marshall Space Flight Center in Huntsville, AL has the agency lead to develop space transportation technologies. Within ASTP, under the Hypersonics Investment Area, third generation technologies are being pursued.

The Hypersonics Investment Area's primary objective is to mature vehicle technologies to enable substantial increases in the design and operating margins of third generation RLVs (current Space Shuttle is considered the first generation RLV) by incorporating advanced propulsion systems, materials, structures, thermal protection systems, power, and avionics technologies.

Advancements in design tools, better characterization of and testing in the operational environment will result in reduced design and operational variabilities leading to improvements in margins.

Improvements in operational efficiencies will be obtained through the introduction of integrated vehicle health management, operations, and range technologies. Investments in these technologies will enable the reduction in the high operational costs associated with today's vehicles by allowing components to operate well below their design points resulting in improved component operating life, reliability, and safety which in turn reduces both maintenance and refurbishment costs. The introduction of advanced technologies may enable horizontal takeoff by significantly reducing the takeoff weight and allowing use of existing infrastructure. This would be a major step toward the goal of airline-like operation. These factors in conjunction with increased flight rates, resulting from reductions in transportation costs, will result in significant improvements of future vehicles.

The real-world problem is that resources are limited and technologies need to be prioritized to assure the resources are spent on technologies that provide the highest system level benefits. Toward

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that end, a systems approach is being taken to determine the benefits of technologies for the Hypersonics Investment Area. Technologies identified to be enabling will be funded. However, the other technologies will be funded based on their system's benefits. Since the final launch system architecture will not be decided for many years, several vehicle concepts are being evaluated to determine technology benefits. Not only performance, but also cost, safety/reliability and operability are being assessed. This will become an annual process to assess these technologies against their goals and the benefits to various launch systems concepts.

The paper describes the system process, tools and concepts used to determine the technology benefits. Preliminary results will be presented along with the current technology investments that are being made by ASTP's Hypersonics Investment Area.

Introduction

NASA's Office of Aerospace Technology (OAT) is trying to answer the following fundamental questions:

(1) How can we enable revolutionary technological advances to provide air and space travel for anyone, anytime, anywhere, more safely, more affordably, and with less impact on the environment, and improve business opportunities and global security?
(2) What cutting edge technologies, processes, techniques, and engineering capabilities must we develop to enable our research agenda in the most productive, safe, economical, and timely manner? How can we most effectively transfer knowledge from our research and discoveries to benefit both commercial ventures and the quality of human life?

To address these questions, OAT has set the following four goals:

(1) Revolutionize Aviation: Enable a safe, environmentally friendly expansion of aviation.
(2) Advanced Space Transportation: Create a safe, affordable highway through the air and into space.
(3) Pioneer Technology Innovation: Enable a revolution in aerospace systems.
(4) Commercialize Technology: Extend the commercial application of NASA technology for economic benefit and improved quality of life.[1]

The Advanced Space Transportation Program (ASTP) Office at the NASA's Marshall Space Flight Center (MSFC) in Huntsville, Ala. focuses on future space transportation technologies in support of OAT Enterprise's mid- and long-term goals. ASTP's primary objectives are to significantly improve safety and reduce payload transportation cost to low earth orbit (LEO) and in-space. The Hypersonics Investment Area, one of three investment areas in ASTP, focuses on the third generation reusable launch vehicles (RLV), see Figure 1, with goals to significant improve safety and reduce operational costs of future space access vehicles.

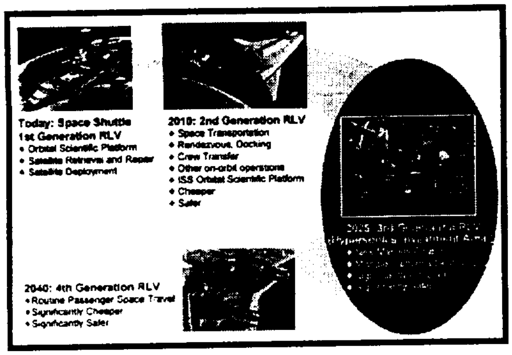

Figure 1. RLV Evolutionary Plan

The plan is to substantially increase the design and operating margins to improve component robustness by allowing components to operate well below their design point. This approach will increase life, reduce maintenance and refurbishment requirements, and improve reliability. Improvements in operational efficiencies will be provided through use of advanced integrated health management, operations, and range technologies. These technologies have the potential of enabling horizontal takeoff by reducing the takeoff weight and achieving the goal of airline-like operation. These factors in conjunction with increased flight rates from an expanding market resulting from decreases in the cost of accessing space will result in significant improvements in both safety and costs of future vehicles.

The Hypersonics Investment Area consists of the following three main areas of technology focus:

- Propulsion
- Airframe (non-propulsive)
- Flight Demonstrators

Figure 2 indicate how the resources are to be invested in each of the areas over the next six years. The majority of the investment is applied to propulsion technologies. The next major investment is the flight demonstrators with the remaining resources applied to primarily to airframe technologies. Some limited investments are being made in facilities.

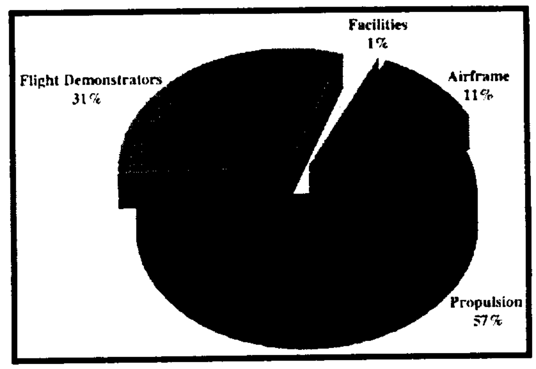

Figure 2. Hypersonics Investment Distribution

Because resources are limited, technologies need to be prioritized to assure the resources are spent on these technologies that provide the highest system level benefits. Toward that end, a systems approach is being taken to determine the benefits of technologies for the Hypersonics Investment Area. Technologies identified to be enabling will be funded. However, the other technologies will be funded based on their system's benefits.

Since the final launch system concept will not be decided for many years, several vehicle concepts (see Figure 3) are being studied to establish which architecture would best meet the established goals. Single stage to orbit (SSTO) and two-stage to orbit (TSTO) vehicles that would utilize either vertical takeoff (VTO) or horizontal takeoffs (HTO) are being assessed. All configurations land horizontally. Hydrocarbon, hydrogen, and dual fuel are part of the trade space.

Performance, cost, safety/reliability, and operability are the major attributes being assessed. This assessment will become an annual process to compare these technologies against their goals and to assess their progress toward these goals.

	VTO	HTO
SSTO	H2 Airbreathing Concepts	H2 HC (Dual Fuel)
TSTO	Rockets	H2 HC

Figure 3. Vehicle Concepts

The paper describes the system process, tools and concepts used to determine the technology benefits. Preliminary results will be presented along with the current technology investments that are being made by ASTP's Hypersonics Investment Area.

System Analyses Approach

Significant uncertainty exists in quantifying characteristics of future transportation system elements, future markets, and the impacts of advanced technologies and engineering methods on key system metrics. To address these uncertainties, two coordinated systems analysis efforts have been initiated. First, the ASTP-sponsored Integrated Technology Assessment Center (ITAC) has developed a probabilistic approach to modeling in which key concepts are reduced to simulations and then assessed with respect to applied technologies and metrics important to ASTP. Second, the NASA 3rd Generation RLV Inter-center Systems Analysis Team (3rd Gen. ISAT) has developed a networked computing system to automate data flow to/from several preliminary design codes. This provides a rapid, deterministic vehicle design capability for the direct assessment of candidate technologies. By using high and low estimates of technology characteristics, ranges of impacts can be established.

The ITAC Process

As noted above, ITAC was established to 1) identify long-term technology needs, 2) quantify technology investment payoffs for key technologies currently below technology readiness level 6 (prototype demonstrated in relevant environment), and 3) assess progress in ASTP-sponsored technology programs. For this, ITAC has engaged a diverse and talented team representing a broad cross section of the aerospace community. ITAC has also defined an assessment process and the tools required. Figure 4 shows the key aspects of the ITAC process in general terms and Figure 5 shows the process in more detail.

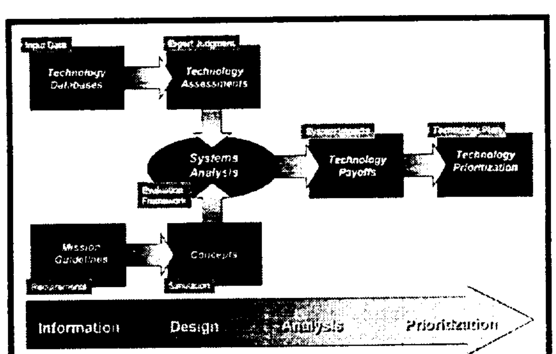

Figure 4. ITAC Process Overview

The actual systems analysis task is accomplished through an evaluation framework based on an analyst-friendly analysis tool called the ASTP technology investment management system (ATIMS).

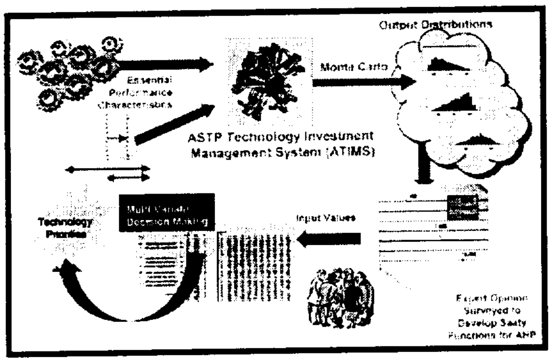

Figure 5. ITAC Process

The ATIMS tool uses both concept models and technology data to output probabilistic estimates of the impacts of technologies (singular or in suites). The output data is then used with customer-given metrics, weightings and technology development cost estimates (e.g. critical technologies for individual concepts, high impact technologies across concepts, cost to benefit ratios, etc.) to provide inputs for the ASTP technology prioritization process. The outputs of the ATIMS framework are stored in a very logical and "easy-to-mine" database. This database can be used for further post processing and will serve as a basis for assessment of the technologies progress. As in all analysis processes, the reliability and accuracy of the outputs are fundamentally dependent on the required inputs. For ITAC, this first means that the concept simulations must be reasonably high fidelity representations of the transportation concept under study. Next, the characteristics of the technologies applied in the analyses efforts must be well founded in fact and expert judgement.

The ITAC simulations used in ATIMS are termed ITAC Concept Models (ICM). Once a concept for analysis is selected, an integrated design team builds a model incorporating key features of the concept in all the traditional areas (e.g. weights, propulsion, safety, cost – see Figure 6).

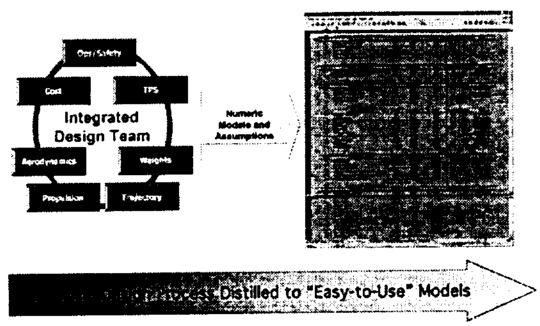

Figure 6. ITAC Concept Model

The process is open to designs from any source but employs standardized model interfaces for compatibility within the team and configuration control. The classical design process is distilled to a spreadsheet-based framework organized on the basis of "influence factors." For the concepts pertaining to hypersonics, these are termed vehicle influence factors (VIFs) and a typical set is shown in Figure 7.

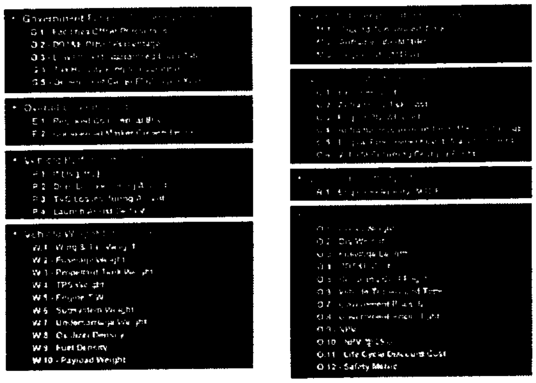

Figure 7. Vehicle Influence Factors

To assess the impact of a technology, the basic characteristics of the technology must be input along with the impacts of that technology on each of the VIFs that the technology affects. To date, most of the technology assessment has been done using information from the aerospace community and the judgement of the experts on the ITAC team applied in a series of technology penetration studies. In the future, it is anticipated that heavy use of the ASTP-sponsored Space Transportation Information Network (STIN) database will be heavily mined for technology data. Expert judgement via technology penetration studies will still be required to adapt the data to the ITAC concepts.

ITAC Progress

Since its inception in August of 2000, ITAC has matured rapidly. In the early stages of the program, the process was developed and demonstrated using models available from previously funded efforts at Georgia Institute of Technology. In the ETO area, both an all rocket- based SSTO concept (ACRE 92) and an air breathing/rocket-based SSTO concept (Hyperion) were examined. Once the process was demonstrated, an ITAC "tiger team" composed of experts in key disciplines (e.g. trajectories, safety, cost, propulsion, sizing, etc.) was formed to develop a new TBCC-based HTHL TSTO concept of specific interest to ASTP. All these concepts are shown in Figure 8.

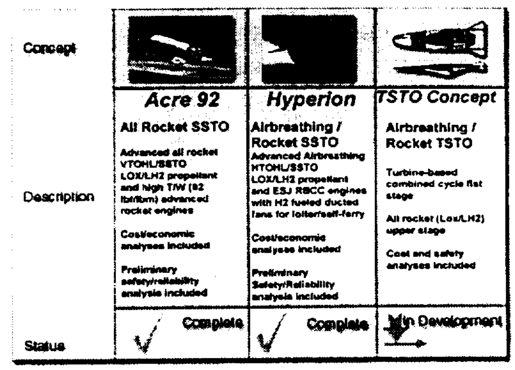

Figure 8. ITAC ETO Concept Models

Results from the ACRE 92 analysis will be provided here for demonstration purposes. In the ACRE 92 assessment, several technologies were deemed enabling (i.e. required for concept viability). Five other technologies were deemed enhancing (i.e. not essential but of high interest). In each assessment, the enabling technologies and some combination of the enhancing technologies was run. To run all of the possible cases, 32 technology portfolios were required (2^5). In each portfolio analysis, the uncertainties in the basic characteristics of each technology selected, impacts on the VIFs from all of the enabling technologies, and the enhancing technologies contained in the portfolio are input to ATIMS. Approximately 500 Monte Carlo runs were required to provide results that fell in the 90 percent confidence interval. Figures 9 & 10 show typical results. In each figure a different output metric is plotted. The x-axis shows the value of the metric. The y-axis shows the number of times the value ended up in a certain range in the 500 Monte Carlo run sequence (Figure 9 shows price/pound to orbit, Figure 10 shows number of flights between loss of vehicle). The first two choices reflect NASA emphasis on cost and safety. Many other metrics (e.g. GLOW, vehicle dry weight, turn-around time) were provided by the analysis and the results show clearly that the technology suite providing the best results vary from metric to metric.

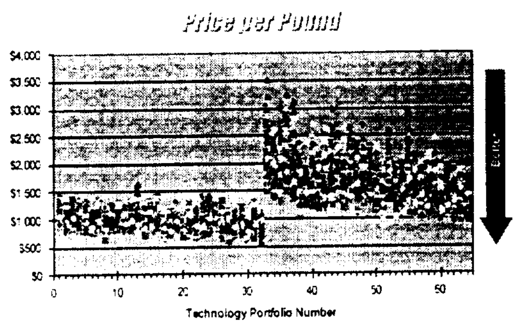

Figure 9. Preliminary Output

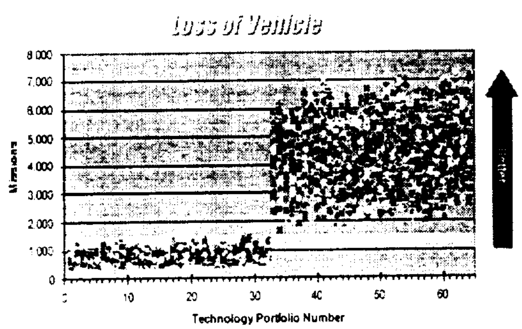

Figure 10. Preliminary Output

ITAC Directions

As noted above, both the ACRE 92 and Hyperion models were used as test cases to simply prove out the ITAC process. The TSTO model being developed at this writing will be the first in what is anticipated to be a series of models that bound the 3rd generation design space. This initial model is based on a concept developed by Mehta, et. al., at the Ames Research Center that has been scrubbed and modified as required by the ITAC tiger team. In addition, the ITAC team is working to develop and incorporate advanced approaches to improve and speed up the analysis process. For a start in these directions, the TSTO model will likely include a simple neural net designed to select the optimal trajectory given feedback from the rest of the analysis. Both parallel and distributed processing schemes will be examined as will the efficacy of using high-speed network connectivity to support the analysis. Finally, more generic architectures with state-of-art simulation capability will be explored.

Summary

In attempt to quantify the uncertainties associated with various future space transportation options, the ITAC has put in place a probabilistic tool to exercise evolving concept models. The team including NASA, the US Air Force, Universities and various US aerospace companies, will continue to refine the existing concept models and develop others to help drive ASTP's investments to get the biggest payback.

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