SpaceWorks Engineering, Inc. (SEI)

A Review of Technology Assessment Methods for Space Transportation Systems

GT-SSEC-B.6
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Technical Fellow and Founder:
Dr. John R. Olds
Introduction to SEI

SpaceWorks Engineering, Inc. (SEI) was founded in 2000 as an aerospace systems analysis and concept development firm in support of the US space program and our NASA, Air Force, DARPA, and commercial industry partners. The firm specializes in providing timely and unbiased analysis of advanced space concepts ranging from space launch vehicles to deep space missions.

Our core disciplinary analysis specialties include:
- Propulsion
- Mass Properties and CAD
- Trajectory Simulation
- Aerodynamics and Aeroheating
- Thermal Protection Systems
- Development and Operations Cost Estimation
- Reliability
- Life Cycle Cost
- Program Risk Assessment
- Technology Impact Analysis

SEI is a small business, employing 8 aerospace engineers and 2 business specialists. Annual revenues are approximately $1.2M. In addition to providing engineering services, the firm also markets specialized engineering analysis software for analysis and optimization of space transportation systems. Our software products include REDTOP, REDTOP-2, Sentry, and RBCC-Designer.
Concepts and Architectures

Including:
- 2nd, 3rd, and 4th generation full and partially reusable Launch Vehicle (RLV) designs (rocket, airbreather, combined-cycle)
- Human Exploration infrastructures in support of U.S. VSE
- Space Solar Power (SSP) deployment
- Launch assist systems
- In-space transfer vehicles and upper stages and orbital maneuvering vehicles
- Lunar and Mars transfer vehicles and landers for human exploration missions
- In-space transportation nodes and propellant depots
- Interstellar missions
- In-space and surface human habitats

Image sources: SpaceWorks Engineering, Inc. (SEI), Space Systems Design Lab (SSDL) / Georgia Institute of Technology
Recent Firm Engagements

**DARPA:** Hypersonic cruise vehicle demonstrator system (HCV-DS) Northrop Grumman subcontract for FALCON program

**DARPA:** Responsive Access Small Cargo Affordable Launch (RASCAL) program subcontract for performance analysis

**AFRL-WPAFB:** Innovative concept development for RLVs using combined-cycle propulsion for military applications

**Lockheed Martin Astronautics:** Assessment of optimization codes for space transportation case studies

**NASA Institute for Advanced Concepts (NIAC):** Phase I Award for asteroid planetary defense

**NASA Institute for Advanced Concepts (NIAC):** Phase I Award for Mars telecommunication networks

**NASA LaRC:** Next Generation Launch Vehicle (NGLT) architecture support

**NASA MSFC:** Quickstrike ETO/In-Space trade tree concept studies for Advanced Concepts Group

**NASA MSFC:** Lunar architecture design studies

**NASA MSFC:** SPLV – Small payload launch vehicle (SPLV) assessment

**NASA MSFC:** Air-launch to orbit (ALTO) study support

**NASA MSFC:** ARTS dual fuel RLV concept with launch assist

**NASA MSFC:** 3rd Gen RLV concept assessment and engineering tool development for Advanced Concepts Group

**NASA MSFC / SAIC:** Space transportation technology prioritization for Integrated Technology Assessment Center (ITAC)

**NASA MSFC:** Heavy-lift launch vehicle configurations predicated on SLI technologies for Program Planning Office

**NASA MSFC:** Database and tool development for Revolutionary Aerospace Systems Concept (RASC) program

**NASA KSC:** Design for Operations (D4Ops) space transportation study

**NASA KSC:** Facilities and Ground Operations Analysis (FGOA) tool development for future space transportation systems

**NASA 2nd Gen RLV / Space Launch Initiative (SLI) Program:** Advanced Engineering Environment (AEE)

**NASA Headquarters:** FY2002 RLV technology goals assessment

**NASA inter-center Value Stream Analysis Program:** Micro and macro level technology implications for 3rd Gen RLVs

**Orbital Sciences Corporation:** Space exploration architecture development for NASA CE&R program

**Pratt Whitney Rocketdyne:** Systems analysis and concept development for ERST engine and power module studies

**SAIC and NAL (Japan):** ATREX engine test program performance assessment
State-of-Practice circa early 1990’s

Due to limited technology development budgets, decision makers must make tough decisions to direct scarce resources. Current resource allocation approaches include (Cetron [1972]):

1. **Squeaking Wheel**: cut resources from every area and then wait and see which area complains the most. Based on the loudest and most insistent, then restore budget until ceiling is hit.

2. **Level Funding**: budget perturbations minimized and status quo maintained; if this approach continues within a rapidly changing technology field, the company, group, or agency will end up in serious trouble.

3. **Glorious Past**: “once successful, always successful”. Assign resources solely on past record of achievement.

4. **White Charger**: best speaker, last person to brief the boss, or the department with the best presentation wins the money.

5. **Committee Approach**: a committee of “experts” tells the manager or decision-maker how to allocate resources. (AHP and QFD might be valuable tools here)

* - info courtesy Michelle R. Kirby, GT ASDL
Background

In support of the technology portfolio manager, expert-based technology assessment and ranking methods are being replaced with more quantitative, simulation-based technology assessment methods from the field of systems engineering and analysis.

Portfolio managers in space transportation-oriented fields at NASA and the US Air Force have been adopting new decision-making methods since the late 1990’s. A range of new methods (processes) and computer tools are available to use from academic and non-academic research teams.

This presentation will survey quantitative technology assessment techniques developed and used at Georgia Tech’s Space Systems Design Lab and SpaceWorks Engineering from 1995 - 2005 (based on the author’s familiarity with this work).
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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| AHP        | Analytic Hierarchy Process  
- expert-based method based on pairwise comparison |
| ATIES      | Abbreviated TIES process |
| ATIMS      | Advanced Technology Investment Management System  
- software product proposed under ITAC but never developed |
| Enhancing Technology | An optional, overlay technology that improves the performance, cost, or reliability of a candidate space vehicle concept |
| Enabling Technology | A prerequisite technology that is fundamental to a particular space vehicle concept (i.e. a nuclear reactor for an NTR vehicle) |
| ITAC       | Integrated Technology Assessment Center |
| OEC        | Overall Evaluation Criteria  
- a single weighted sum of the key output figures of merit |
| ROSETTA Model | Reduced Order Simulation for Evaluating Technologies and Transportation Architectures  
(prior to 2001, called RDS models)  
- a fast, multidisciplinary closure Excel workbook that serves as the numerical engine for the ATIES process |
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>QFD</td>
<td>Quality Function Deployment - an expert-based decision technique based interactions in a House of Quality</td>
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<tr>
<td>TCM</td>
<td>Technology Compatibility Matrix - defines acceptable technology combinations</td>
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<td>TDB</td>
<td>Technology Database - source of k-factors for TIM</td>
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<tr>
<td>TIES</td>
<td>Technology Identification, Evaluation, and Selection process - process for ranking technologies developed by GT’s ASDL</td>
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<tr>
<td>TIM</td>
<td>Technology Impact Matrix - a matrix of k-factors for each affected VIF</td>
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<tr>
<td>VIFs</td>
<td>Vehicle Influence Factors - physical or programmatic assumptions (e.g. Isp, tax rate)</td>
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<tr>
<td>k-factors</td>
<td>k-factors (multiplication factors on VIFs) (aka Technology Performance Metrics) - represents the +% or -% a technology has on a VIF</td>
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<tr>
<td>RSEs</td>
<td>Response Surface Equations - simplified second-order curve fits from more complex analyses</td>
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Overview
Technology Identification, Evaluation, and Selection (TIES). Developed in the mid-1990’s by Kirby and Mavris at Georgia Tech’s Aerospace Systems Design Lab (ASDL). TIES is an eight-step probabilistic process to quantitatively evaluate technology options at the vehicle-level. Uses uncertainties in individual technology performance (k-factors) to generate distributions in vehicle evaluation metrics. Uses Technology Impact Matrices (TIMs) and Technology Compatibility Matrices (TCMs) to additively combine the effects of multiple, compatible technologies. Follows with a multi-attribute decision making method to rank the candidate technologies across several evaluation metrics.

Status
The TIES method is still actively used at Georgia Tech and is taught to graduate design students each year in GT’s Advanced Design Methods I course.

References
TIES: Technology Identification, Evaluation, and Selection

1. Define the Problem
2. Define Concept Space
3. Modeling and Simulation
4. Investigate Design Space
5. Evaluate System Feasibility
6. Identify Technologies
7. Evaluate Technologies
8. Select Technologies

Techniques or Inputs:
- QFD
- Management and IPTs
- Level of Confidence: R&D or direct link (discipline specific)

Results of Outputs:
- Customer Requirements, Budget, Schedule (EJS)
- Customer Requirement Matrices

Morphological Matrix (Alternative and Design Spaces)

TIES Process
Overview
Abbreviated Technology Identification, Evaluation, and Selection. An adaptation made by Charania in the SSDL during the spring of 2000 to the original 8-step TIES process of Kirby and Mavris. ATIES reduced the original TIES method to a more streamlined 6-step process suitable for advanced space systems design. Eliminated early steps for requirements definition, morphological matrices, QFD, etc. under the premise that the method should focus on the quantitative evaluation of technology alternatives for a given concept. Introduced the notion of n-factors (noise-factors) and multiplicative combination of technology k-factors when simulating a technology portfolio. Multi-attribute decision making techniques are retained (e.g. TOPSIS) as well as Technology Impact (TIM, k-factors) and Technology Compatibility (TCM) matrices.

Status
ATIES is the standard quantitative technology ranking process used at Georgia Tech’s SSDL and at SpaceWorks Engineering, Inc. (SEI).

References
**Baseline Concept Determination**
- Requirements = Objectives + Constraints
  - (e.g. CH4 Lunar Lander)

**Technology Identification**
- Technology Alternatives

**Technology Evaluation**
- Physics-based Modeling and Simulation Environment
  - (Fixed Vehicle with constraints on design space exploration)
- Spreadsheet-based ROSETTA model or RSE based upon following disciplines:
  - trajectory, weights, operations, cost, economics, safety

**Technology Filtering**
- Symmetric Matrix
- Technologies

**Technology Impact**
- Technology Impact Matrix (TIM)
  - Technologies

**Technology Selection**
- Analytic Hierarchy Process (AHP) and / or Pugh Evaluation Matrix (PEM)
  - TOPSIS: Best Alternatives
    - Rank Alternatives for Desired Weighting

**Compatibility Matrix**
- Matrix:
  - 1: compatible, 0: incompatible
  - Example:
    - Composite Wing: 1, 1, 1, 0, 1, 1, 1, 0, 0, 0, 0
    - Composite Fuselage: 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
    - Circulation Control: 1, 1, 1, 1, 1, 1, 1, 1
    - HLFC: 1, 1, 1, 1, 1
    - Environmental Engines: 1, 1, 1, 1, 1
    - Flight Deck Systems: 1, 1, 1, 0, 1, 1
    - Propulsion Materials: 1, 0, 1, 1, 1
    - Integrally, Stiffened Aluminum Airframe Structures (wing): 1, 0, 1, 1
    - Smart Wing Structures (Active Aeroelastic Control): 1, 1, 1
    - Active Flow Control: 1, 1
    - Acoustic Control: 1

**Aircraft Morphing**

**ATIES Flowchart**

*Diagram showing the flowchart of the Technology Identification, Evaluation, and Selection (ATIES) process.*
**ATIES Background**

Abbreviated TIES is a modified and enhanced version of the basic TIES process. Developed by A.C. Charania, former graduate student at Georgia Tech’s SSDL and now Senior Futurist at SpaceWorks Engineering, Inc.

- Streamlined basic TIES method for our application by eliminating steps not needed for NASA space applications
  - e.g. societal needs, system requirements, and quantitative metrics and goals are already well defined; concept alternatives already exist
- Introduced concept of funding constraints on technology program (both annual and cumulative) as an additional filter prior to evaluating potential technology portfolios
- Replaced aircraft simulation & modeling environment (RSE’s of FLOPS/ALCCA) with fast-acting ROSETTA models for advanced space systems synthesis
More ATIES Modifications

- Added **programmatic** influence factors (PIFs) as possible design impacts
  - e.g. market size, gov’t financial packages, variable commercial IRR

- Added **safety metrics** as key element of ROSETTA models (Cat III model)

- Changed economic measures to more space-oriented outputs
  - e.g. IRR, NPV, cost/lb. of payload, price/lb. of payload

- Replaced TRL-dependent Weibull distributions on k-factors with simpler high/most likely/low triangular distributions
Example SSTO RLV Application of TIES with 5 Technologies
Typical Deterministic vs. Probabilistic Metric Comparison

Gross Weight Comparisons - Deterministic vs. Probabilistic

A = High T/W rocket engine, B = MMC airframe structures, C = self-healing, long-life TPS, D = Slush LH2, E = GrEp propellant tank structures
Technology Selection Using TOPSIS Technique with 3 Weighting Scenarios

Overall Evaluation Criterion (OEC) Comparison

Overall Ranking of Technology Portfolios: Probabilistic @ 80% Certainty

Based upon multiple metrics which are aggregated and ranked using decision making methods such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) for a particular weighting scenario.

A = High T/W rocket engine, B = MMC airframe structures, C = self-healing, long-life TPS, D = Slush LH2, E = GrEp propellant tank structures

Cost and Safety Focus
Geometry and Operations Focus
Broad Average of Scenarios
ROSETTA

Overview
Reduced-Order Simulation for Evaluation of Technologies and Transportation Architectures. An Excel-based multi-sheet workbook for rapidly assessing the performance and economic impacts of changes to various inputs variables (VIFs -- vehicle influence factors). New name adopted in Fall 2000 to replace RDS Model. ROSETTA models are parametric so that sensitivities of cost and weights variables can be determined as a function of changing inputs such as Isp, unit weights, payload, and other VIFs, as well as programmatic influence variables (PIFs) such as market size, tax rates, incentive return. Depending on detail, ROSETTA models can be Type I (performance loop only, weight estimation and trajectory closure), Type II (adds cost and economics closure, price per pound, etc.), or Type 3 (adds Safety and Reliability). Unlike top-level meta-modeling techniques, ROSETTA models retain disciplinary distinction and a reasonable level of disciplinary fidelity. However, ROSETTA models are fast-acting and thus offer a practical simulation engine for probabilistic analysis unlike a complete, multi-legacy code, distributed simulation environment such as AEE.

Status
Since 2000, SSDL and SpaceWorks Engineering have created and published a number of ROSETTA models for rapidly simulating various space systems including: Hyperion SSTO, ACRE-92 SSTO, Solar Clipper, Bimese TSTO, Gen2 Follower TSTO (all SEI); and Swarm SEP OTV, Bimodal-NTR MTV, Solar Sail, TurboStar TBCC TSTO, Aztec TBCC TSTO, Vega RBCC SSTO (all SSDL).

References
Simulation Fidelity vs. Speed

Increasing Execution Speed

- Integrated Design Teams
- ROSETTA model (Multi-sheet Excel Workbook)
- Represents best model compromise for ATIES
  \[ \text{price} = 230 - 0.015 \times Isp^2 + \ldots \]
- Meta-Models (Single RSEs)

Increasing Analysis Fidelity
Sample RLV DSM

Aerodyn. & Ext. Geom.
Ref. Config & Packaging
Propulsion
Trajectories
Aeroheating & TPS
Weights & Sizing
Operations & Facilities
Safety & Reliability
Cost & Bus. Econ.

feedback links, iteration
feedforward links

No feedback here for rocket-only case

strong link
weak link

Resulting Point Design
Tall Poles in Full Simulation (All-rocket RLV Example)

Goal is to reduce execution speed to 1 - 2 seconds while retaining as much accuracy as possible in the ROSETTA model.

- Candidate to have non-dimensional values held constant
- Candidate for multi-variable RSE curve fit (discipline meta-model)
- Candidate for direct retention (already a spreadsheet-class model)
- Candidate for reduced complexity analysis, simplifications
Solution Approach

1. For a given technology portfolio assessment case, add all k-factor effects and apply aggregate to RDS model VIF’s on I/O page
   - note this process typically invalidates both the closure model (required Mass Ratio ≠ available Mass Ratio and NPV at 25% discount rate ≠ $0)

2. Use Excel® built-in Solver to simultaneously adjust vehicle physical scale factor (length) and market price until performance closure and economic solutions are reestablished
   - note that iteration within and between individual sheets in the workbook will be required

3. Record new weight, sizes, costs, price and safety metric
   - note in a deterministic case, this completes the analysis for this technology combination. In a probabilistic case, the process must be repeated about 1000 times
ROSETTA Model

Vehicle Influence Factors (Parametric “Knobs”)

ROSETTA

Outputs that Measure Progress toward NASA Goals

**ROSETTA Model Characteristics**

- **Fast**
  - executes each architecture simulation in **one or two seconds**

- **Robust**
  - VIF’s can be changed over a range to vary outputs **without crashing**

- **Standard I/O Interfaces**
  - follow standard WBS to allow **automated process to vary VIFs**
<table>
<thead>
<tr>
<th>Cat I</th>
<th>Produces traditional physics-based outputs such as transportation system weight, size, payload and the NASA metric <strong>in-space trip time</strong></th>
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</thead>
<tbody>
<tr>
<td>Cat II</td>
<td>In addition to above, adds additional ops, cost, and economic analysis outputs such as turnaround time, LCC, cost/flight, ROI, IRR, and the NASA metric <strong>price/lb. of payload</strong></td>
</tr>
<tr>
<td>Cat III</td>
<td>In addition to above, adds parametric safety outputs such as catastrophic failure reliability, mission success reliability, and the NASA metric <strong>probability of loss of passengers/crew</strong></td>
</tr>
</tbody>
</table>
Overview
Advanced Technology Investment Management System. A software simulation environment for assessing the probabilistic effects of advanced technologies on sample space transportation vehicle configurations. Conceived by Georgia Tech (J. Olds) in response to a NASA MSFC request (Lyles and Hyde) in the spring and summer of 2000. ATIMS was to be developed by software developers at SAIC Huntsville. ATIMS was to consist of a custom GUI which allowed users to select candidate technologies, edit their associated k-factors, then drive a Excel-based ROSETTA model through several hundred or a thousand simulations to obtain statistical distributions of key outputs such as payload price per pound, loss of crew reliability, vehicle empty weight, etc.

Status
Some preliminary development of ATIMS took place during the summer of 2000 then was incorporated into the ITAC contract as a software development task. ATIMS was later abandoned due to the high development cost.

References
Overview
A ModelCenter-based simulation environment for implementing the ATIES process. TechSim was jointly created by Georgia Tech’s SSDL (J. Young and I. Clark) and SpaceWorks Engineering (M. Graham) during the fall of 2003 and the spring of 2004. TechSim is both a technology portfolio optimization tool and a probabilistic simulation environment. At present, it only evaluates one vehicle concept at a time (i.e. only one ROSETTA model is being operated on). By its nature, TechSim only optimizes the enhancing technologies that are applicable to the concept. Enabling technologies are, by definition, “on” in the simulation of a given vehicle.

Status
TechSim is the current automated modeling approach for implementing ATIES at both SSDL and SEI. However, NASA’s interest since 2004 has shifted away from reusable launch vehicles (STS replacements) toward lunar and Mars exploration. With these new missions, technology modeling must be moved to an architecture level, where multiple space vehicles are needed to represent an entire transportation system (e.g. launch, cis-lunar transfer, descent to surface, etc.). In principle, ATIES as a process is still applicable, but TechSim is currently limited to one ROSETTA model per simulation. One solution is to separately evaluate the effect of a technology or portfolio of technologies on each of the vehicles in the architecture, then simulate an entire campaign using the “modified” flight vehicles (with MSAT, for example) to determine architecture-level metrics. These new metrics can then be compared to those from the baseline.
TechSim (screen shot)
Overview
Technology Roadmapping and Investment Planning System. A new strategic, technology planning process being developed at Georgia Tech’s Space Systems Design Lab to focus on the development risks and implications of technology choices during the technology maturation phase of a project. Unlike previous technology assessment methods, TRIPS allows multiple vehicle solutions to be active at any time. In addition, TRIPS simulates the temporal effects of scheduling technology programs over several years and at different levels of effort (both cost and schedule risk). Probabilities of success/failure of individual technology programs are simulated with Monte Carlo analysis. A Genetic Algorithm driver allows optimization of a long-range technology strategy considering annual budget constraints, program implementation year, and positive benefits of FOMs. Unlike previous methods, TRIPS can consider enabling as well as enhancing technologies.

Status
Until recently, TRIPS was currently under development at Georgia Tech’s Space Systems Design Lab and was partially supported by URETI funding through the University of Florida and the NASA ICP ATLAS project (now terminated). New funding sources are being sought. TRIPS runs in the ModelCenter environment.

References
TRIPS Components

GA determines optimum selection of active technologies and appropriate funding of each as a function of to achieve a required confidence in meeting project technical goals (e.g. reliability or cost per mission) subject to annual technology funding limits.

Transition probabilities from one TRL to the next TRL are based on Markov chain data and applied funding level. Technologies have “real-world” behaviors such as missed milestones, test failures, cost overruns. Transition results are simulated probabilistically for 500 - 1000 replications of the probability catalog tool.

TRIPS is implemented in Phoenix Integration’s ModelCenter.
Contact Information

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## Master VIF List

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1. List Technical X Factor Elements</td>
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<td>7.</td>
<td>0.4 Tax Holiday Program Duration</td>
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<td>8</td>
<td>8.</td>
<td>0.5 Government Cargo Flights per Year</td>
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<td>9</td>
<td>9.</td>
<td>0.6 Required Internal Rate of Return (IRR)</td>
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<td>Commercial Market Growth Factor</td>
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0. Create Technology Database (TDB)
   - data must include TRL, R&D³, annual and cumulative to TRL 6 funding requirements, expected +/- multiplier on a variety of vehicle influence factors (high/most likely/low k-factors for subsequent TIM), and any technology incompatibilities (for the subsequent TCM)

0. Establish Programmatic Assumptions and Budgetary Constraints
   - sensitivity to government financial support, market growth and overlays, and technology budget ceilings can later be used to perform sensitivity studies

A. Create a parametric ROSETTA model around baseline reference point for each candidate vehicle design
   - designers must include a list of key enabling technologies from TDB (‘gotta-haves’)
   - RDS model VIF’s and outputs should be consistent with master VIF WBS list
ATIES Steps (2)

B. Technology Identification
   - cross reference VIF’s from the RDS model with technologies that affect those VIF’s from the TDB to enumerate potential technology portfolio candidates
   - note that designer identified enabling technologies must be included in each candidate portfolio

C. Technology Filtering
   - eliminate certain technology portfolios based on annual and cumulative funding ceilings, technology incompatibilities (from TCM), and engineering judgement
   - ideally, no more than 20 - 30 candidate technology portfolios should be carried forward

D. Technology Impact
   - create the TIM which contains the k-factors for each technology vs. the affected VIFs
   - for a probabilistic analysis, the TIM will contain k-factors in the form of triangular distributions (low/most likely/high)
   - for a deterministic analysis, the TIM will contain only the most likely values
ATIES Steps (3)

E. Technology Evaluation
- use the RDS model to assess the output metrics (price, trip-time, safety) for each candidate technology portfolio; build a single OEC based on each result
- for a probabilistic analysis, evaluation of each candidate technology portfolio requires about 5000 separate analyses to build cumulative distributions and confidence values
- for a deterministic analysis, only a single RDS model run is required for each technology portfolio

F. Technology Selection
- use TOPSIS, Pugh, or other MADM technique to rank technology combinations based on their impact on the weighted OEC or on each of the key NASA metrics individually

When multiple vehicle candidates exist in a mission category (highly likely), the ATIES process must be repeated for each candidate, then a MADM technique like TOPSIS can be used to weight the best technology portfolio across all concepts (weight by best OEC, SPST preference, etc.)
Overview
Integrated Technology Assessment Contract (or Center). A multi-organization contract managed by SAIC. ITAC was awarded to SAIC and its subs and suppliers in the fall of 2000 and continued for several years. Original teammates included SAIC Huntsville, Georgia Tech SSDL, SpaceWorks Engineering, Boeing, Orbital Sciences, Lockheed Martin, Andrews Space, McKinney Associates, and PMC. The goal of the center was to develop and implement an annual technology assessment process in support of NASA’s Advanced Space Transportation Program office at NASA MSFC. The original NASA COTR was MSFC’s Bill Pannell. Approximately 10 - 15 new parametric concept models (ROSETTA models, later ICM) were to be created each annual cycle by the “design organizations” in ITAC. Concepts were to be drawn from ETO, near-Earth in-space, cis-lunar, planetary, and interstellar space transportation. “Evaluation organizations” on the team were to apply a quantitative technology ranking and evaluation process based on GT’s ATIES process to the annual concepts to determine the most positive technology impacts. The ATIMS software environment was to be used as the software tool that implemented the process.

Status
Due to differences in technical approach, SEI left ITAC in May of 2001. Georgia Tech SSDL left ITAC in August of 2001 due to contractual payment issues and intellectual freedom and control differences. ITAC continued under SAIC management with limited participation from the original team members until it was integrated into NGLT-SA activities in 2002.

References
NASA ASTP users will use custom ATIMS interface to prioritize and assess technologies based on a modified version of the Georgia Tech TIES method (ATIES).

**ASTP ATIMS**

**MODE**
- ● Assess new technology set
- ○ Track progress of funded technology
- ○ Look for technology gaps

**Technology Available**
- Tech A
- Tech B
- Tech C

**Vehicles Available**
- Hyperion
- ABLV-92
- Bimese

**Government financial programs**

Select one or more

Button goes to Gov't financial Incentives page
ICM

Overview
ITAC Concept Model. Name change promoted by SAIC Huntsville to supercede and replace ROSETTA model the latter assumed to be too closely linked with Georgia Tech and SEI work in this area. ICM created a sense of something new being developed by the new ITAC activity.

Status
In late 2000 and 2001, an ICM was nothing more than a renamed ROSETTA model. ICMs were multi-sheet Excel workbook with performance, cost, and safety elements that could be used to rapidly predict the FOMs of a concept given a list of k-factors or n-factors. As ITAC was superceded by NGLT-SA, the concept of an ICM became associated with the elements of a concept closure model in FASTPACT. Current ICMs consist of separate Excel worksheets (one for each discipline) rather than an integrated Excel workbook like a ROSETTA model.

References
Overview
ModelCenter is a commercial multidisciplinary design environment developed and marketed by Phoenix Integration, Blacksburg VA. ModelCenter, along with the companion product Analysis Server, allows the creation of a distributed, multidisciplinary design simulation environment by allowing distributed analyses, heterogeneous computing platforms, automated data exchange, data recording, optimization, and data plotting. ModelCenter is extensible through a series of plug-ins and Java applets that perform response surface fitting, Mote Carlo simulation, etc. ModelCenter forms the basis of NASA’s Advanced Design Environment (AEE), Boeing’s BVIDS, SAIC’s FASTPACT, SSDL’s TRIPS, and SSDL/SEI’s TechSim simulation environments.

Status
ModelCenter is the standard computing environment for both Georgia Tech’s SSDL and SpaceWorks Engineering. ModelCenter was first adopted by SSDL in Feb. 2000 and become the leading environment after a comparative evaluation of competing frameworks (iSight, AML) performed by A. Scott in spring of 2001. ModelCenter was adopted by SEI as its environment of choice in Fall 2000. Pi Blue Software’s OptWorks and ProbWorks commercial packages are add-ons to Phoenix’s ModelCenter.

References
Genetic Algorithms

Overview
A stochastic optimization technique pioneered in the 1970’s by Goldberg, et al. GA’s use the paradigm of natural evolution (survival of the fittest) to identify a set of preferred design solutions. GA’s are particularly well suited to technology selection due to the discrete nature of technology portfolios (each technology can be “on” or “off”) and the non-smooth nature of the output metrics.

Status
GA optimization is taught to all graduate design students at Georgia Tech in Advanced Design Methods II (and predecessors since 1995). In SSDL, GA’s were first used for RLV economic optimization research by Steadman in 1998. Subsequently, Palisade’s commercially-available Evolver plug-in for Excel was used for stochastic optimization (McCormick, Charania, 2000). In the summer of 2002, SpaceWorks Engineering released its commercially available OptWorks package of optimization plug-ins for ModelCenter, the license for which was later sold to Pi Blue Software. OptWorks includes two Genetic Algorithm drivers -- GA and AutoGA. OptWorks_GA is currently the baseline GA driver at SSDL and SEI and is a standard component of the SSDL/SEI TechSim technology selection environment.
Monte Carlo Simulation

Overview
A direct probabilistic simulation approach in which input values are sampled from a specified probability distribution over many trails in order to build distributions of key output variables (aka forecast variables). While alternative approaches exist that attempt to approximate the output distribution and speed up the simulation, direct Monte Carlo methods are still widely used and are considered to most accurate.

Status
Monte Carlo simulation techniques are taught to all graduate design students at Georgia Tech in Advanced Design Methods I. In SSDL, Decisioneering’s Crystal Ball plug-in to Excel has been in widespread use since 1995 for robust, probabilistic design simulation. Palisade’s @Risk plug-in for Excel offers similar capabilities. In 1998, McCormick and Olds used Crystal Ball to compare weight growth sensitivities for various RLV approaches. In 2002, SpaceWorks Engineering, Inc. released its commercially available ProbWorks package for ModelCenter that includes an upgraded Monte Carlo driver component. ProbWorks was subsequently sold to Pi Blue Software. ProbWorks_MonteCarlo is currently the baseline Monte Carlo driver at SSDL and SEI and is a standard component of the SSDL/SEI TechSim technology selection environment.

References
2. Pi Blue Software, see www.piblue.com
ROSETTA Models Interface w/ATIMS (circa 2000)

By using a standard I/O definition, ROSETTA models from a variety of sources can be opened and manipulated by ATIMS to generate required analysis results.
ROSETTA Example -- ETO Concept

- **Required Outputs**
  - Price/lb. of cargo to NASA
  - Probability of loss of passengers/crew

- **Contributing Analyses within the ROSETTA model**

  - Aerodynamics
  - CAD/Packaging/Geometry
  - Propulsion
  - Aeroheating/TPS
  - Trajectory
  - Mass Properties/Closure
  - Operations
  - Non-Recurring Cost
  - Recurring Costs
  - Reliability/Safety

  **Cat I discipline**  **Cat II discipline**  **Cat III discipline**
## SSDL RLV Design Toolset

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Tool</th>
<th>Developing Org.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamics</td>
<td>APAS (S/HABP)</td>
<td>NASA - LaRC</td>
</tr>
<tr>
<td>CAD &amp; Packaging</td>
<td>I-DEAS</td>
<td>SDRC (commercial)</td>
</tr>
<tr>
<td>Propulsion (rocket)</td>
<td>SCORES</td>
<td>Georgia Tech</td>
</tr>
<tr>
<td>Propulsion (RBCC)</td>
<td>SCCREAM</td>
<td>Georgia Tech</td>
</tr>
<tr>
<td>Trajectories</td>
<td>POST (3-DOF)</td>
<td>NASA - LaRC</td>
</tr>
<tr>
<td>Aeroheating &amp; TPS</td>
<td>T-CAT/Miniver/TPS-X</td>
<td>GT/NASA - LaRC/ARC</td>
</tr>
<tr>
<td>Mass Properties</td>
<td>Excel-based MERs</td>
<td>various sources (LaRC)</td>
</tr>
<tr>
<td>Operations &amp; Facilities</td>
<td>AATe/RMAT/OCM</td>
<td>NASA - KSC/LaRC/MSFC</td>
</tr>
<tr>
<td>Safety &amp; Reliability</td>
<td>GT Safety</td>
<td>Georgia Tech</td>
</tr>
<tr>
<td>Cost &amp; Economics</td>
<td>CABAM/NAFCOM</td>
<td>GT/NASA - MSFC</td>
</tr>
</tbody>
</table>

The table lists the tools used in various disciplines of spacecraft design and their corresponding developers.
### Sample Vehicle Influence Factors (VIFs)

<table>
<thead>
<tr>
<th>G.1</th>
<th>Gov't Facilities Offset Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.1</td>
<td>Required Commercial IRR</td>
</tr>
<tr>
<td>P.1</td>
<td>$isp_bar$ (avg. propulsive Isp w/o losses)</td>
</tr>
<tr>
<td>P.2</td>
<td>Drag Losses During Ascent</td>
</tr>
<tr>
<td>W.1</td>
<td>Wing and Tail Weight</td>
</tr>
<tr>
<td>C.1</td>
<td>Facilities Cost</td>
</tr>
<tr>
<td>M.1</td>
<td>Ground Turnaround Time multiplier</td>
</tr>
<tr>
<td>C.1</td>
<td>ETO Launch cost [$/kg]</td>
</tr>
<tr>
<td>W.1</td>
<td>Payload mass [kg]</td>
</tr>
<tr>
<td>P.1</td>
<td>Sail density [g/m²]</td>
</tr>
<tr>
<td>P.2</td>
<td>Sail support structure [kg/m²]</td>
</tr>
<tr>
<td>P.3</td>
<td>Sail reflectivity (0 to 1)</td>
</tr>
<tr>
<td>P.4</td>
<td>Sail area [m²]</td>
</tr>
<tr>
<td>O.1</td>
<td>Gross Weight [lb]</td>
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<tr>
<td>O.2</td>
<td>Dry Weight [lb]</td>
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<tr>
<td>O.7</td>
<td>Gov't Price/lb of Payload [$ (2000)]</td>
</tr>
<tr>
<td>O.10</td>
<td>Net Present Value [$ (2000)]</td>
</tr>
<tr>
<td>O.12</td>
<td>Safety Metric [flights between LoL]</td>
</tr>
<tr>
<td>O.1</td>
<td>Trip time [years]</td>
</tr>
<tr>
<td>O.2</td>
<td>Vehicle weight [kg]</td>
</tr>
<tr>
<td>O.3</td>
<td>DDT&amp;E cost [$B]</td>
</tr>
<tr>
<td>O.4</td>
<td>Operations cost [$B]</td>
</tr>
<tr>
<td>O.5</td>
<td>Total Life Cycle Cost [$B]</td>
</tr>
</tbody>
</table>

ETO Concept

Interstellar Concept

**Subset**