SmallSat Conceptual Design Trade and Cost Modeling Tool

Dr. Deganit Armon
Advatech Pacific, Inc.

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Team

- Advatech Pacific, Inc.
  - John Carsten
  - Deganit Armon
  - Dana Sherrell
  - Michael Paisner
  - Mark Sutton
  - Steve Mysko
  - Paul Dorman
  - David Cantwell

- Air Force Research Laboratory, Space Vehicles Directorate
  - Brent Hamilton
  - Ross Wainwright

- MCR LLC
  - Roy Smoker
  - Daniel Feldman

- Tecolote Research
  - Al Milton
  - John Trevillion
  - Darren Elliott

- Rocket Science Solutions, Inc.
  - Jerry Sellers
Advatech Company Overview

- Founded in 1995, Owned/Operated by Aerospace Engineers
- Locations in California, Arizona and Virginia

R&D and Engineering Services

- Integrated tool development and analysis
  - Space vehicle modeling
  - Launch vehicle design and cost
  - Hypersonic vehicles
  - Trajectory analysis
  - Range safety (Responsive Range Safety)

- Software design and development

- Engineering design and analysis
  - Structural
  - Thermal
  - Composites
  - Advanced space propulsion (electric / nuclear)
  - Tactical communications
Traditional Design Approach

Early Design Challenges of High-Performance Complex Systems

What is the current design process?

- Payload Design
- Satellite Bus Design
- Propulsion Design
- Launch Options
- Operations Analysis
- Cost Risk Analysis

System Requirements

- Mission requirements
- Size, weight, power
- New technology insertion
- Performance
- Schedule

Communication challenges

Slow And Expensive!
Integrated Design Approach

Solution to Early Design Challenges of High-Performance Complex Systems

*Integrated optimizing tools provide:*
Integrated Tool Suite Benefits

- Continuous trade study capability throughout the acquisition life cycle
- Iteratively model key parameters in the pre-system acquisition phase
  - ConOps
  - Performance
  - Cost
  - Schedule
  - Technology risk
- Responsive turnaround – days, not weeks!
- System and subsystem trade analysis
- Continuous knowledge capture and update

Fundamental enabler for building the best performing system within the cost, schedule and technology constraints
Advatech Integrated Projects

- Space vehicle design and cost (ACES-ISET)
- Advanced Cost Model (ACM)
- Launch vehicle design, operations and cost (IPAT)
- Hypersonic aeromechanics tool (IHAT, FPAT)
- Integrated Physics Based Cost / Risk Analysis Tool (ICAT)
- Composite Rotor Blade and Wing Structural Design Tool
- Component Integrated Modeling Simulation and Test Analysis Environment (CIMSTA)
- Naval Engineering Analysis Tool (NEAT)
- Virtual Satellite Integration Effort (VSIE)
- Small Satellite Launch Vehicle (SPRITE)
- Analytical Methods for Sandwich Core Termination
- Integrated High Payoff Rocket Propulsion Technology (IHPRPT)
- Aircraft Vulnerability Model (AVM)
- Combined Hall Effect Thruster Code (CHETC)
- Field Reverse Configuration (FRC) Thruster Model – Orbit Transfer Vehicle System Model
- Highly Mobile Tactical Communications (HMTC)
- Integrated Solid Motor Analysis Tool (ISMAT)
SmallSat Conceptual Design Tool

- Advanced Computational Engineering Simulator – Integrated Space Analysis Tool (ACES-ISET)

- Customer: Air Force Research Laboratory, Space Vehicles Directorate, Kirtland AFB, NM

- Partners: Tecolote Research, MCR LLC, RSSI

- An integrated, multi-disciplinary engineering tool suite
  - Optimizes the design and cost of space vehicles
  - Models the space environment
  - Selection of launch vehicles and modeling launch operations
  - Perform mission planning trade studies
  - Visualization of results
Integrated System and Cost Model (ISCM) - Tool Suite

**Launch Vehicle Module**
- Launch Vehicle Design
- Trajectory analysis

**Life Cycle Cost Module**
Space Vehicle - Launch Vehicle
- Development & Production Cost
  - LCC Cost/Risk
  - TRL
  - Cost Growth
- O&M Cost Module
  - Mission
  - ConOps
  - Infrastructure
  - Resources

**Space Vehicle Module**
- Space Vehicle Design (SMAD)
- Space Vehicle Propulsion
- Orbit Propagation
- Space Vehicle Costing (ACEIT)
  - Radiation Exposure
  - Radiation Detector Response
  - On Orbit Operations

**Visualization**
- ATSV – Trade space
- STK, SOAP – Specific mission

**Historical/Knowledge Database**
ACES Conceptual Design

Mission
Requirements
- Payload
- Orbit
- ...

Space Vehicle Module
- SV Design (SMAD)
- Radiation Environment

Launch Vehicle Module
- LV Design (IPAT)
- Trajectory Analysis

Cost Modules
- SV Cost
- SV Operations Cost
- LV Cost (ACM)
- LV ConOps (SCM)

Optimized Design
Cost Estimating

- Cost modules fully integrated with design tools
- Cost estimating relationships based on
  - historical data
  - sub-system weights
  - materials
- Historical data used to identify cost growth rates related to Technical Readiness Levels (TRL)
- Cost and schedule are related to TRL and system engineering milestones
- Built in risk estimating capabilities
Cost Risk Estimates

Cost growth incurred as technology matures

PDR  →  CDR  →  FCA  →  IOC
TRL 4-5  TRL 5-6  TRL 6-7  TRL 7-8

Risk

Triangular bounds (L,M,H) on weights drive S-Curves

Determined using FRISK, a deterministic risk analysis tool

S-Curves shift to the right with cost growth
Applications

Examples of Trade Studies

- Effect of subsystem reduction on total vehicle design
- Concept evaluations of proposed TacSat-5 concepts
- Cost impact of alternative TacSat-3 designs
- Launch vehicle selection and cost for satellite constellation
- Trajectory analysis for DSX alternative orbits
- Concept modeling for ORS modular satellite architectures
Sensitivity Study

Study highlights

- Quantitative and qualitative data on the impact of decreasing Size, Weight and Power (SWAP) of individual subsystems on the overall space vehicle SWAP

- Insight on space vehicle subsystems & components interaction

- Determined feasibility of reducing Space Vehicle mass by factor of 4
  - Only through cross-subsystem functionality

- Identified two major areas for future focused research
  - energy conversion
  - structural materials

- Presented at the 6th Responsive Space Conference 2008

Expectations for return on research investments can be bound by quantifying system-level effects of a single breakthrough
Sensitivity Study – Sample Results

Effect of subsystem 10x mass reduction on total space vehicle mass
Each bar represents the effect of a single subsystem mass reduction
TacSat-5 Concept Evaluations

- Study highlights
  - Source solicitation evaluation
  - Tiger Team approach
Integrated Design Approach

Solution to Early Design Challenges of High-Performance Complex Systems

Integrated optimizing tools provide:

- Integration Core Module
- Payload Module
- Propulsion Module
- Launch Module
- Operations Module
- Cost/Risk Module

System Requirements
- Mission requirements
- Size, weight, power
- New technology insertion
- Performance
- Schedule

In Days Not Weeks!
TacSat-5 Concept Evaluations

- Study highlights
  - Source solicitation evaluation
  - Tiger Team approach
  - Thirteen concepts evaluated (classified and unclassified)
  - Identified and quantified issues with concept proposals:
    - Projected costs that exceed available budget
    - Costs that assume payload design heritages not supported in proposal
    - High risk payloads based on low TRLs, long development schedules or payloads exceeding mass budget limits
  - Identified and quantified issues with transitioning to operational version
  - Demonstrated that some proposals/CONOPS
    - Contained inconsistent assumptions
    - Contained questionable assumptions that needed further investigation

Knowledge gained during conceptual design phase enabled decisions about designs and mission capabilities before a large investment was committed
Alternative TacSat-3 Designs

- Study highlights
  - Ongoing study
  - Determine subsystem design changes needed to create an “operationalized” version of TacSat-3.
    - Model and evaluate design modifications
      - Baseline design
      - Payload reductions
      - Increased mission length
      - Subsystem redesign with newer technologies
  - Determine cost of design modifications
  - Select and determine procurement costs of launch vehicles needed to launch a satellite constellation

Cost estimates for design modifications are affected by subsystem heritage and technology maturity.
Lessons Learned

- Selecting integration environment
  - License cost
  - Performance (speed)
  - Portability (platforms)
  - Flexibility and ease of development
  - Scalability
  - Automated parameter management (facilitates trade studies)
  - User interface

- Selecting M&S tools to be integrated
  - Existing customer tools
  - Validation level (industry accepted)
  - OTS versus development

- Data availability and reliability
  - Proprietary data
  - Validation level

- Export control and use restrictions

- Managing customer expectations
Conclusions

● Integrated tools suites
  ▪ provide substantiated, traceable and reproducible results
  ▪ reveal interdependencies of cost, risk, schedule, and performance
  ▪ provide higher confidence in cost and schedule estimates
  ▪ enable better management of technology investment by decision makers

Concepts and processes are applicable to design domains beyond space