Mission Design for Deep Space CubeSats

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NASA Ames' CubeSat Missions

NASA Ames has the oldest NASA effort in CubeSats

- Peer-review Science with its CubeSat Missions since 2006
- 21 Mission flown (31 CubeSats) or in active development
- Deployed NASA's first 1U and 3U CubeSats from ISS (2012, '14)
- Developed the first CubeSat Science Swarms (Oct 2015, '16)
- Developing the first Beyond LEO Bio-nanosat (Biosentinal 2018)

Ames CubeSats have been supporting the goals of:

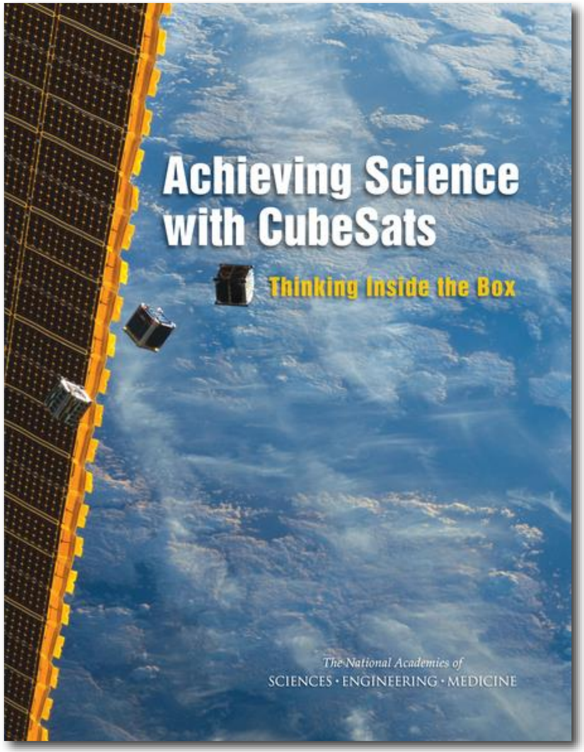
- Space Biology Science,
- Swarm Science, and
- Technology Development.

Current State-of-the-Practice

Domain:	Low Earth Orbit
Deployment:	Secondary Payload
	Hosted Payload
	ISS
Lifetime:	Weeks to Years (limited by orbital altitude)
Trajectory:	Passive
	Differential Drag
	Propulsion (in development but not yet routine)
Tracking:	GPS
	Transponders (in development)
Communications:	UHF, S-band and X-band
	Networked (Iridium, GlobalStar) (in development)
	Optical (in development)
Applications:	Education
	Technology Demonstrations/Maturation
	Space Biology/Life Sciences
	Earth Science

The Future Need

- ***Solar and space physics, Earth science and applications from space—Exploration of Earth's atmospheric boundary region.*** CubeSats are uniquely suited because of their expendability to explore the scientific processes that shape the upper atmospheric boundary using short-lifetime, low-altitude orbits.
- ***Earth science and applications from space—Multi-point, high temporal resolution of Earth processes.*** Satellite constellations in low Earth orbit could provide both global and diurnal observations of Earth processes that vary throughout the day, such as severe storms, and are currently under-sampled by Sun-synchronous observatories.
- ***Planetary science—In situ investigation of the physical and chemical properties of planetary surfaces or atmospheres.*** Deployable (daughter-ship) CubeSats could expand the scope of the motherships with complementary science or site exploration.
- ***Astronomy and astrophysics, solar and space physics—Low-frequency radio science.*** Interferometers made of CubeSats could explore the local space environment and also galactic and extragalactic sources with spatial resolution in ways not accessible from Earth.
- ***Biological and physical sciences in space—Investigate the survival and adaptation of organisms to space.*** CubeSats offer a platform to understand the effects of the environment encountered in deep space, such as microgravity and high levels of radiation.



Committee on Achieving Science Goals with CubeSats; Space Studies Board; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine, 2016, Committee Chair: Thomas Zurbuchen

The 2016 NAS/SSB report describes example science application areas for CubeSat-class missions.

Challenges of Deep Space Applications

The Deep Space environment can be much more challenging than LEO in terms of:

Radiation

Thermal

Deep Space Communications are much more difficult than LEO:

Range

Antenna Size

Transmit Power

Ground Networks

Power: Spacecraft are physically small, so require large area/mass SA

Deep Space Missions frequently require active trajectory control:

Propulsion needed either: (1) to maintain the desired science orbit, or

(2) to get from the secondary payload drop-off to the desired destination

Use of propulsion implies: (1) tracking

(2) orbit determination

(3) scheduled communications passes, and

(4) maneuver planning and execution

Deployment: Hosted payload accommodation to destination

Transit from secondary payload drop-off to desired trajectory

Lots of impulsive dV or Low Thrust (high transit time in radiation belts)

Challenges of Deep Space Applications

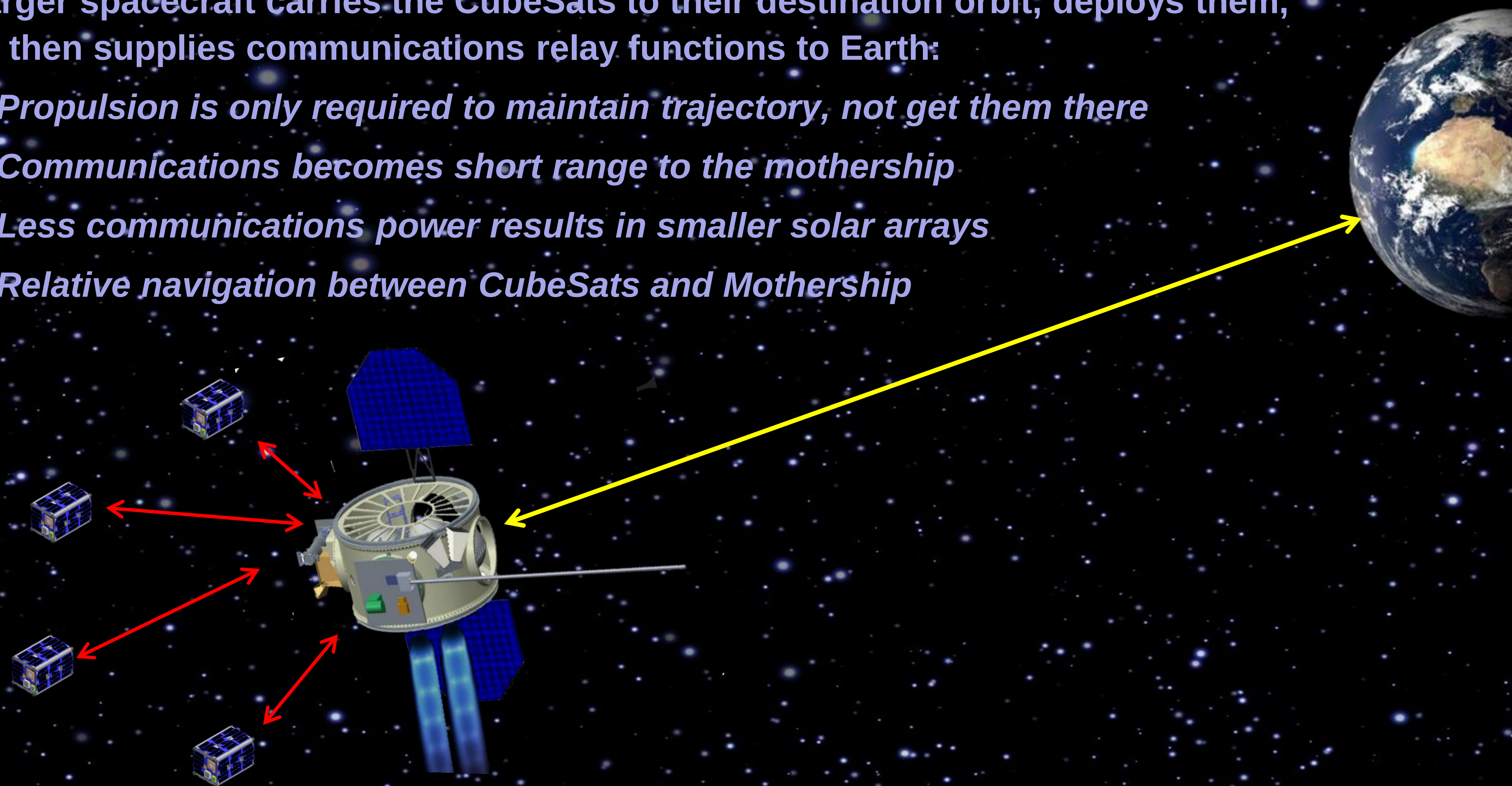
The low-cost LEO CubeSat operations model does not apply to Deep Space

Deep Space mission operations do not change based on the size or cost of the spacecraft!

Mothership Concept

A larger spacecraft carries the CubeSats to their destination orbit, deploys them, and then supplies communications relay functions to Earth:

- ***Propulsion is only required to maintain trajectory, not get them there***
- ***Communications becomes short range to the mothership***
- ***Less communications power results in smaller solar arrays***
- ***Relative navigation between CubeSats and Mothership***



Mission Design Center (MDC)

Provide Mission Concept and Spacecraft Design Support for NASA, Academia, other Government agencies.

- Dedicated team of experienced SMEs in all aspects of mission design with the capability to reach out to specialized areas for specific concept requirements.
- Integrated end-to-end mission design and simulation tools with ongoing development efforts to enhance current version and create new tools
- Extensive database of heritage flight hardware, instruments, and mission concepts to leverage for current and future concepts and spacecraft designs.
- Authors of the NASA SSTP State Satellite State of the Art Report imbedded in the concept teams to provide leading edge knowledge of spacecraft technology.
- Collaborative facilities and software tools which enhance the cooperative design environment of the MDC.
- Rapid prototyping capability with the Ames Space Shop (3D printing, CNC, laser cutting, etching, Raspberry Pi, Arduino, and other prototyping tools and systems.

MDC provides comprehensive integrated end-to-end mission design to win proposals

PI Concept Development

Science Instrument Development

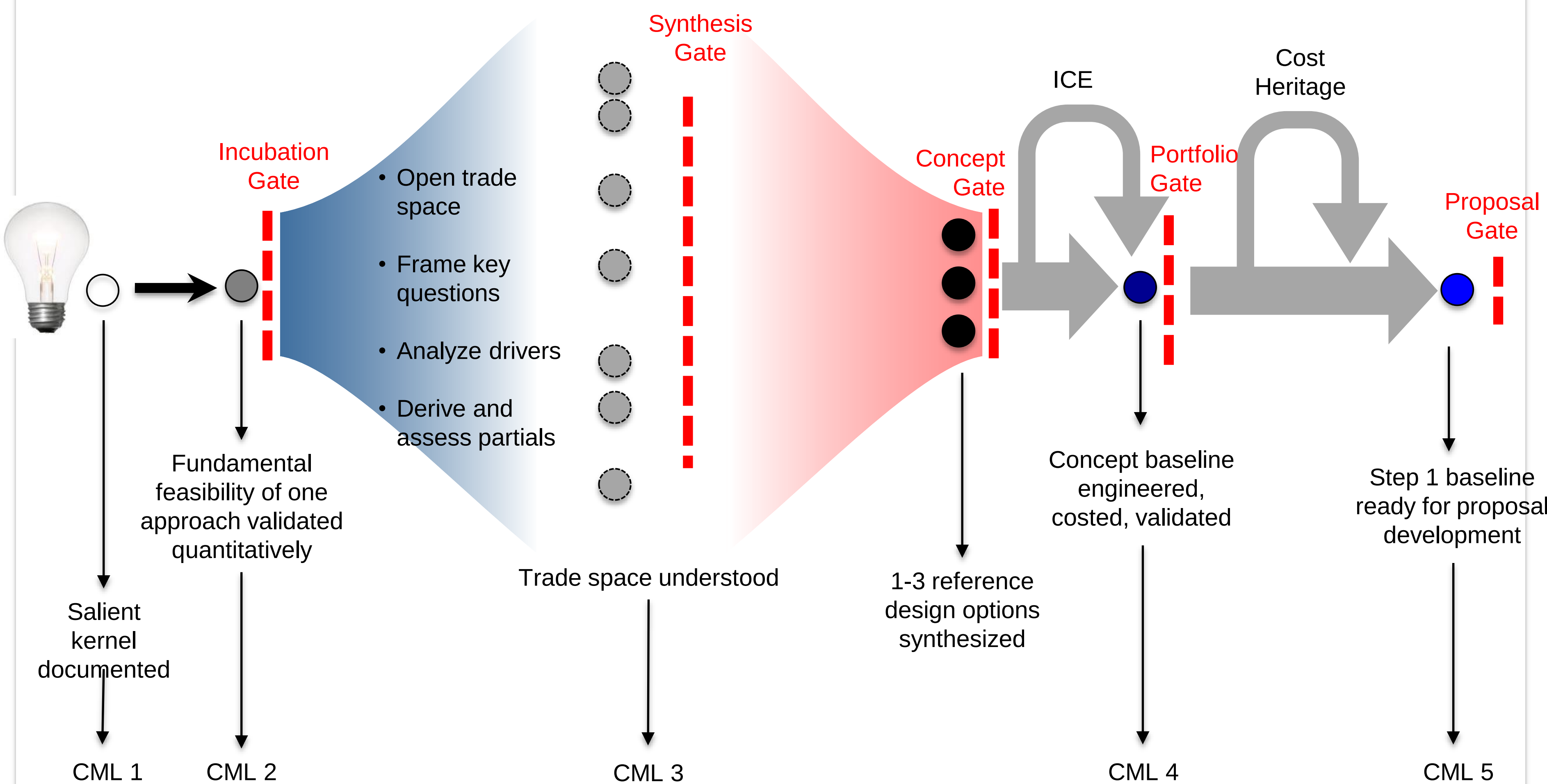
Technology Development

Constellations Designs

Geographic Region Coverage

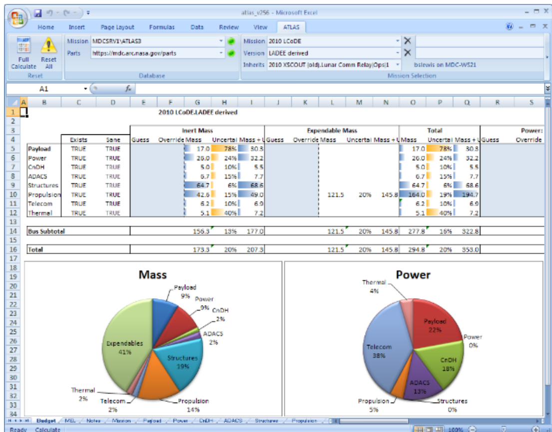
Swarm Formation & Communications

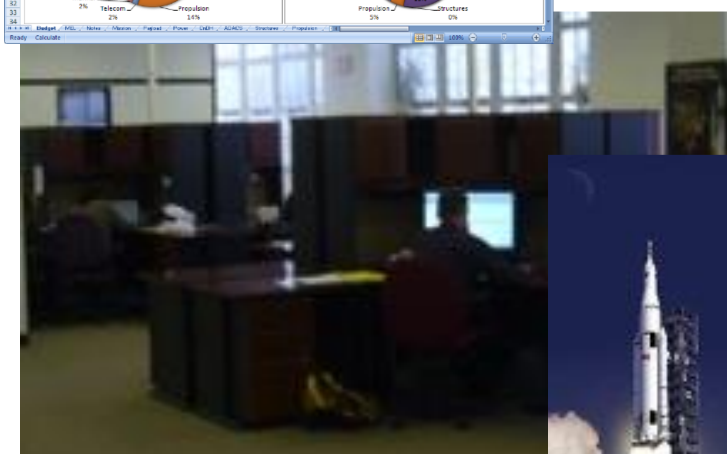
Ames' MDC supports concepts throughout development process



JPL Innovation Foundry CML: Concept Maturity Level ICE: Integrated Concurrent Engineering

Proposal and Project Development Support





The MDC develops marketing material for concepts through standard products and services

- Feasibility Evaluation - for quick decision-making
- Conceptual Whitepaper - key technical considerations
- Technical Proposal – lays out credible solutions

MDC is also a shared, prioritized resource for all projects at any development phase.

- Almost all spaceflight concepts are supported by the MDC at some point in planning or implementation
- LCROSS, LADEE, IRIS, O/OREOS, TES 1-6, BioSentinel, NLAS, and other projects have all received MDC support

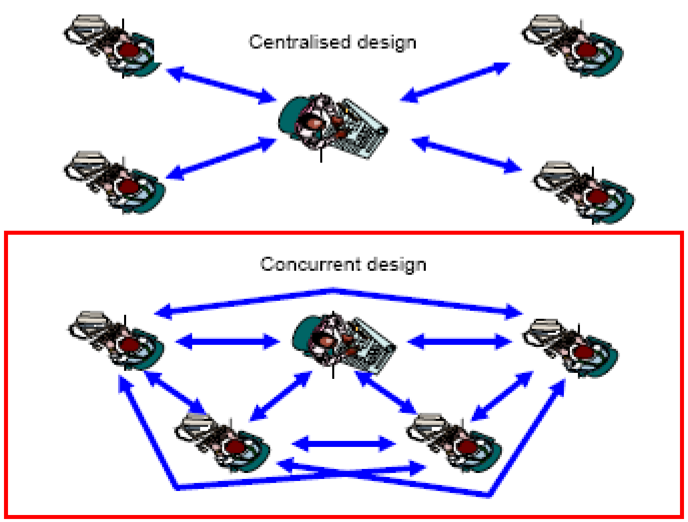
Concepts to Flight

MDC Supports Missions
from Proposal to Operations

Concurrent Engineering

The ARC Mission Design Center is a concurrent engineering facility

- “War Room” environment for design teams
- Similar to Team X (JPL), COMPASS (GRC), MDL (GSFC), MDF (ESA), and several in industry, such as CIEL (Boeing)
- Uses small multi-disciplinary core team augmented with support from other specific subject matter experts



Leverage IT Product Development to Space Mission Design

- Searchable database of previous mission designs
- Database of COTS hardware components and characteristics – Small Sat State of the Art Report
- Custom-built and commercial software tools comprise an Integrated Concurrent Engineering (ICE) environment

Category	Item	Atlas (custom ARC tool)	STK, SOAP, GMAT	MAnE	Copernicus, Malto, Mystic	SPENVIS, Traprad	SolidWorks, MSC Nastran	Thermal Desktop	NICM, SSCM, NAFCOM	DOORS	MS Project	Sharepoint, NSCKN, MINX	MatLab/Simulink	Microsoft Office	Total Software Capability*
Mission	Orbit and Operational Analysis	Some Utility	Detailed Analysis	Some Utility	Some Utility								Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
	Radiation Dosage					Detailed Analysis							Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
	Trajectory Optimization (impulsive)	Some Utility	Some Utility	Detailed Analysis	Detailed Analysis								Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
	Trajectory Optimization (finite/ low thrust)		Some Utility		Detailed Analysis								Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
Subsystems	ADACS	First-Order / Engineering Estimate	First-Order / Engineering Estimate				Some Utility						Non-Standard / Specialized	Non-Standard / Specialized	First-Order / Engineering Estimate
	Telecom	First-Order / Engineering Estimate	Detailed Analysis	Some Utility	Some Utility								Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
	Power	First-Order / Engineering Estimate	Some Utility	Some Utility	Some Utility			Some Utility					Non-Standard / Specialized	Non-Standard / Specialized	First-Order / Engineering Estimate
	Thermal	First-Order / Engineering Estimate	Some Utility					Detailed Analysis					Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
	Structures	First-Order / Engineering Estimate	Some Utility			Some Utility	Detailed Analysis	Some Utility					Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
	C&DH	First-Order / Engineering Estimate	Some Utility										Non-Standard / Specialized	Non-Standard / Specialized	First-Order / Engineering Estimate
	Propulsion	First-Order / Engineering Estimate	Some Utility	Detailed Analysis	Detailed Analysis								Non-Standard / Specialized	Non-Standard / Specialized	Detailed Analysis
System Engineering	Hardware Equipment Lists	Detailed Analysis					Some Utility							Non-Standard / Specialized	Detailed Analysis
	Requirements Management									Detailed Analysis				Non-Standard / Specialized	Detailed Analysis
	Mass Budgets	Detailed Analysis			Some Utility		Some Utility							Non-Standard / Specialized	Detailed Analysis
	Spacecraft Configurations	First-Order / Engineering Estimate					Detailed Analysis							Non-Standard / Specialized	Detailed Analysis
Project Management	Task Tracking										Detailed Analysis	Detailed Analysis			Detailed Analysis
	Collaboration	Detailed Analysis										Detailed Analysis			Detailed Analysis
	Knowledge Management	First-Order / Engineering Estimate										Detailed Analysis			Detailed Analysis
	Schedule								Some Utility		Detailed Analysis	First-Order / Engineering Estimate			Detailed Analysis
	Cost Estimates	First-Order / Engineering Estimate							First-Order / Engineering Estimate		Some Utility				First-Order / Engineering Estimate
	Documentation	First-Order / Engineering Estimate										Detailed Analysis		Detailed Analysis	Detailed Analysis

Legend
Detailed Analysis
First-Order / Engineering Estimate
Some Utility
Not Applicable
Non-Standard / Specialized

*Note: First Order software analysis is supplemented with mission design experience to produce detailed results

Ongoing Development is Focused on Providing High Fidelity Day-in-the-life Mission Simulations

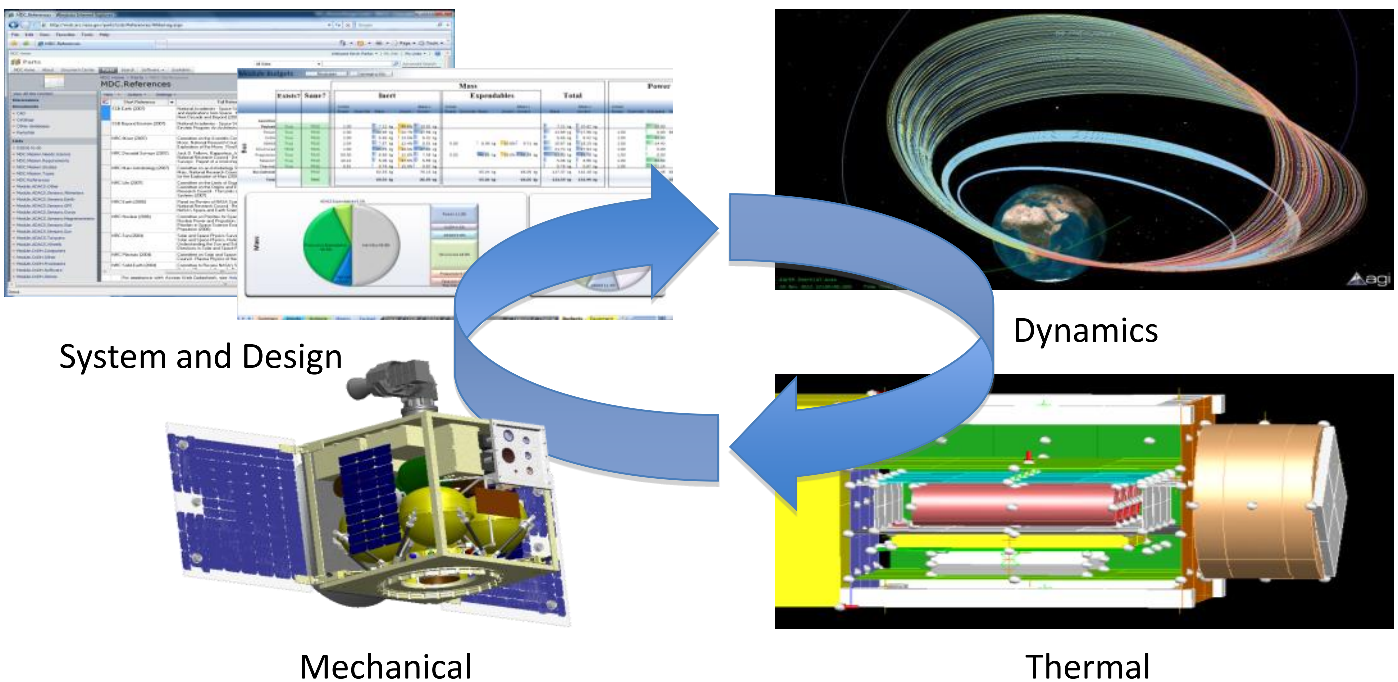
Integrated Design & Simulation Tools

Current Toolsets

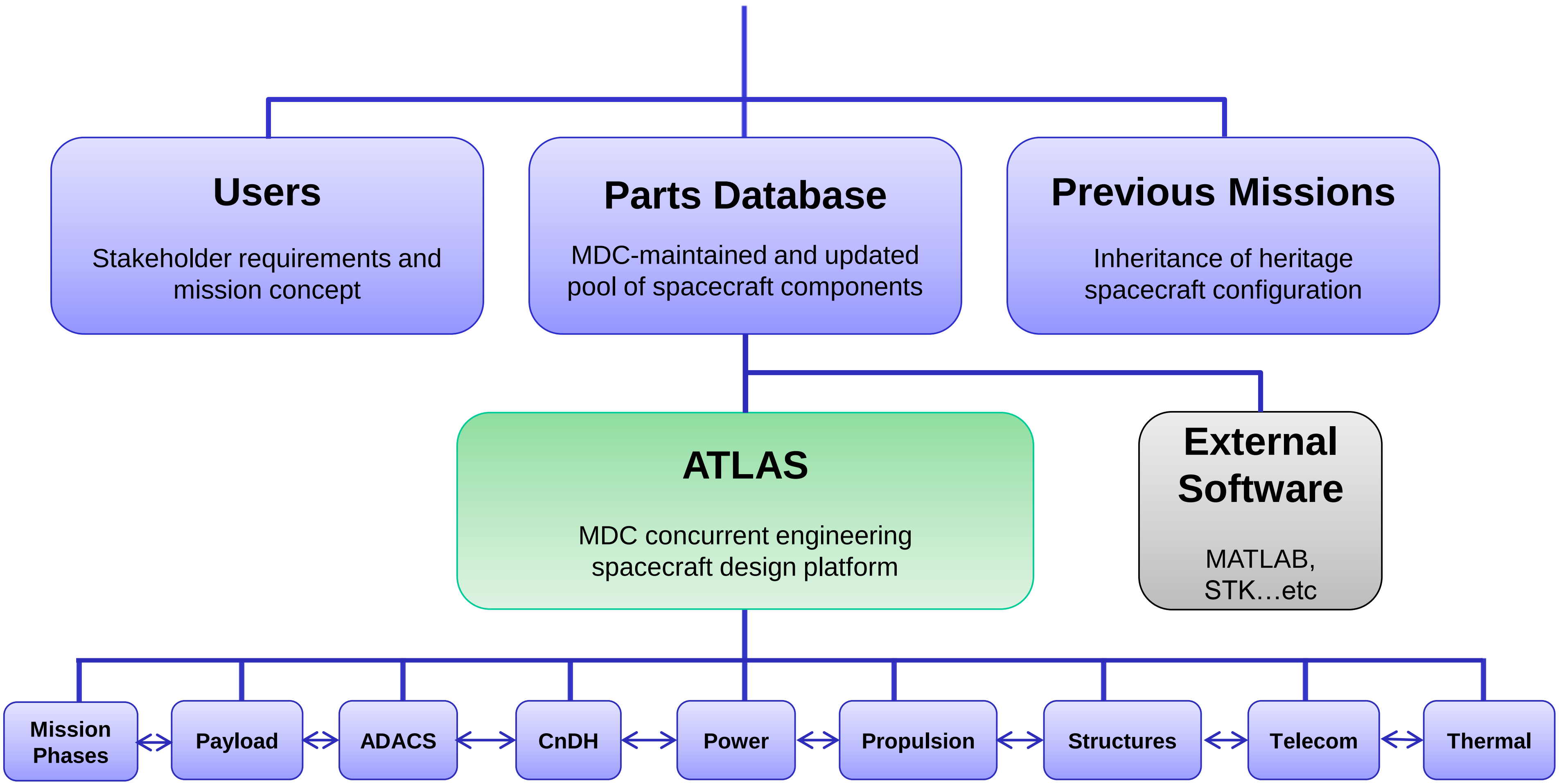
- Atlas and ICEicle – Internal integrated concurrent engineering
- SharePoint – Database, project storage
- STK / SOAP – Trajectories, coverage
- Solidworks – CAD, Mechanical Designs
- Matlab/Simulink – GNC / ADCS modeling and analysis
- Thermal Desktop – Thermal Analysis
- MSC Nastran – FEA modeling

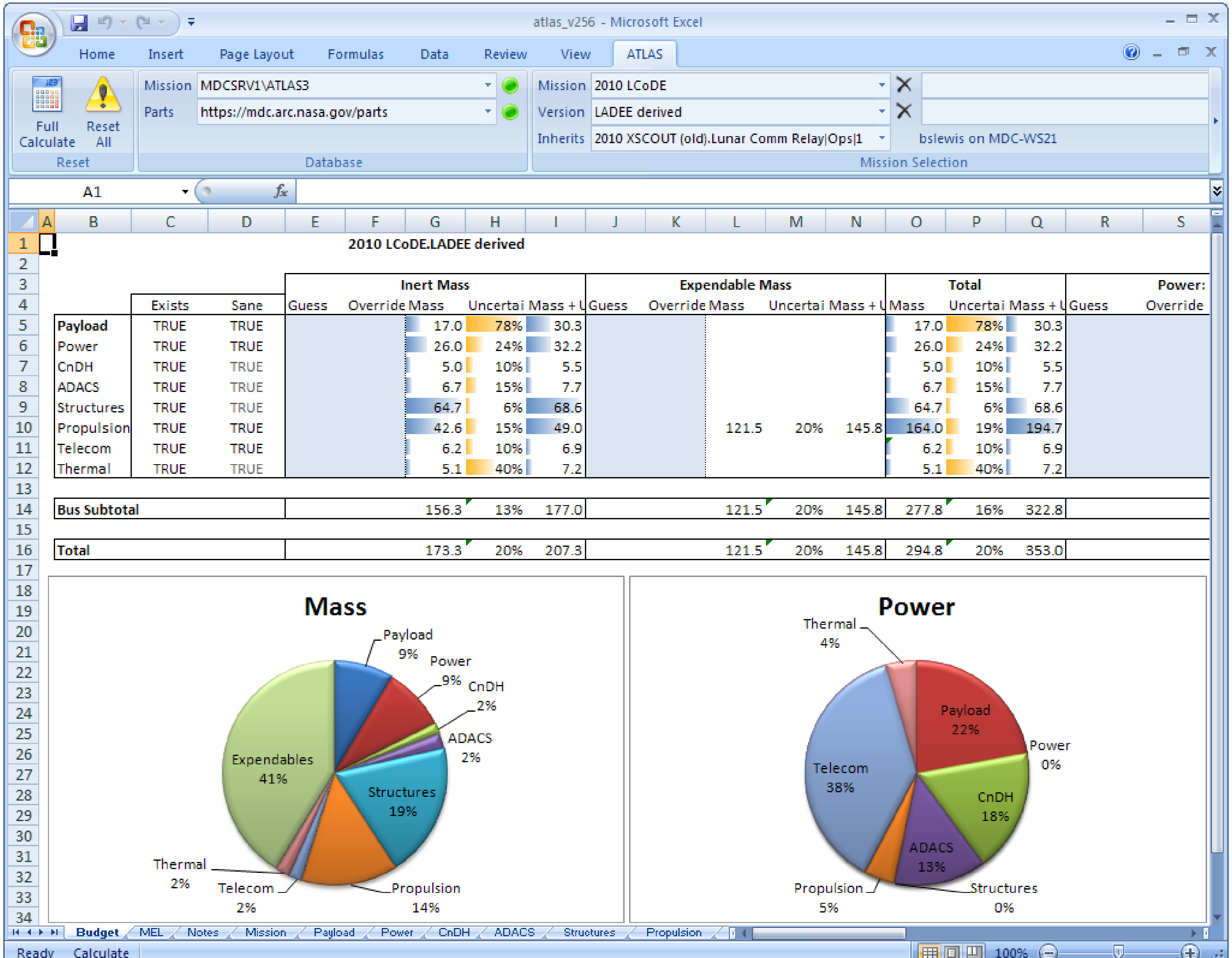
Toolsets in Progress

- Generation of xTEDS from database designs
- Integration of plug-and-play software into mission modeling
- Autocode of ConOps software
- Full simulation based design validation
- Autocoded control software



Atlas Architecture

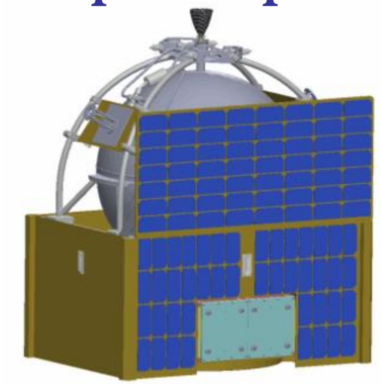




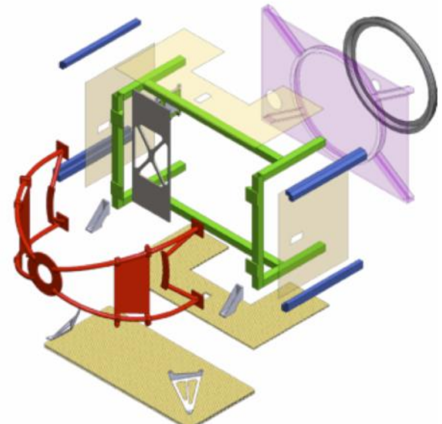
2010 LCoDE.LADEE derived

			Inert Mass					Expendable Mass					Total			Power:	
	Exists	Sane	Guess	Override	Mass	Uncertai	Mass + U	Guess	Override	Mass	Uncertai	Mass + U	Mass	Uncertai	Mass + U	Guess	Override
Payload	TRUE	TRUE			17.0	78%	30.3						17.0	78%	30.3		
Power	TRUE	TRUE			26.0	24%	32.2						26.0	24%	32.2		
CnDH	TRUE	TRUE			5.0	10%	5.5						5.0	10%	5.5		
ADACS	TRUE	TRUE			6.7	15%	7.7						6.7	15%	7.7		
Structures	TRUE	TRUE			64.7	6%	68.6						64.7	6%	68.6		
Propulsion	TRUE	TRUE			42.6	15%	49.0			121.5	20%	145.8	164.0	19%	194.7		
Telecom	TRUE	TRUE			6.2	10%	6.9						6.2	10%	6.9		
Thermal	TRUE	TRUE			5.1	40%	7.2						5.1	40%	7.2		
Bus Subtotal					156.3	13%	177.0			121.5	20%	145.8	277.8	16%	322.8		
Total					173.3	20%	207.3			121.5	20%	145.8	294.8	20%	353.0		

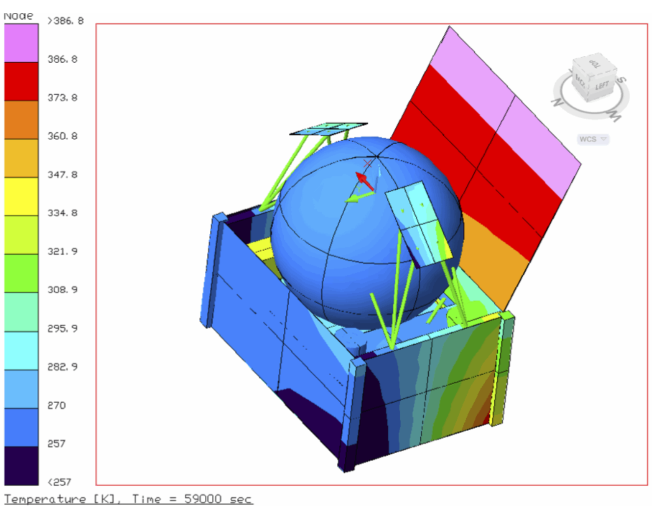
Example: Spacecraft modeling and analysis



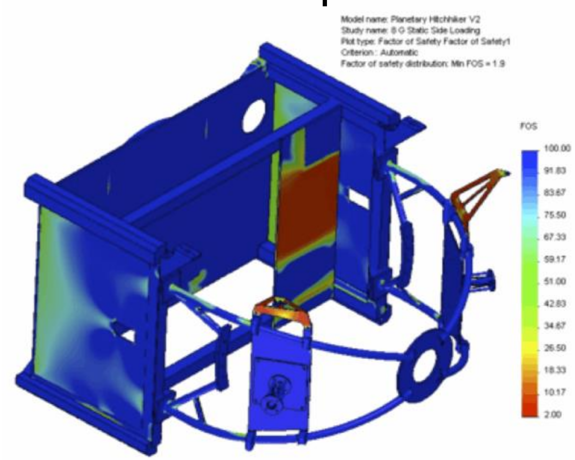
SolidWorks CAD model



SolidWorks exploded view



Thermal Desktop model

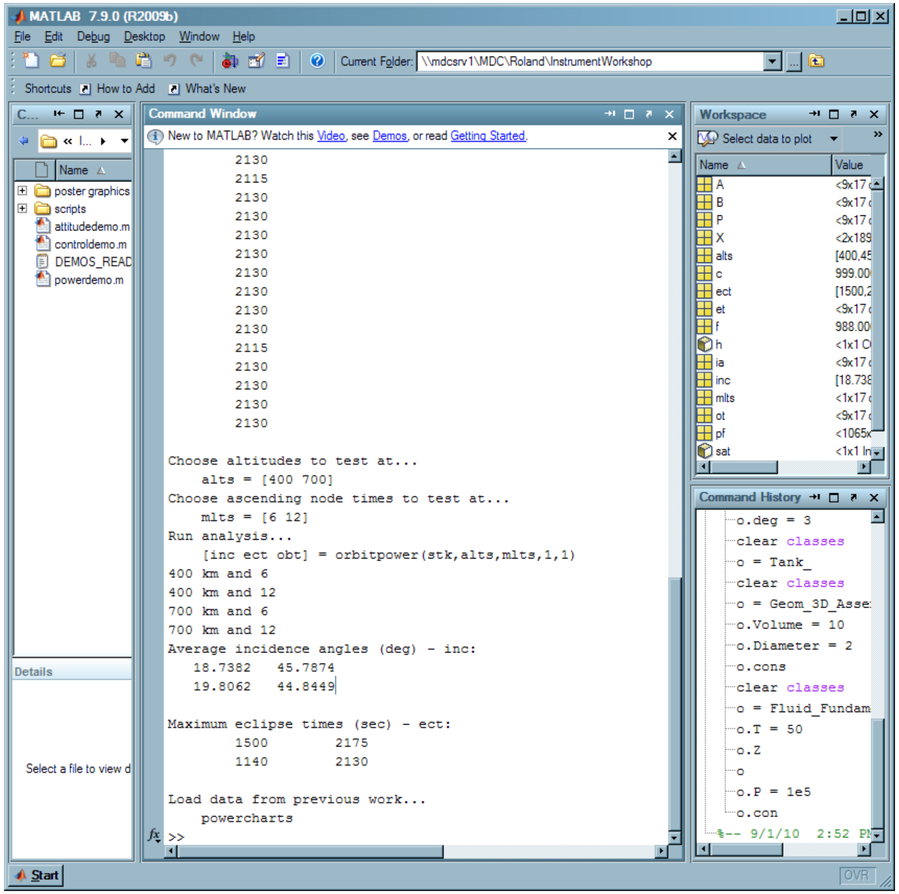


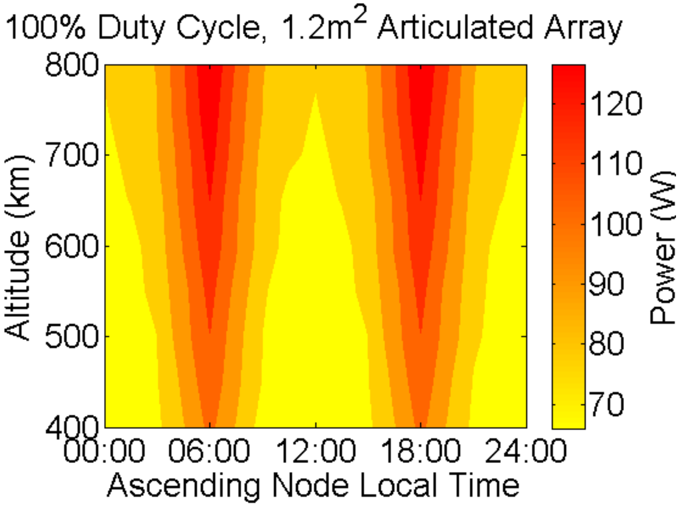
SolidWorks Finite Element Analysis

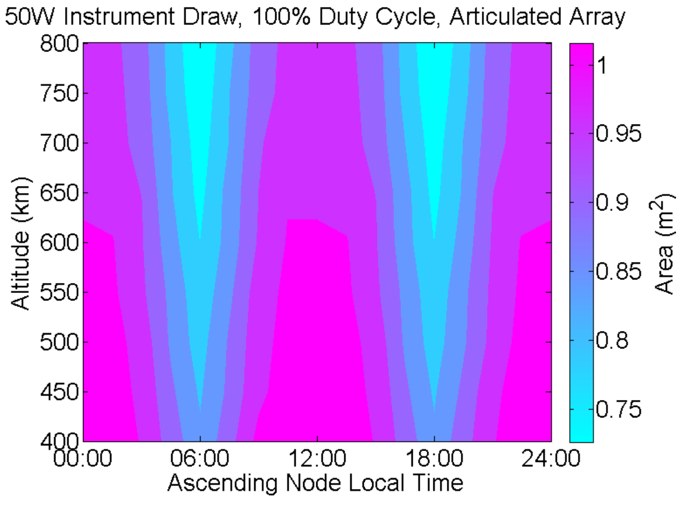
Example: MATLAB Solar Electric Power Script

AGESS Power Analysis

- MATLAB Attitude and Top Level Parameters
- STK Power and Orbit Propagation



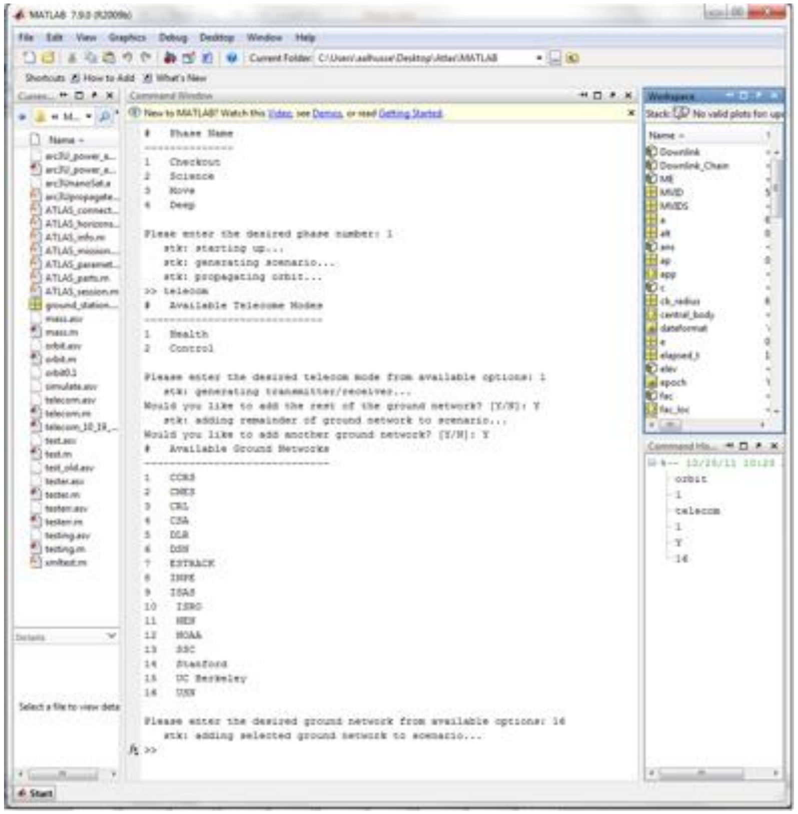


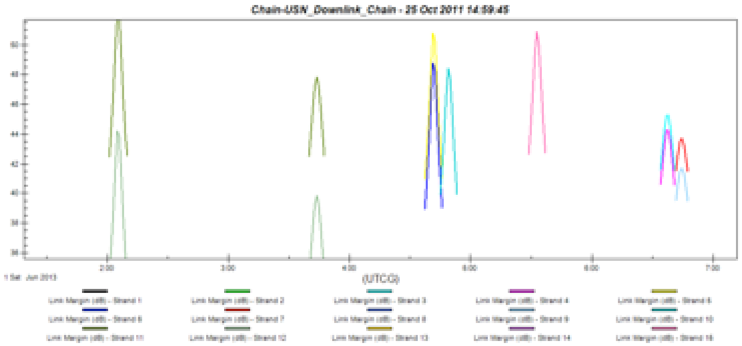


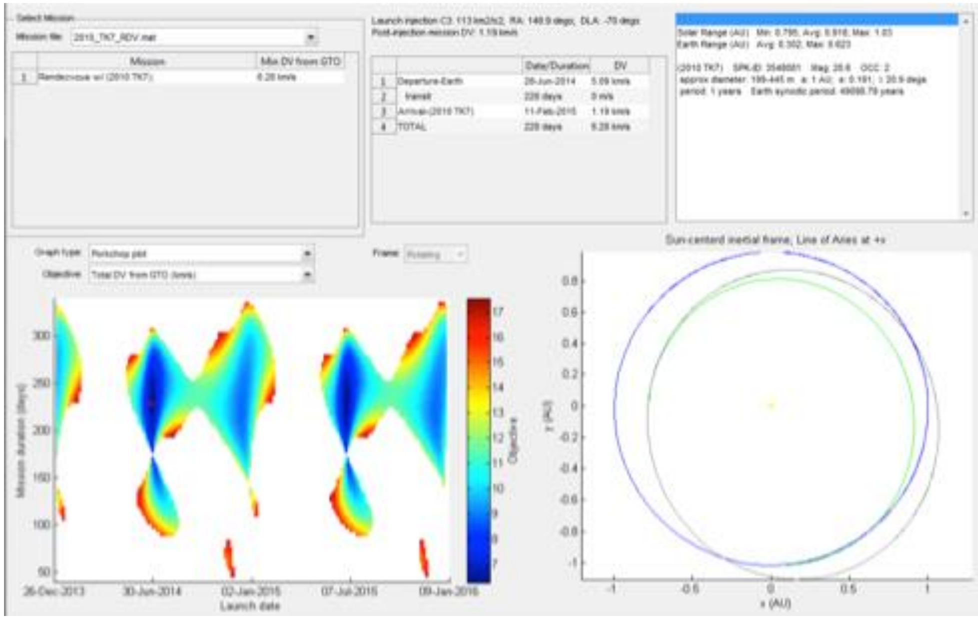
Example: Atlas-STK Interface

ATLAS/STK Telecom Add-on:

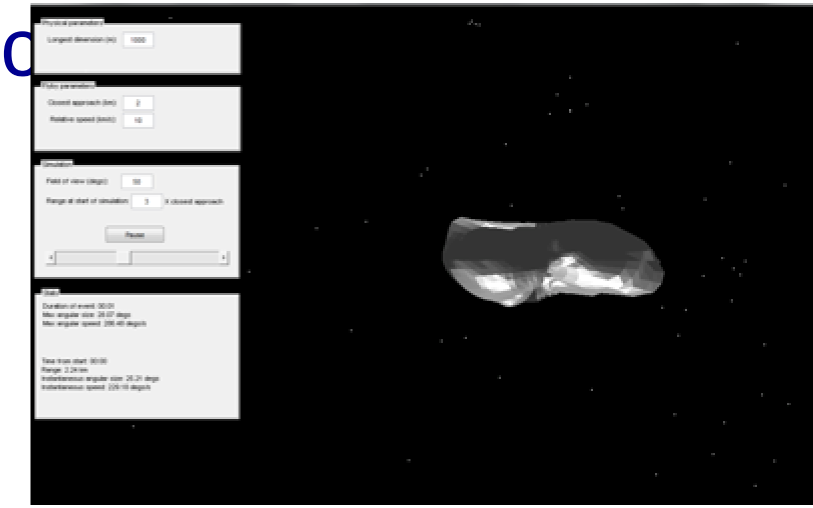
- Exports ATLAS telecom design rapidly to STK
- Populates ground stations from MDC database
- Allows quick trades between ground networks







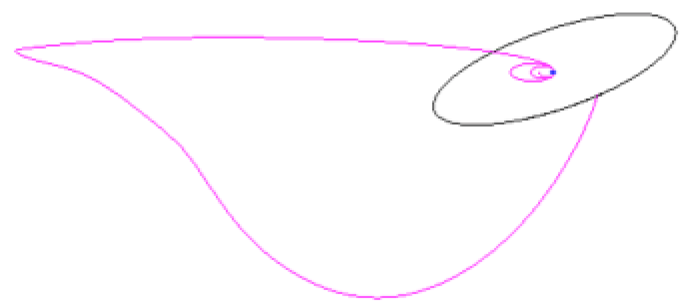
Interplanetary trajectory solver for NEOs and planets



Flyby encounter optimizer

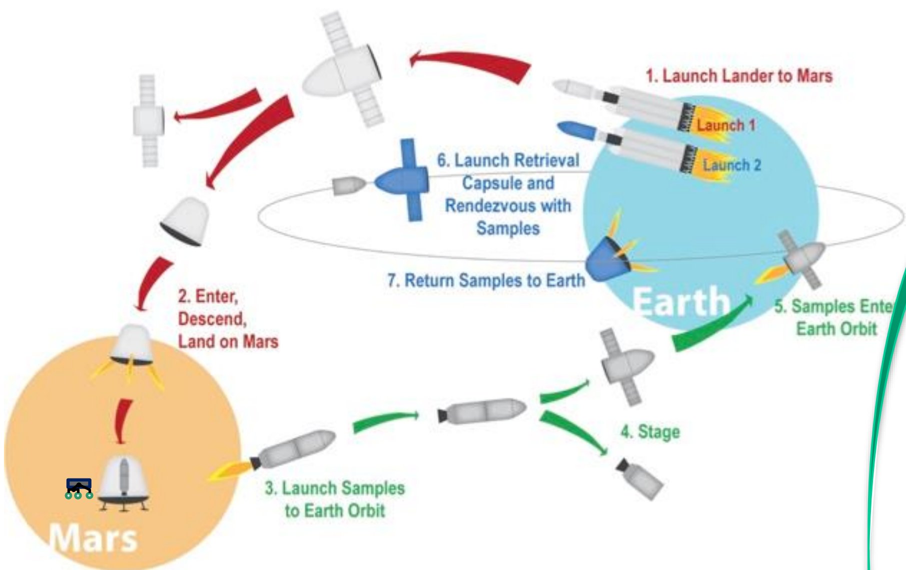
In-House Trajectory Tools for:

- Solving patched conic and N-body interplanetary trajectories to NEOs and planets
- Obtaining low-energy transfers to the Moon
- Optimizing flyby encounter characteristics
- Optimizing EP thruster maneuvers and trajectories



Secondary payload from GTO to the Moon transfer solver

Red Dragon Mars Sample Return Study



Demonstrated that compact and efficient use of emerging commercial capabilities to perform a high priority science mission is feasible.

Capabilities of Mission Design Division used to augment analytical work from other Ames organizations

How much mass and volume is required for Earth return rocket and related subsystems?

- Conduct parametric optimization study for Earth return rocket using in-house computational tool, HAVOC
- Determine sensitivity of design to: propellant choice, rocket motor design, staging Δv, aerodynamics, etc.
- Choose baseline design for Earth return rocket
- Perform bottom-up design of Earth return rocket and related subsystems
- Develop solutions for support equipment

Will This

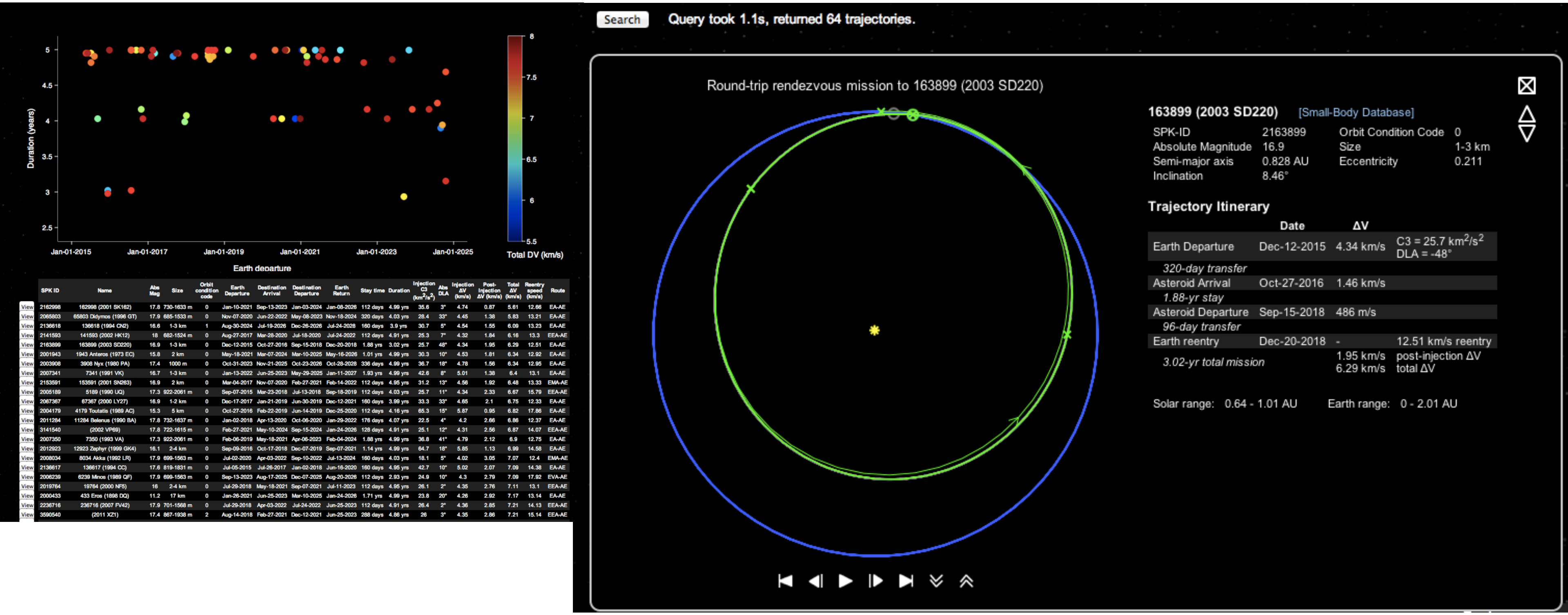
Fit Into

This ?

Yes !

How much mass and volume can Red Dragon deliver to Mars?

- Construct aerodynamic model of Dragon
- Include model of retro-propulsion system
- Compute EDL trajectories from entry interface down to surface
- Use in-house computational tool, TRAJ; commercially available tool, POST
- MARSGRAM atmospheric model
- Determine mass limit for successful EDL



- Web application for searching and assessing candidate mission trajectories
- Originally developed for internal use
- Now publicly accessible at **http://trajbrowser.arc.nasa.gov**

Questions?