AIAA-2002-3550
Integrated Technology Assessment Center (ITAC) Update

J. L. Taylor and M. A. Neely
NASA Marshall Space Flight Center
and
F. M. Curran, E. R. Christensen, D. Escher, and N. Lovell
SAIC Huntsville

38th AIAA/ASME/SAE/ASEE
Joint Propulsion Conference

7-10 July 2002
Indianapolis, Indiana

INTEGRATED TECHNOLOGY ASSESSMENT CENTER (ITAC) UPDATE

J. L. Taylor and M. A. Neely
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

F. M. Curran, E. R. Christensen, D. Escher, and N. Lovell
Science Applications International Corporation
National Space Science and Technology Center
Huntsville, AL 35805

Abstract

The Integrated Technology Assessment Center (ITAC) has developed a flexible systems analysis framework to identify long-term technology needs, quantify payoffs for technology investments, and assess the progress of ASTP-sponsored technology programs in the hypersonics area. For this, ITAC has assembled an experienced team representing a broad sector of the aerospace community and developed a systematic assessment process complete with supporting tools. Concepts for transportation systems are selected based on relevance to the ASTP and integrated concept models (ICM) of these concepts are developed. Key technologies of interest are identified and projections are made of their characteristics with respect to their impacts on key aspects of the specific concepts of interest. Both the models and technology projections are then fed into the ITAC's probabilistic systems analysis framework in ModelCenter®. This framework permits rapid sensitivity analysis, single point design assessment, and a full probabilistic assessment of each concept with respect to both embedded and enhancing technologies. Probabilistic outputs are weighed against metrics of interest to ASTP using a multivariate decision making process to provide inputs for technology prioritization within the ASTP. ITAC program is currently finishing the assessment of a two-stage-to-orbit (TSTO), rocket-based combined cycle (RBCC) concept and a TSTO turbine-based combined cycle (TBCC) concept developed by the team with inputs from NASA. A baseline all rocket TSTO concept is also being developed for comparison. Boeing has recently submitted a performance model for their Flexible Aerospace System Solution for Tomorrow (FASST) concept and the ISAT program will provide inputs for a single-stage-to-orbit (SSTO) TBCC-based concept in the near-term. Both of these latter concepts will be analyzed within the ITAC framework over the summer. This paper provides a status update of the ITAC program.

Introduction

The development of a new generation of reusable launch vehicles (RLV) capable of carrying significant payloads at low cost and with both rapid turn-around capabilities and safety margins well beyond those of current systems is an area of great interest both to NASA and the Department of Defense. Many of the hypersonic concepts now under study will require the development of airbreathing engine and other advanced technologies and new operational strategies. These RLV concepts are relatively far-term, however, and the impacts of advanced technologies and engineering methods on key system metrics are not well known. NASA's Advanced Space Transportation Program (ASTP) is responsible for making far-term investments in low technology readiness level (TRL) technologies (TRL < 6) for advanced hypersonic transportation systems. To help guide the investment process, ASTP supports the Integrated Technology Assessment Center (ITAC) at the National Space Science and Technology Center (NSSTC). ITAC has developed and demonstrated a flexible framework for systems analysis that identifies long-term technology needs, provides fast turn-around sensitivity and gap analyses, and quantifies technology investment payoffs in a probabilistic fashion. The system can also be used to measure progress in ASTP-sponsored technology programs. ITAC has engaged a diverse team representing a broad cross section of the aerospace community, defined a sophisticated and comprehensive systems analysis process, developed the necessary tool set, and is currently implementing the process on a number of concepts selected by ASTP.

The systems analysis task is accomplished through the use of the Framework for Advanced Systems Trade-Offs using Probabilistic Analysis of Concepts and Technologies (FASTPACT). FASTPACT is an evaluation framework based on an analyst-friendly analysis tool called ModelCenter®. Integrated Concept Models (ICM) characterize selected concepts and include modules describing performance, operations, cost, safety, business, and economics. For analysis, the ICM of interest is integrated into the FASTPACT framework along with estimates of the effects of technologies, Technology Characterization Models (TCM) of interest. Both the ICMs and the TCMs are generated from information obtained by the ITAC team from a variety of expert sources (both within and outside the team). The framework also incorporates

Monte Carlo, Optimization, Multi-Attribute Decision Making (MADM), and Genetic Algorithm (GA) analysis components.

The outputs are probabilistic estimates of the impacts of technologies (singular or in suites). Output data is then processed in a sophisticated multi-variate decision making tool developed by ITAC, MADM, to provide quantified inputs on technology impacts (e.g. critical technologies for individual concepts, high impact technologies across concepts, and benefit-to-cost ratios). Customer-supplied metrics (and weightings) along with technology development cost estimates gleaned from available data and expert judgments are key inputs. These outputs also serve as a basis for comparisons in progress assessments as ASTP-sponsored development programs mature. Furthermore, the ITAC-generated ICMs can also be easily exercised in sensitivity analyses to rapidly identify high leverage areas and technology gaps. In addition, FASTPACT uses the GA component to rapidly assess suites of technologies and determine the suites that provide the biggest payoff as measured by the MADM module.

The ITAC systems analysis process will be described in this paper, as will the concepts currently being processed, the schedule, and recent results.

Current ITAC Concepts and Schedule

The first three vehicle concepts being examined in the ITAC program are an all rocket, vertical take-off, horizontal landing (VTHL) two-stage-to-orbit (TSTO) system (ICM-1), a horizontal take-off, horizontal landing (HTHL) TSTO system with a 1st stage hydrogen (LH2) fueled turbine-based combination cycle propulsion system and a rocket-based upper stage (ICM-2), and a HTHL TSTO with a LOX/LH2 rocket-based combined cycle 1st stage propulsion system and a rocket-based upper stage (ICM-3).

The all rocket concept serves as a baseline for analysis and will incorporate features of interest from multiple past and present programs. Similarly, both HTHL TSTO concepts draw significant heritage from the NASA-sponsored Access-to-Space (ATS) study[1] and the Air Breathing Launch Vehicle (ABLV) study[2].

A top-level schedule for the ITAC program is shown in Figure 1.

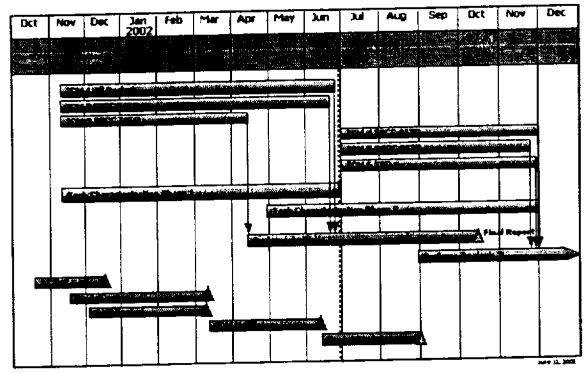

Figure 1. ITAC Top Level Schedule

This schedule is comprised of four segments:

- ICM Development
- Technology Characterization
- Systems Analysis
- Tools Development

The reverse order of delivery in the numbered ICM in the April/June timeframe is due to changes in priority within ASTP. ICM-3 was delivered on schedule and is currently in the systems analysis process, and ICM-2 was nearing completion at the time of this writing. The results shown in this paper are initial results from the ICM-3 development efforts.

In addition to the three concepts described above, the Boeing Aerospace Company (a key member of the ITAC team) has recently submitted the performance module for their Flexible Aerospace System Solution for Tomorrow (FASST) concept. This concept is likely to become ICM-4 on the schedule. Additionally, the data required to develop the performance module for a single-stage-to-orbit (SSTO), TBCC will shortly be delivered by NASA's Integrated Systems Analysis Team (ISAT) and this will be the basis for ICM-5.

ITAC Concept Models (ICMs)

To rapidly assess technology tradeoffs for a particular concept in a probabilistic manner, the ITAC team has created fast-running parametric models of the vehicle concept. The model relates system output responses such as price per pound and turnaround time to input variables such as required vehicle parameters like payload, thrust-to-weight, propulsion system characteristics, cost factors, safety and reliability factors, etc. To generate the model, a concept point design is converted to a fast running parameterized format, the ICM, which is typically in the form of Microsoft Excel workbooks. The ICM can be thought of as similar to a system response surface model of the concept that is valid for a given region about the baseline reference (or operating) point. Each ICM is composed of a series of modules that represent the overall system. These modules currently include a performance module (also contains the weights, sizing, and trajectory information), a cost module, an operations module, and a safety and reliability module. Each of these modules is discussed in more detail below.

The performance module is actually composed of two parts – the weights and sizing model and the trajectory model. The weights and sizing model contains the weight, volume, and area equations for the vehicle systems and uses photographic scaling to re-size the vehicle as necessary to meet the mission mass ratio requirements. This scaling is iterative and is done automatically in Excel. The required mass ratios are determined from the trajectory analysis. Initially, an external trajectory code, Optimal Trajectories by Implicit Simulation (OTIS) version 3.1 is used to generate a closed trajectory to the desired orbit for the vehicle. This is an iterative process between the weights and sizing model and the trajectory code. Typically only two to three iterations are required to converge to a closed solution. Using this converged baseline or reference trajectory, a series of additional trajectories are calculated using thrust-to-weight and area-to-weight ratios as parameters to generate a trajectory response surface. The response surface can then be used to very quickly and easily examine the effects of changes in vehicle parameters due to new technologies. For a given vehicle weight, it can supply a required mass ratio to the weights model and thus the new weight and mass ratios are determined by iteration between the two models.

The operations module is based on an Excel spreadsheet called The Architectural Assessment Tool – enhanced (AATe)[3], developed by NASA/Kennedy Space Center, which is a tool for performing operations analysis and decision making support during the conceptual design phase of a reusable space transportation system. AATe can generate rapid estimates for both a reusable space transportation systems cost and cycle times from landing to launch. These estimates are generated based principally on the systems design and technology, which is input to the tool. AATe is used as a relative comparison tool to evaluate various vehicle configurations. Typical input values include vehicle dimensions and configuration, payload, vehicle reliability and design life, and the level of ops-related technologies like IVHM, etc. Outputs include vehicle turnaround time, fixed and variable operating cost, and facilities acquisition cost.

The NASA-Air Force Cost Model (NAFCOM) developed by SAIC[4] is the basis for the cost module. NAFCOM consolidates numerous existing cost models and databases used throughout NASA. This fully automated software tool employs an easy-to-use spreadsheet environment to predict the cost of space hardware at the subsystem and component levels. The information within NAFCOM represents the best of the aerospace project data from the Resource Data Storage and Retrieval (REDSTAR) library, NASA's major repository of cost, technical, and programmatic information dating back to the 1960s. Cost estimates created within NAFCOM are based on specific analogy and database averaging techniques. The user selects analogous data points from the database within NAFCOM to create specific analogy cost estimating relationships (CERs). After making these selections, the user further refines the CER database by choosing from more than 100 filters within the cost model that relate to the technical and programmatic characteristics of the data points. For the ITAC cost model NAFCOM was used to construct an Excel workbook which calculates costs and which contains the interface to other modules, primarily the weights which are used to calculate costs using the appropriate CERs.

The safety and reliability module is based on a fault-tree analysis of vehicle failure modes. Failure modes analyzed include propulsion system failures (ejector failure, ramjet failure, scramjet failure, turbopump failures, engine cooling failures, etc.), TPS failures, separation system failures, and landing failures.

The ITAC team has completed an RBCC-based TSTO ICM, and is completing a second TBCC-based TSTO ICM. Both vehicles are HTHL with an airbreathing propulsion system for the first stage and an all rocket second stage. Each of these vehicles is described in more detail below.

ICM-3: RBCC-based TSTO Vehicle

An ICM for the RBCC-based TSTO vehicle has been created. The assumed mission is to deliver a 20,000 lb payload in a 12 ft x 15 ft x 30 ft payload bay to a 100 nautical mile orbit due east of Cape Kennedy. Both stages are un-crewed, but the payload can be either passengers or cargo.

The mission can be summarized as follows:

- Vehicle takes off from the launch site in ejector (rocket) mode
- Vehicle transitions to ramjet mode and then scramjet mode
- Ascends to staging Mach number (varies from Mach 6 to Mach 12)
- Conducts a "pull up" maneuver to a dynamic pressure (q) of 500 psf
- Powers off 1st stage propulsion and climbs until q = 200 psf

- Stages separate
- 2nd stage continues by rocket power to orbit
- 1st stage does an unpowered "turnaround" maneuver
- 1st stage cruises under ramjet power (<M=6)
- 1st stage propulsion powers off (M = 3 to 5)
- 1st stage makes unpowered landing at the launch site
- 2nd stage delivers payload
- 2nd stage reenters atmosphere and returns to the launch site for an un-powered landing

A weights and sizing model of this vehicle was constructed and used in conjunction with OTIS to create a closed trajectory. The first stage weight model was derived from the airbreathing/rocket SSTO vehicle that was designed in the NASA Access to Space (ATS) study[1]. It has a wedge-shaped fore body profile lifting-body configuration with all moving horizontal tails, twin vertical tails with rudders, and trailing edge body flaps. The LH2 tank is a cold graphite epoxy (Gr/Ep), integral, conformal, I-stiffened tank that contains pressurized fuel and carries the airframe loads. There is a non-integral aluminum lithium (Al/Li) LOX tank and a Gr/Ep shell structure fore and aft of the integral LH2 tank. There are two six-wheel main landing gear and a two-wheel nose gear. All moving horizontal controls and twin verticals/rudder are constructed of Titanium Matrix Composites.

The thermal protection system (TPS) utilizes Fibrous Refractory Composite Insulation (FRCI-12) over Rohacel (cryogenic closed cell foam) with Toughened, Unipiece Fibrous Insulation (TUFI) coating used on the windward surface. Tailorable Advanced Blanket Insulation (TABI) over Rohacel with Protective Ceramic Coating (PCC-B) is used on the leeward surface. The tank insulation consists of Rohacel plus ceramic reusable surface insulation (RSI). The aerosurface TPS is Carbon/Silicon carbide (C/SiC) over portions exceeding 1960 deg R with carbon-carbon (C/C) leading and trailing edges.

The ATS weights model was altered as follows to match the TSTO first stage requirements:

- Removed external rocket system, crew cabin weights
- Added structural provisions for 2nd stage
- Added separation system weights
- Altered propulsion system weight for RBCC engine

Model volumes included fixed volume for subsystems (from ATS report), propellant tank volume, and volume for the second stage immersion.

The second stage is also a lifting body shape and was based on a TSTO vehicle designed by NASA/Ames Research Center[5]. Some modifications were made:

- Added a body flap for hypersonic trim
- Re-sized the aerosurfaces for maximum landing speed
- Set aerosurface trailing edge sweep to 0 degrees to eliminate adverse yaw due to roll control
- Re-sized payload bay to 12' x 15' x 30'

The second stage also utilizes cold, integral, conformal Gr/Ep LH2 tanks and an Al-Li non-conformal LOX tank. The rocket engine is assumed to be similar to the Pratt and Whitney RL-X[6] and has an assumed thrust to weight of 70 and specific impulse of Isp = 455 seconds. Separate OMS/RCS systems were assumed with associated tanks and lines. Electromechanical actuators were assumed for control surface actuation (no hydraulics). The Fuselage TPS consisted of Advanced Carbon-Carbon on the high temperature areas as well as TABI tiles. The tail uses Shuttle type Reusable Carbon-Carbon (RCC)/ceramic. The body flap and base also use shuttle type ceramic TPS. Dry weight margins of 15% were used on both stages. A summary of the baseline vehicle weights is shown in Table 1.

Table 1. RBCC-based TSTO Vehicle Weights

Item	First Stage	Second Stage
Wing	14,556 lb	0 lb
Tail	2,814 lb	1,874 lb
Body	88,140 lb	15,575 lb
TPS	18,378 lb	9,906 lb
Undercarriage	35,923 lb	4,648 lb
Propulsion	35,601 lb	9,929 lb
Sub-Systems	27,182 lb	11,204 lb
Dry Weight Margin (15%)	39,281 lb	8,740 lb
Dry Weight	261,876 lb	61,875 lb
Payload	348,251 lb	20,000 lb
Propellant (includes residuals and losses)	609,465 lb	266,376 lb
Gross Weight	1,219,592 lb	348,251 lb

The aerodynamic model of the first stage was based on data from another similar vehicle in a NASA/Langley Research Center study done by the Boeing Company[7]. Boeing generated the first stage propulsion data deck used in the trajectory analysis as well. The aerodynamic model of the second stage was created using the Aerodynamic Preliminary Analysis System (APAS) code.

The baseline trajectory assumed that the vehicles staged at Mach 8. Trajectory analysis results are shown in Figures 2 and 3.

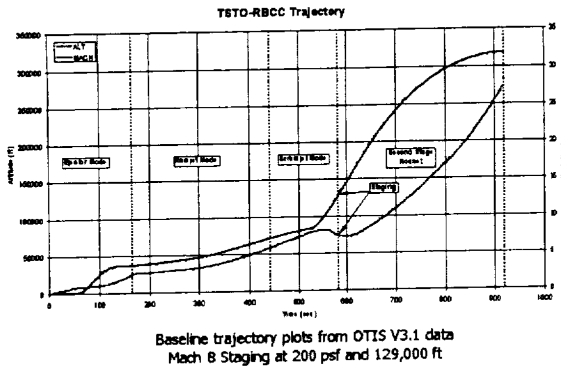

Figure 2. Mach and Altitude vs. Time

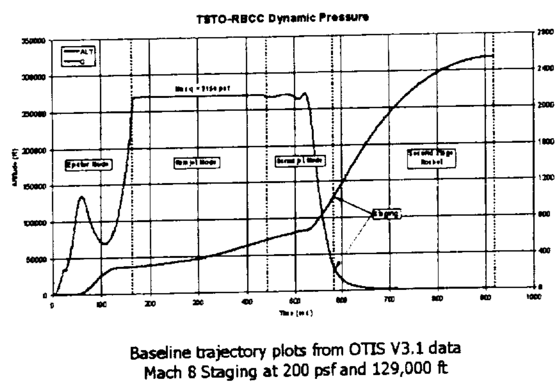

Figure 3. Altitude and Q vs. Time

As described above, these results were used to create a trajectory response surface with parameters of thrust to weight (T/W) and surface area to weight (S/W). This response surface is shown graphically in Figure 4.

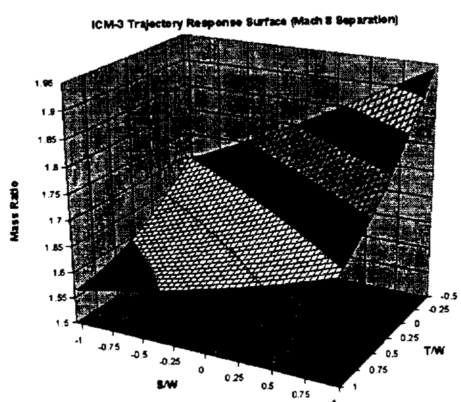

Figure 4. Typical Trajectory Response Surface

The response surface equations were then integrated into the closure module of the ICM. Based on initial outputs, a second set of trajectory runs were performed and a second response surface equation developed so that analyses for Mach 10 staging could also be performed.

ICM-2 TBCC-based TSTO Vehicle

The second vehicle being studied is very similar to the RBCC-based TSTO except for the 1st stage propulsion system. A Turbine Based Combination Cycle (TBCC) engine that consists of an over-under arrangement with the hydrogen-fueled turbojet engines located above the Ramjet/Scramjets is used. The turbojets operate from takeoff until the Ramjet mode is started and the sequence of events is then very similar to the RBCC vehicle. However, after separation the turbojets are eventually restarted to allow a powered descent and landing.

Except for the differences due to the addition of the turbojets, the layout and weights of this vehicle are similar to the RBCC. A detailed analysis of this vehicle is still underway so a baseline weights and trajectory statement is not yet available.

ITAC Systems Analysis

The systems analysis framework leverages commercial-off-the-shelf software to create an easily configured set of components that are integrated to form a rapidly configurable set of analyses. The Excel Workbooks used to create the ICM modules are integrated into the ModelCenter® framework using wrappers to expose the interface variables. A typical analysis is depicted in Figure 5.

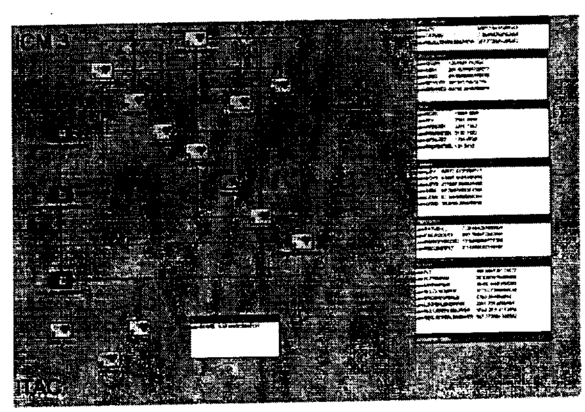

Figure 5. N-squared Diagram for ICM3 in FASTPACT

In this figure we see all of the components of ICM3 and the FASTPCT framework. First across the diagonal from upper left towards lower right are the major ICM-3 components. Each model component represents the Excel spreadsheet that performs the calculations for that module. Then along the left side are three Monte Carlo components specific to economic, concept analysis, and technology analysis disciplines.

Next, the technology impact analysis is performed using components in the lower left portion of the figure—these include the TCM, GA Study, MADM and ITAC GA Monte Carlo modules. Finally on the right side are configurable data monitors that display a condensed list of parameters and values in real-time as the model is run.

The first sets of studies conducted were sensitivity analyses to examine and verify the proper functioning of all the model components. Typically, each component within the ICM is studied individually to determine the value range of input and output variables so that these results can be verified against the modelers' expected values. In most instances, the process begins with a screening analysis using a Placket-Burman or Taguchi type design of experiments to identify the variable main effects within the component. Determining the variable main effects allows the analyst to reduce the number of variables within the design of experiments so that a more complete set of runs can be conducted.

Once the variables of interest are selected, a full or fractional factorial analysis of these variables is conducted to determine the main and second order effects on output variables of interest. For ASTP, the key metrics are Cost, Safety, and Operations related. Typical results of sensitivity analyses on key metrics of interest to ASTP are shown in Figures 6 and 7.

Parameter	Main Effect	Percent Impact
Fixed Recurring Cost Factor	3222.71	22%
2nd Stage I_{SP}	-2905.23	20%
Variable Recurring Cost Factor	2809.59	19%
TFU 1st Stage Engine	393.893	2%
2nd Stage Landing Reliability	-307.783	2%

Note: other factors not presented bring total percent impact to 100%

Figure 6. Subset of Factors That Affect Recurring Cost Per Pound

Parameter	Main Effect	Percent Impact
2nd Stage I_{SP}	348360	27%
1st Stage Hypersonic I_{SP}	-149228	11%
2nd Stage TPS Weight	90257.8	7%
1st Stage Takeoff-Mach1 I_{SP}	-66707.5	5%
1st Stage Mach1-Mach3 I_{SP}	-65406.1	5%

Note: other factors not presented bring total percent impact to 100%

Figure 7. Subset of Factors That Affect Gross Takeoff Weight

Once all the components are found to perform as expected, they are integrated into the analysis framework with the analytic components. These components provide the means to perform extensive parametric and probabilistic analysis. The first sets of analyses conducted are the single technology impact studies, where each technology is overlaid onto the concept vehicle and run via a Monte Carlo process to determine the distribution of key metrics output by the model.

Following the sensitivity analyses, Technology Characterization Models (TCM) are used to capture and describe mathematically the effect a specified technology has on a specified concept. The TCMs are developed by ITAC through researching the technology, discussions with technologists, and evaluation by boards of experts. The TCM consists of a collection of input distributions for ICM input variables that reflect the impact a certain technology could have on these variables and the uncertainty assessed for these outcomes.

For example, a new engine technology could improve the trajectory-averaged I_{sp} and thrust to weight ratio (T/W) of the baseline engine from its expected values of 450 seconds and 20. If the technology is expected to produce 550 seconds of I_{sp} but could produce as much as 700 seconds or as few as 450 seconds, the input could be modeled as a triangular distribution with a low value of 450, a peak value of 550, and a high value of 700.

Similarly, if T/W is expected to be 25 with the new technology but could vary symmetrically around that point, the effect on T/W could be modeled as a normal distribution with a mean of 25 and a standard deviation of 5. The technology is overlaid on the concept by replacing the existing input variables with the TCM distributions and conducting a significant number of Monte Carlo simulation runs to collect the performance output metrics. From this analysis we are able to determine the impact a single technology could have on the performance of the concept, as measured by the ASTP metrics.

A key portion of the technology analyses is the multivariate decision making portion of the process. This portion of the analysis allows the performance metrics to be combined into a single value based on the ASTP goals for technology-to-technology comparisons. Using standard Analytical Hierarchy Process (AHP) techniques, ITAC can elicit customer, ASTP, value judgments for each of the metrics of interest. Regression analysis recreates these value judgments in the form of an equation (Saaty Function) that provides the customer's judgment across the range of possible values. For example, we determined ASTP's perceived value of a variety of price per pound of payload outcomes and generated the Saaty Function where the Saaty Value is the value ASTP placed on a particular price per pound outcome. The 3rd Generation RLV goal of \$100 per pound produces a value of 8 where the scores range from a minimum of 1 to a maximum of 9. The curve fit of these judged values provides a ready means of mapping performance variable outcomes into the decision maker's value space. In this example, the curve fit produced the function:

$$Score = -1.3026\ln(x) + 14$$

where x is the price per pound metric determined by the model outputs. Applying similar logic, we are able to determine the Saaty Functions for each metric and an appropriate weighting among the metrics to produce a weighted average score for any set of metric outputs from the model.

In a similar vein, ITAC conducts multiple-technology analyses to determine the impact of a collection or portfolio of technologies on the concept vehicle. When the number of technologies is sufficiently small, exhaustive enumeration of the combinations is used to generate the test cases; otherwise a heuristic optimization routine (genetic algorithm) is used to intelligently select portfolios for analysis. The genetic algorithm (GA) is coded to turn on or off the technology candidates to form a population of portfolios.

These portfolios are then evaluated using the same logic as used in the single technology analysis methodology with one notable exception, the convolution of the TCM distributions into a single set of input distributions. When multiple technologies are considered for analysis, the likelihood of several technologies impacting the same input variable is increased. In those instances, a method for convolving or combining the input distributions is required.

Once the inputs for a portfolio are convolved, the analysis proceeds as described above to produce output distributions of performance metrics and value scores. These scores form the fitness evaluation for the population of portfolios and influence the selection of portfolios allowed to procreate for the next generation in the GA.

Clearly the weighting of the outcomes is a significant driver for technology selection. Therefore, a sensitivity analysis is conducted to see how the technology selections vary as the weights among the metrics are changed. A sample output from this analysis for a technology portfolio analysis is shown in Figure 8.

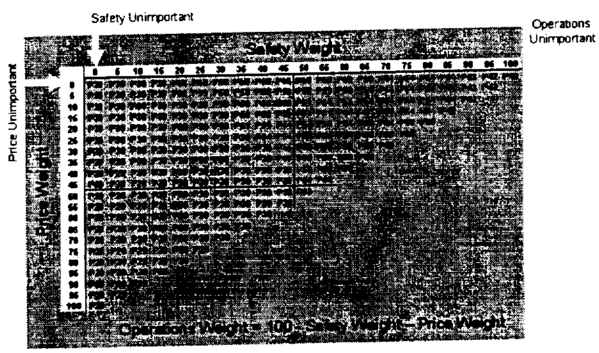

Figure 8. Portfolio Analysis Affected by Weightings

This type of analysis provides users the ability to determine the sensitivity of the technology portfolio selection to variations in the metric weights. Here it is apparent that the weighting of Safety – 50%, Cost – 25% and Operations – 25% produces a portfolio 64 (P64) selection and that reducing the Safety weight to 35% causes a change in preference to a different portfolio.

The final analytic technique available to ITAC is benefit-to-cost analysis. This analysis should not be confused with the cost modeling of the ICM or with the price per pound metric produced by the previous analysis. This analysis attempts to capture the benefits of procuring one or more technologies and balance that with the potential risks with that procurement. In these analyses the benefit portion of the result is generated as described above, the weighted score value for the technology or portfolio. The calculation of the cost portion of the metric involves collecting additional data to develop a weighted score value for cost as was done for benefit. ITAC has used cost metrics involving R&D Costs, R&D Degree of Difficulty, Technology Readiness Levels, and Schedule to develop an AHP based cost methodology. The cost metrics are evaluated and Saaty Functions are developed for each to provide a mapping from the performance domain into the value domain. In this instance low Saaty Scores are preferable to higher scores. Once the functions are defined and the data collected to populate the functions, weighted cost scores are combined to produce an overall cost value. The benefit score value and the cost score value for a particular technology or portfolio are divided to provide a benefit-to-cost ratio. This ratio captures the gains as well as risks or potential problems with a technology selection. This balances the two to provide an overall assessment of which technologies or portfolios provide the most gain for the least risk.

Other analyses are possible using the analysis framework developed. Technology trade-offs, concept evaluations, concept optimizations, and what-if analyses of many types are possible. Continued growth and development of these tools and techniques can provide higher levels of modeling fidelity and more tailored products to support the ASTP program now and well into the future. The value these techniques and tools provide is the rapid means of determining effects and the ability to map those effects into terms relevant to the ASTP goals and decision making processes.

Summary and Directions

The Integrated Technology Assessment Center has developed a flexible framework to provide comprehensive systems analysis to assist in the guidance of ASTP technology development and demonstration programs. A number of RLV concepts based on airbreathing propulsion systems are currently in process along with an all-rocket vehicle for comparison purposes. Results of the first set of probabilistic analyses are nearing completion and it is anticipated that a large suite of concepts will be assessed over the next year.

References

1. Access to Space Study Summary Report, Office of Space Systems Development, NASA Headquarters, January 1994

2. Hunt, J.L., Petley, D.H., Moses, P.L., Martin, J.G., Ferlemann, S.M., Leonard, C.P., Pegg, R.J., Robinson, J.S., Taylor, L.W., Vause, R.F., Pinckney, S.Z., Bouchard, K.A., "Airbreathing Launch Vehicle Study", 50th JANNAF Propulsion Meeting, Salt Lake City, UT, July 11-13, 2001.

3. Zapata, E., Torres, A., "Space Transportation Operations Cost Modeling and the Architectural Assessment Tool – Enhanced", AIAA paper no. IAA-99-IAA.1.1.01

4. NASA/Air Force Cost Model (NAFCOM99) User's Manual, Version 6.0, November 1999, prepared for NASA Marshall Space Flight Center and Air Force Cost Analysis Agency by Science Applications International, Inc.

5. Mehta, U.B., Bowles, J.V., "Two-Stage to Orbit Spaceplane with Growth Potential", Journal of Propulsion and Power, Vol. 17, No. 6, p. 1149-1161, Nov-Dec 2001

6. Bachtel, R., RL-X Datasheet, P&W-Aerojet Propulsion Associates

7. Farrell, D., "Two Stage to Orbit Vehicle Study Overview", The Boeing Co., Final Review of Task 31 NASA Contract NAS1-20341, Presented at NASA Langley Research Center, December 20, 2001.