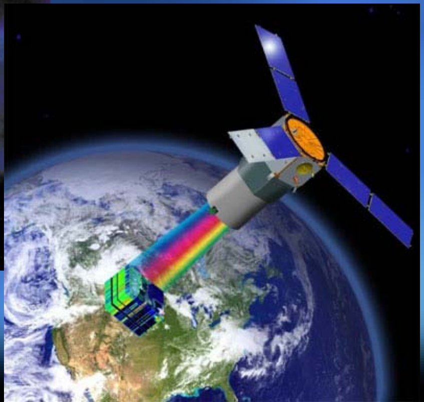
SmallSat Conceptual Design Trade and Cost Modeling Tool



Dr. Deganit Armon

Advatech Pacific, Inc.

NDIA 12th Annual Systems Engineering Conference

Systems Engineering Development Environment

October 29, 2009

Team

- Advatech Pacific, Inc.
  - John Carsten
  - Deganit Armon
  - Dana Sherrell
  - Michael Paisner
  - Mark Sutton
  - Steve Mysko
  - Paul Dorman
  - David Cantwell
- MCR LLC
  - Roy Smoker
  - Daniel Feldman
- Air Force Research Laboratory, Space Vehicles Directorate
  - Brent Hamilton
  - Ross Wainwright
- Tecolote Research
  - Al Milton
  - John Trevillion
  - Darren Elliott
- Rocket Science Solutions, Inc.
  - Jerry Sellers

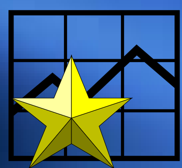
Advatech Company Overview

- **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

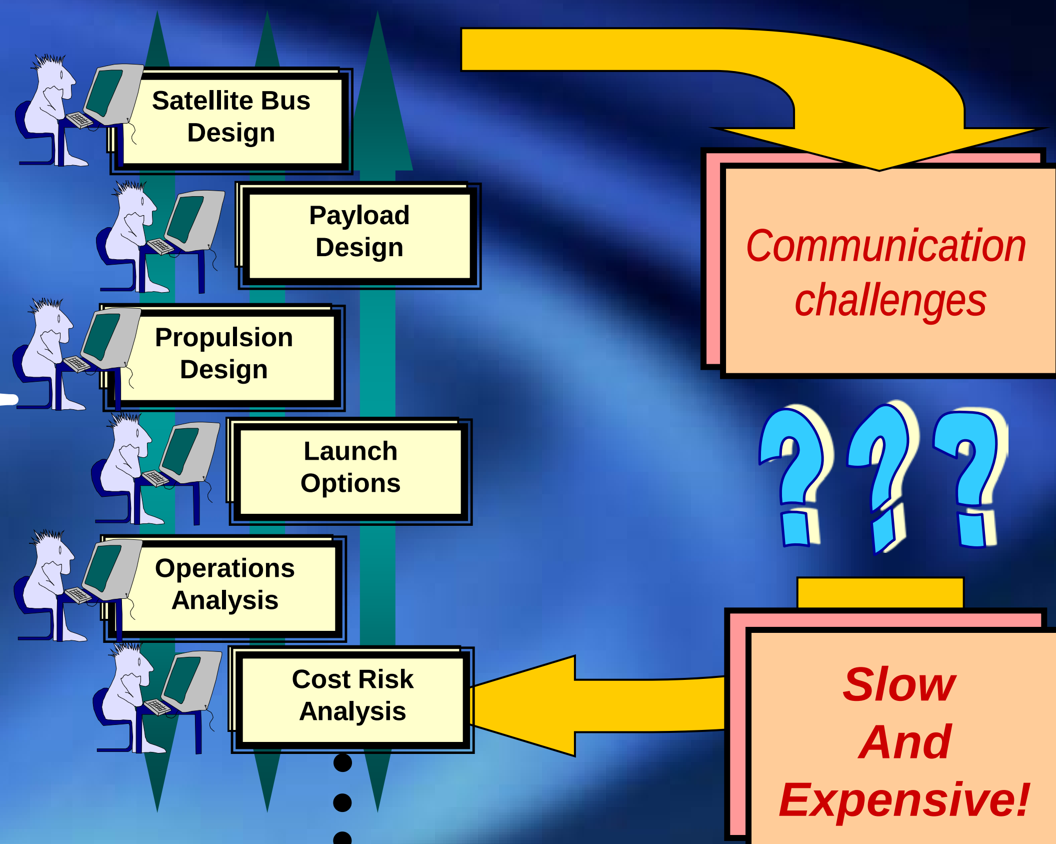
<u>Early Design Challenges</u> of High-Performance Complex Systems

What is the current design process?



System Requirements

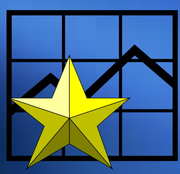
- Mission requirements
- Size, weight, power
- New technology insertion
- Performance
- Schedule
- ⋮



Integrated Design Approach

Solution to Early Design Challenges of High-Performance Complex Systems

Integrated optimizing tools provide:



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Integration Core Module

User Interface Module

Bus Module

Payload Module

Propulsion Module

Launch Module

Operations Module

Cost/Risk Module

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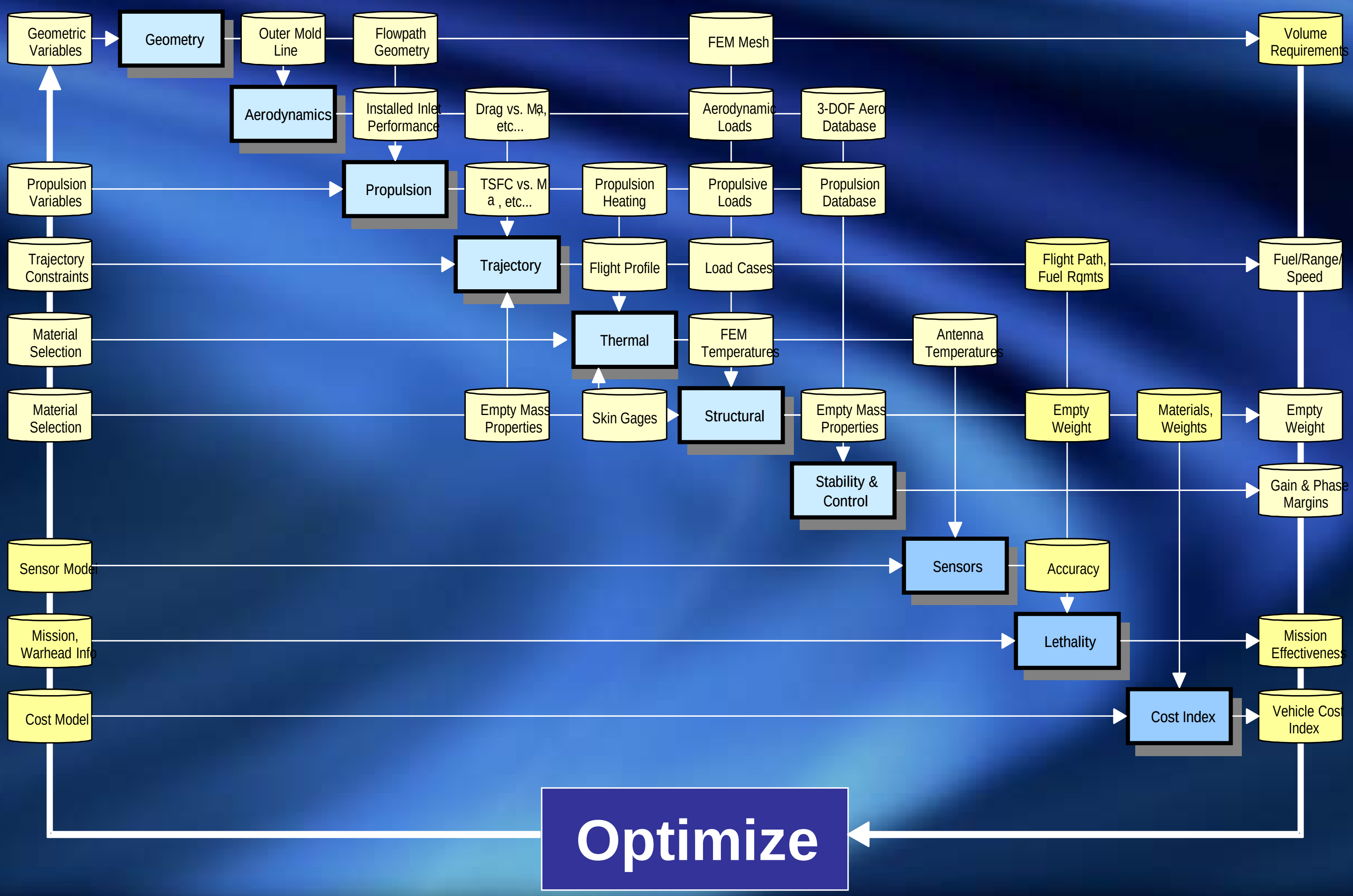
•

In Days Not Weeks!

Integrated Tool Suite Process Flow



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

Space Vehicle Module

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

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

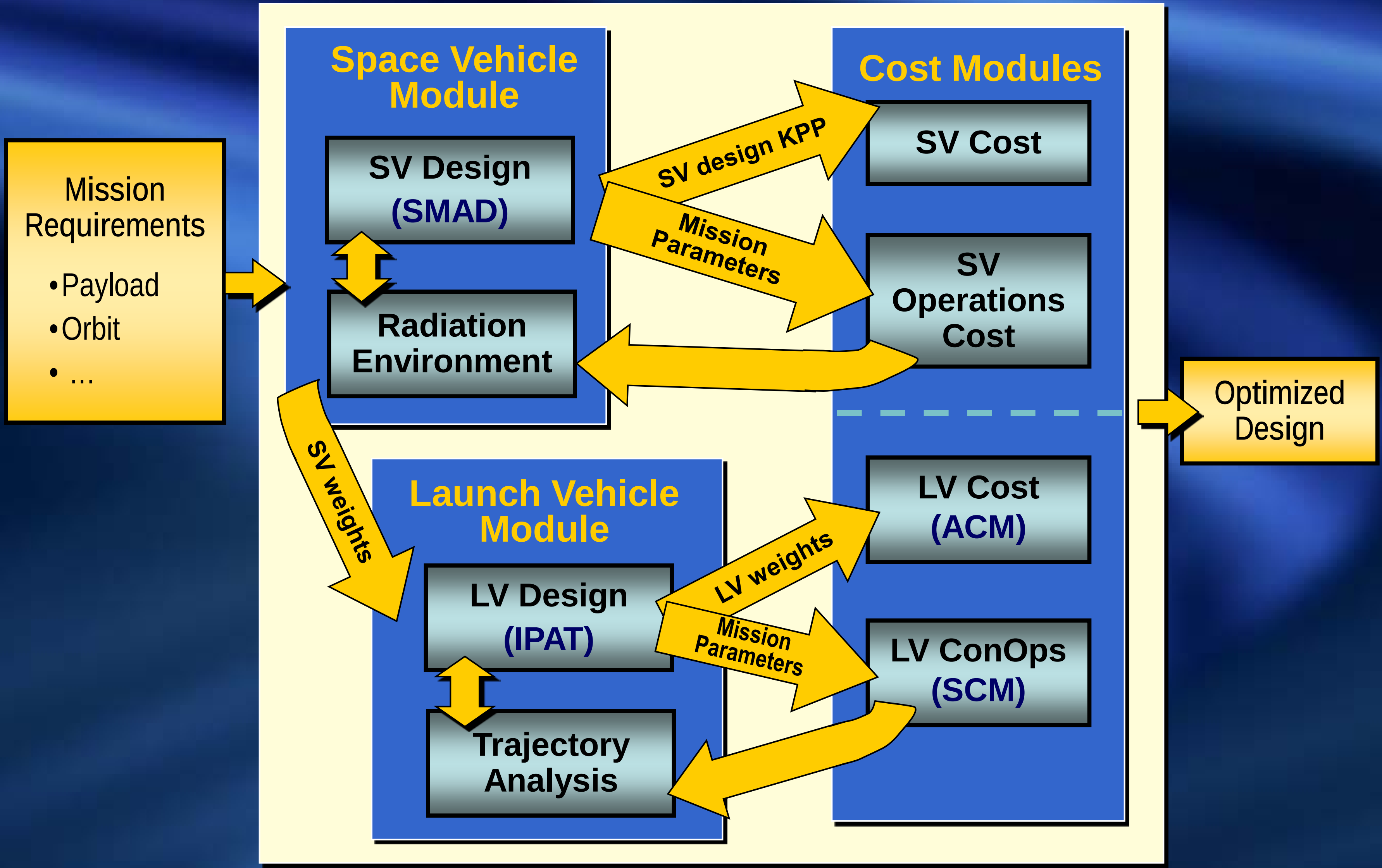
Visualization

ATSV – Trade space

STK, SOAP – Specific mission

Historical/Knowledge Database

ACES Conceptual 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

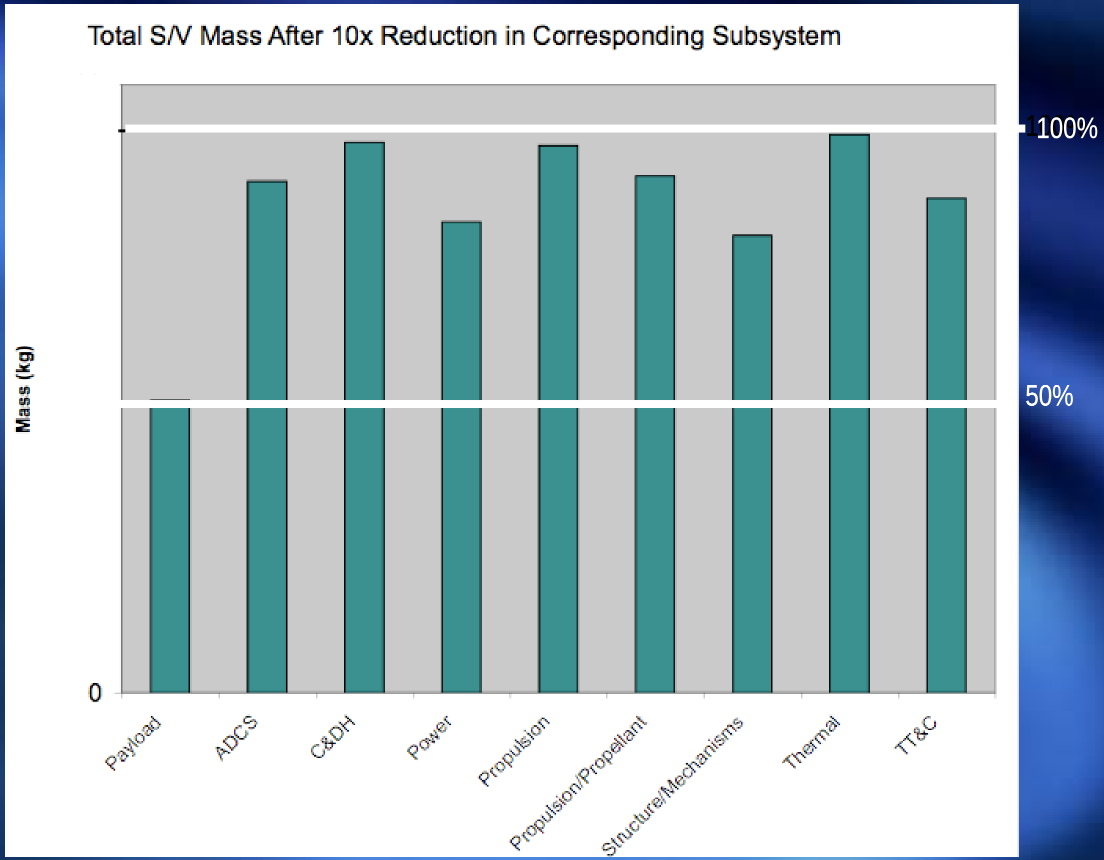
- **Examples of Trade Studies**
  - Effect of subsystem reduction on total vehicle design
  - Concept evaluations of proposed TacSat-5 concepts
  - Cost impact of alternative TacSat-3 designs
  - Launch vehicle selection and cost for satellite constellation
  - Trajectory analysis for DSX alternative 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

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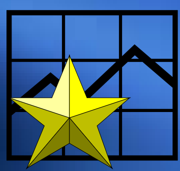

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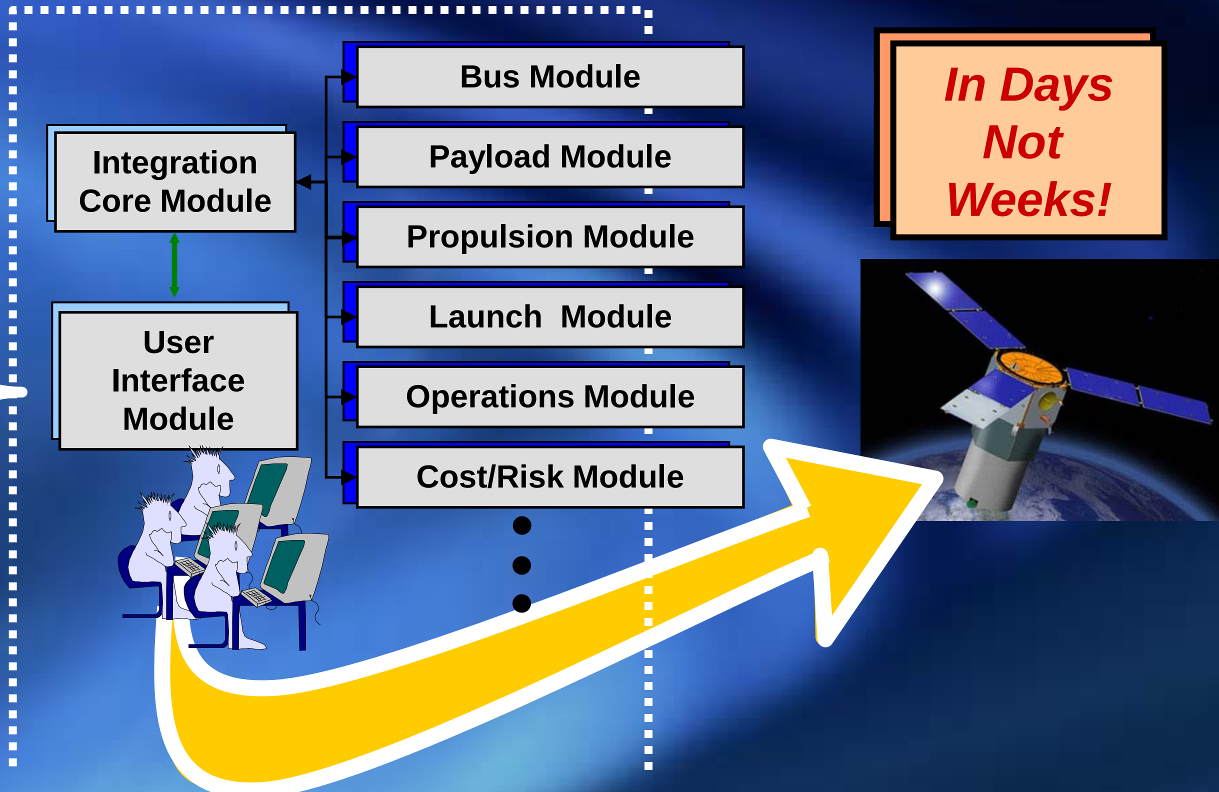

TacSat-5 Concept Evaluations

- 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