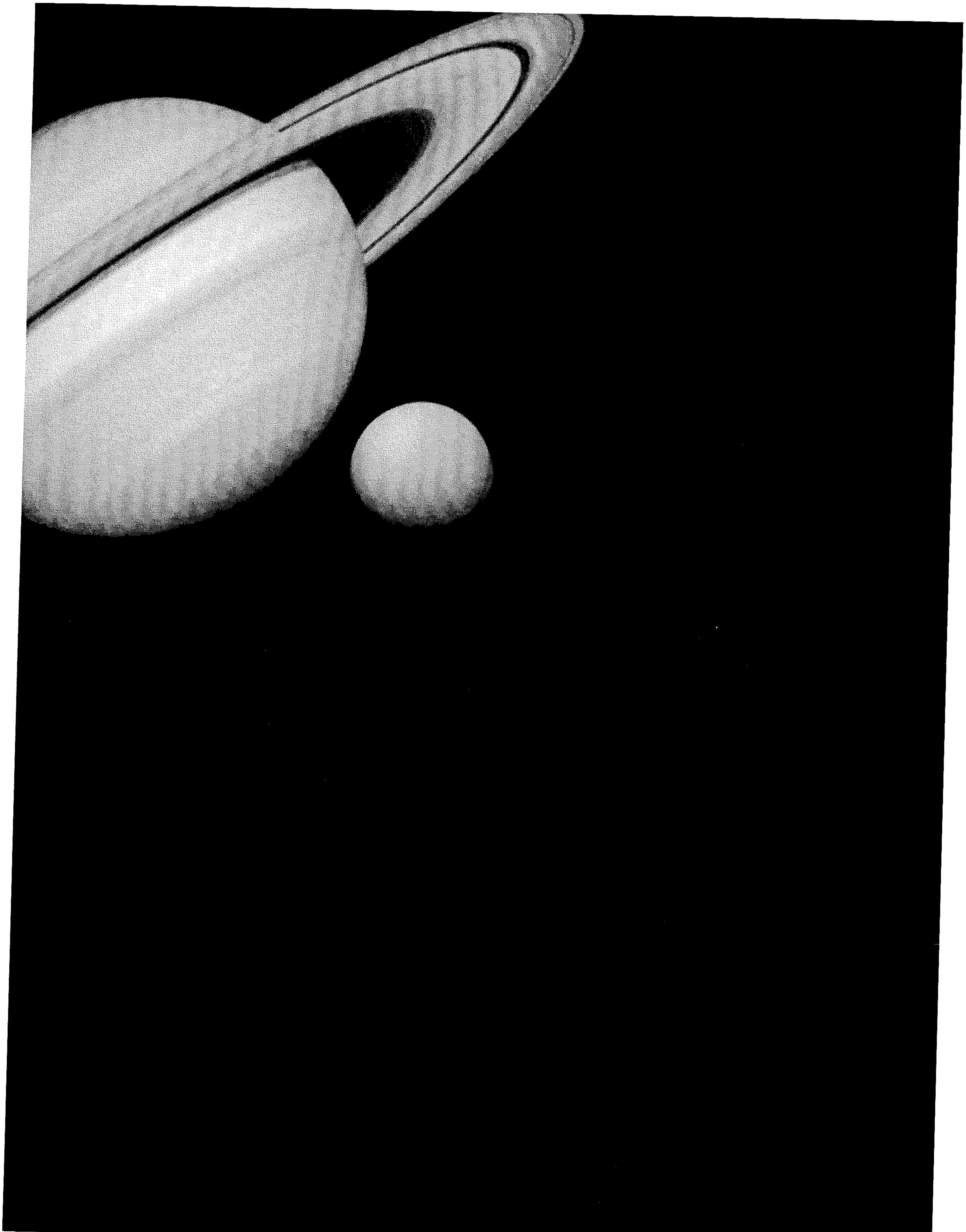


Aerocapture Systems Analysis Review
S/C Design: AGENDA

- Objectives
- Level of Analysis
- Configuration Design
- New Technology Needs
- Additional Trades, Opportunities, Liens

Aerocapture Systems Analysis Review
S/C Design: Level 1 Design Objectives

- Orbiter and Lander delivery to Titan
- LV: Delta IV Medium, 4m fairing
- A priori Titan orbital science
- Lander is "black box", 400kg allocation
- Orbiter performs Lander cmd/telem relay
- Orbiter delivers Lander to Titan entry trajectory
- 2010 Launch Date (TRL 6 cutoff = 2006)
- Orbiter performs aerocapture for Titan orbit insertion
- Goal: Use as much heritage HW as possible
- 3 year Titan Orbital Science Mission
- 10 Year Total Mission lifetime

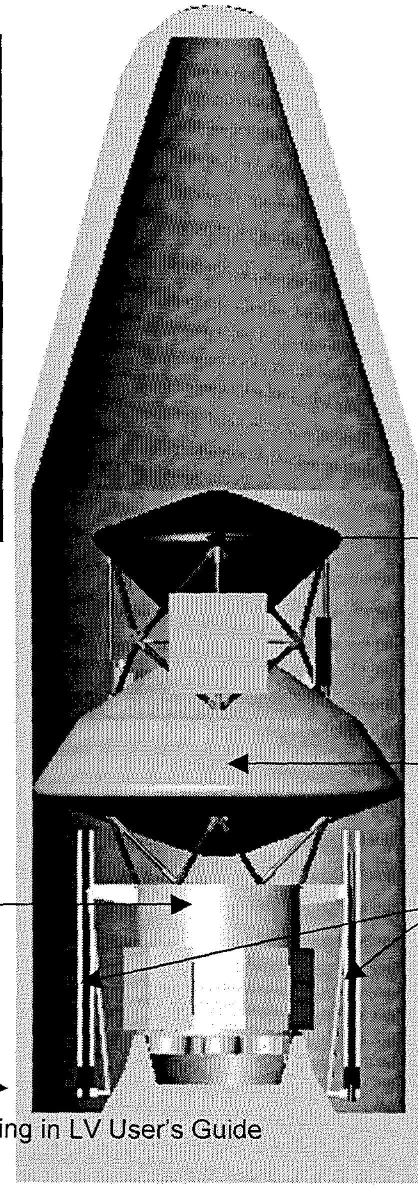
Aerocapture Systems Analysis Review
S/C Design: Level of Analysis

- ♦ **Analysis varies by subsystem**
- ♦ **Generally stopped detailed analysis when feasibility established**
- ♦ **Feasibility subjectively evaluated based on overall system design and margins**
- ♦ **Employed discipline experts to perform first order feasibility analysis in some areas**
  - Science (Synthetic Aperture Radar)
  - Communication (link budgets)
  - Power (RTGs, Solar Arrays)
  - Propulsion (Orbiter propulsion system)
  - Structures (launch stack and vibration)
  - Thermal (Loop Heat Pipes, Thermal Balances)

Aerocapture Systems Analysis Review
S/C Design: Launch Configuration

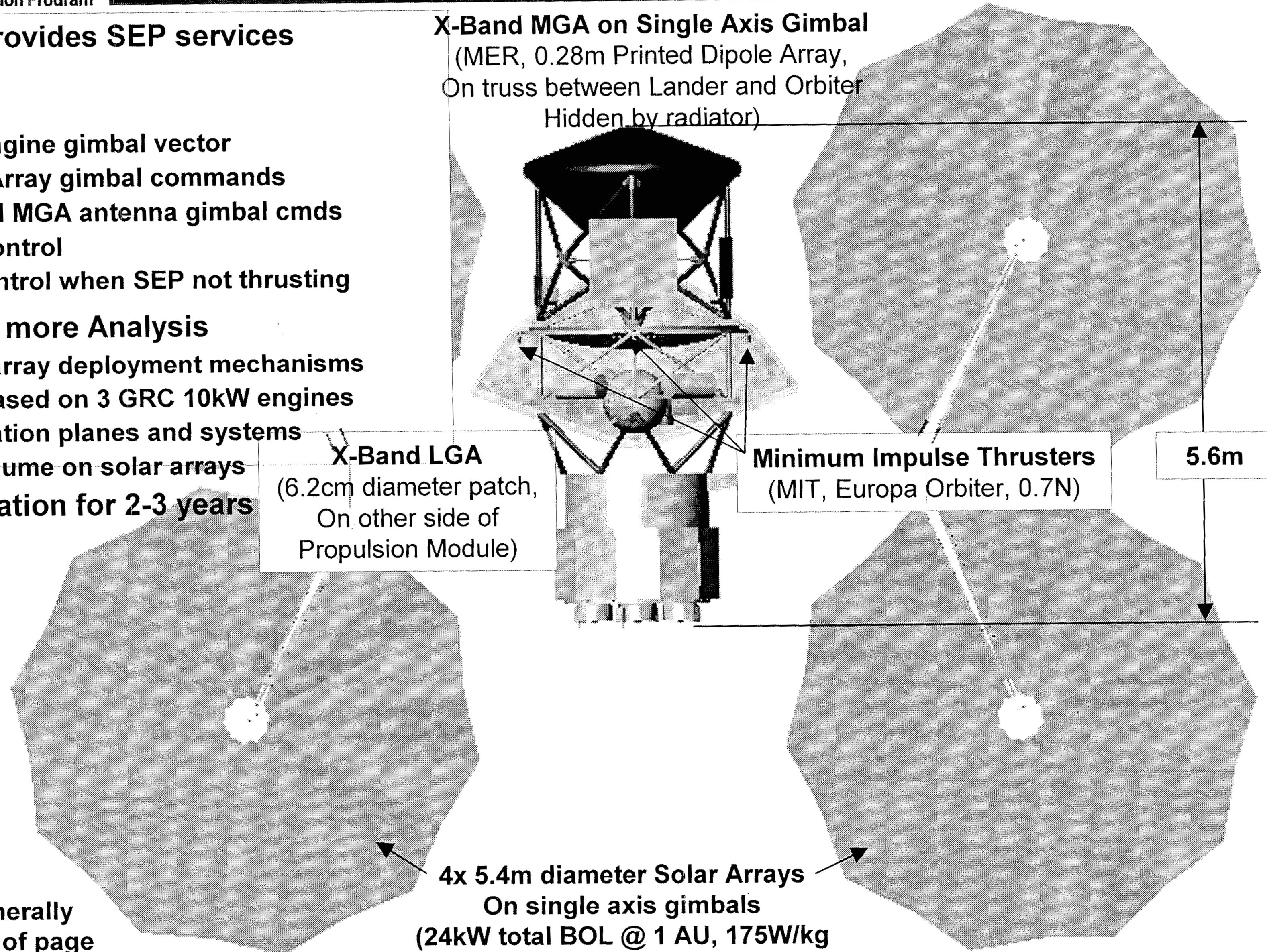
	Subsystem Rack-up			Mass (kg)
Component	Current Best Estimate	% Contingency	Growth	System Allocation
Lander Entry Mass	***280.2***	***29.8%***	***363.8***	***400.0***
Orbiter/Lander Interface	47.5	30.0%	61.8	61.8
Orbiter Launch Wet Mass	***883.6***	***24.2%***	***1097.7***	***1200.0***
Prop Mod/Orbiter Interface	47.3	30.0%	61.4	61.4
SEP Launch Wet Mass	***1084.0***	***21.4%***	***1316.5***	***1450.0***
Launch/Prop Mod Interface	60.0	30.0%	78.0	78.0
Stack Total	2402.6	24.0%	2979.2	3251.2
Launch Vehicle Capability	3423	Delta 4450, EGA, 6.5 km/s entry		
System Level Mass Margin	29.8%	(LV Cap - CBE) / LV Cap		
System Reserve	13.0%	(LV Cap - Growth) / LV Cap		

- **Opportunities to get from EGA to VGA**
  - Current VGA System Reserve is ~6%
  - Need ~150kg of growth mass to get system reserve to ~10%
  - 4m Fairing: 0 to 100kg
  - TPS materials: 0 to 120kg
  - Shorter aeroshell: 0 to 30kg
  - Smaller diameter aeroshell: 0 to 30kg
  - Aerocapture targetting (0–30 m/s dV): 0 – 10kg
- **EGA System Margin with opportunities realized = ~35%**



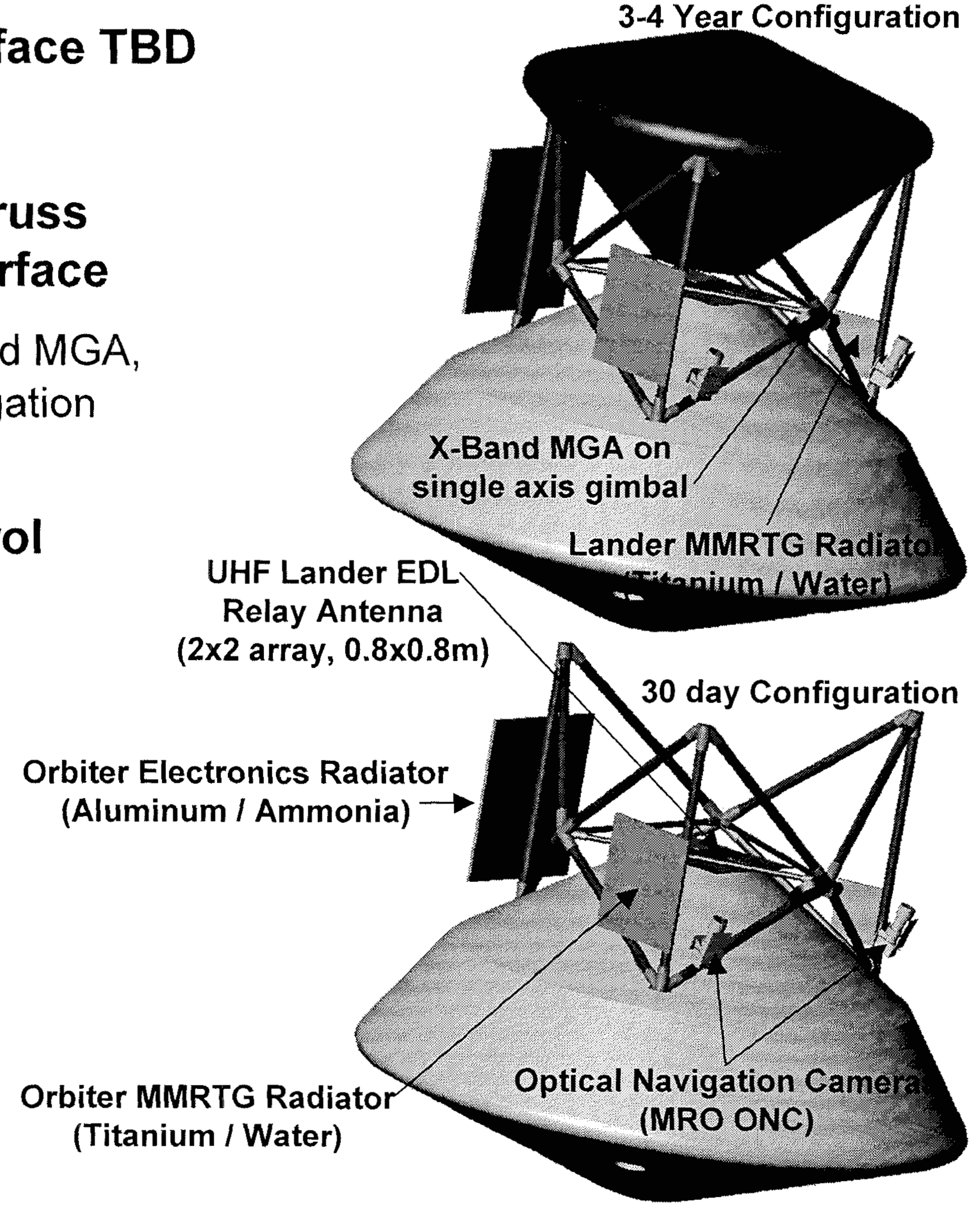
Aerocapture Systems Analysis Review
S/C Design: SEP Cruise Configuration

- ♦ **Orbiter provides SEP services**
  - C&DH
  - ACS
  - SEP engine gimbal vector
  - Solar Array gimbal commands
  - X-Band MGA antenna gimbal cmds
  - Roll Control
  - P/Y control when SEP not thrusting
- ♦ **Requires more Analysis**
  - Solar array deployment mechanisms
  - SEP based on 3 GRC 10kW engines
  - Separation planes and systems
  - SEP Plume on solar arrays
- ♦ **Configuration for 2-3 years**



Aerocapture Systems Analysis Review
S/C Design: Post SEP Cruise Configurations

- **Orbiter to Lander Separation Interface TBD**
  - Lander Radiator to Stay With Lander
- **Components on Orbiter / Lander truss used <1hr before Orbiter aero interface**
  - MMRTG/Electronics Radiators, X-Band MGA, UHF Lander EDL Relay, Optical Navigation Cameras
- **MITs (0.7N) used for attitude control**
- **Components not shown**
  - Star Tracker holes in aeroshell
  - RCS thruster holes in aeroshell
  - Cabling and LHP plumbing
  - MMRTG access door in aeroshell

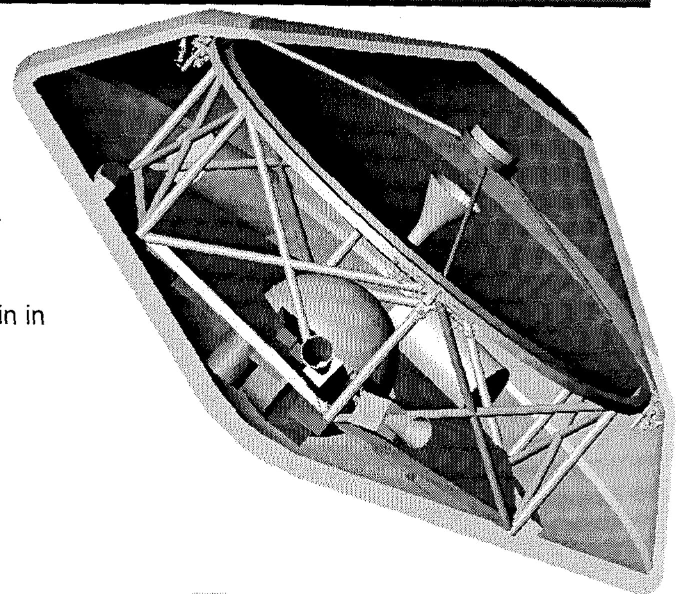


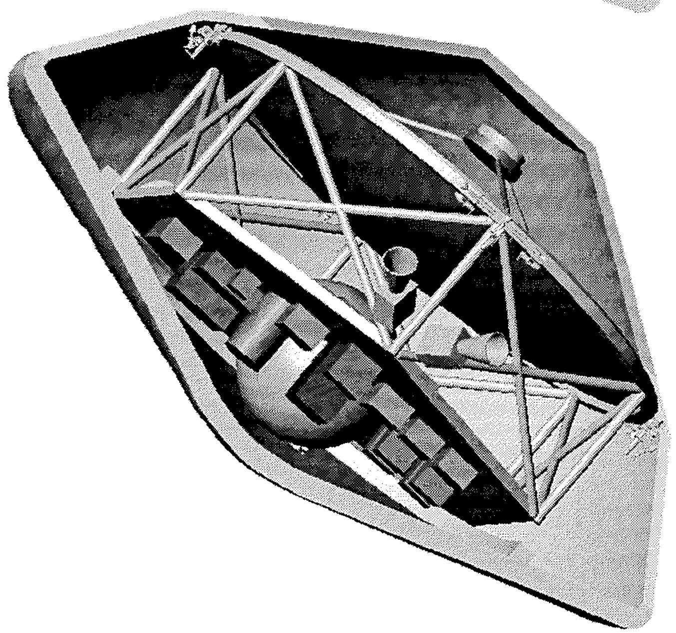
Aerocapture Systems Analysis Review
S/C Design: Orbiter Aerocapture Configuration

Advanced Space Transportation Program

Component	Units	CBE	Contingency	Total Growth
Aerocapture Mass	*6*	*818.07*	*25.4%*	*1026.11*
Aerocapture System	6	327.80	30.0%	426.14
Hydrazine Propellant		88.90	0.0%	88.90
Titan Orbit Wet Mass		*401.37*	*27.3%*	*511.07*
Propellant		10.32	30.0%	13.42
Titan Orbit Dry Mass	*236*	*391.05*	*27.3%*	*497.66*
Instruments	4	32.80	29.8%	42.56
ACS	15	20.22	9.6%	22.16
C&DS	16	15.32	25.6%	19.24
Power	5	80.06	30.0%	104.08
Telecom	13	39.06	23.9%	48.41
Structure	7	136.70	30.0%	177.71
Propulsion	73	39.46	21.2%	47.83
Thermal	103	27.43	30.0%	35.66

← Includes post-aerocapture circularization delta-V (margin in dV, not mass) [for Hydrazine Propellant, 88.90]





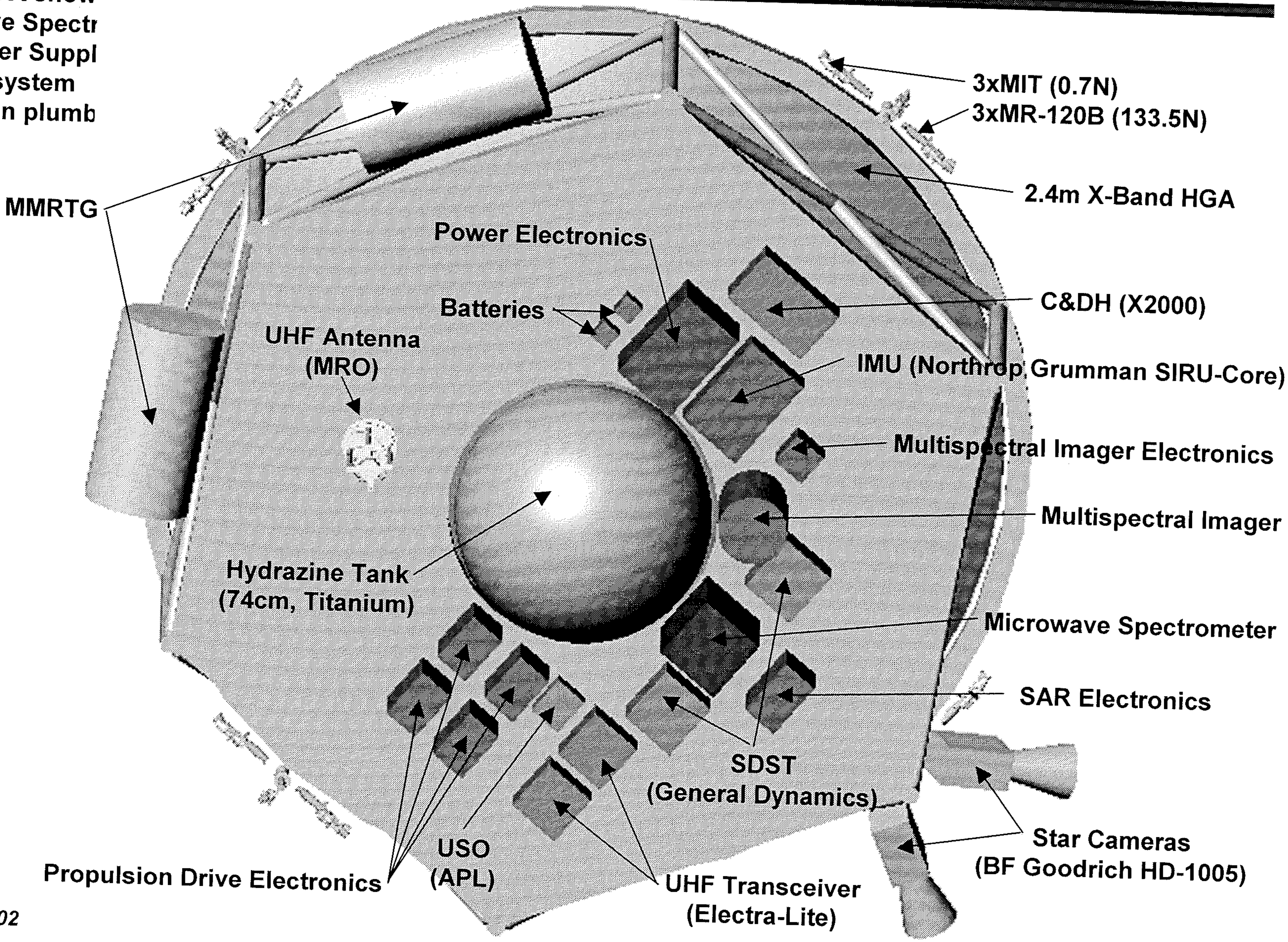
- **Backshell / Heatshield are TUFROC w/ Aluminum honeycomb support structure**
  - Door for MMRTG installation
  - Separation plane and payload deck support
- **MR-120B Engines: 133.5N each**
  - 2 engines adequate for aerocapture roll control
- **Components not shown**
  - Thermal System, Propulsion Plumbing, Cabling

Exploring the Future

Advanced Space Transportation Program

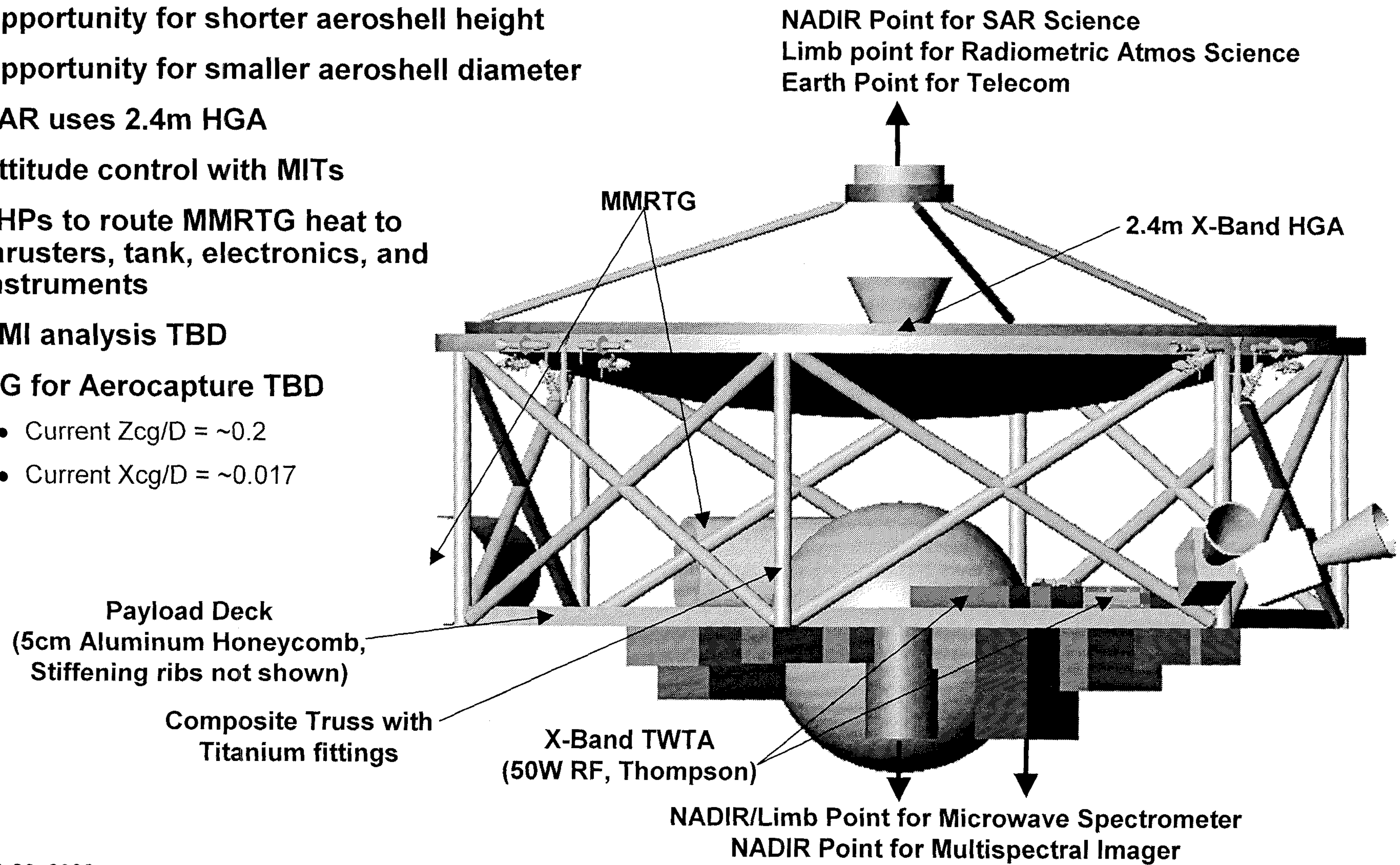
Aerocapture Systems Analysis Review
S/C Design: Titan Science Configuration

Elements not show
- Microwave Spectr
- SAR Power Suppl
- Thermal system
- Propulsion plumb



Aerocapture Systems Analysis Review
S/C Design: Titan Science Configuration - Continued

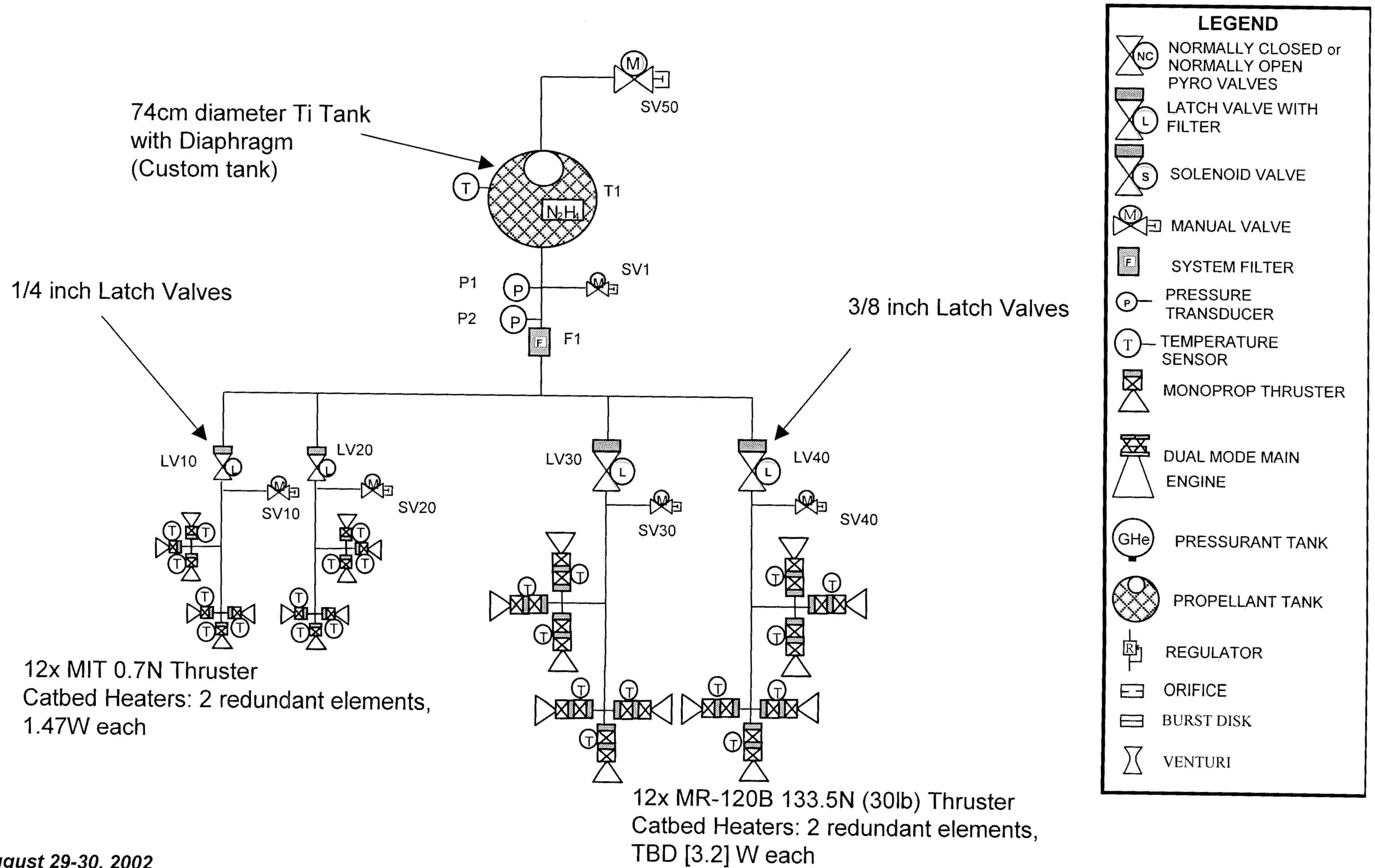
- **MR-106Es shown, MR-120Bs are baseline**
  - Approximately same size with 90 nozzle
- **Opportunity for shorter aeroshell height**
- **Opportunity for smaller aeroshell diameter**
- **SAR uses 2.4m HGA**
- **Attitude control with MITs**
- **LHPs to route MMRTG heat to thrusters, tank, electronics, and instruments**
- **EMI analysis TBD**
- **CG for Aerocapture TBD**
  - Current Zcg/D = ~0.2
  - Current Xcg/D = ~0.017



Aerocapture Systems Analysis Review
S/C Design: Telecom Links

Link Functionality	Freq	Lander Antenna	Orbiter Antenna and Location	Ground Station	Data Rate
Post-launch acquisition Emergency Comm to 0.5 AU	X-Band	N/A	LGA: -6 dBi 0.062m Patch Fixed mount On SEP Prop Module	34m BWG	10 bps @ 0.5AU
Earth-Titan Cruise to 11AU	X-Band	N/A	HGA: 24.8 dBi 0.28m printed dipole array (MER) 0.5° point accuracy On Single axis gimbal mounted to Lander/Orbiter truss	70m	500 bps @ 11 AU
Lander EDL Relay	UHF	LGA 0.38m Omni -3db at 60° half angle Fixed Mount	MGA: 10 dBi 2x2 array (0.8x0.8m total), 0.3m array elements -3db at 30° half angle Between Lander and Orbiter mounted to truss	N/A	Carrier Only @ 85,000km
Orbiter Aerocapture	None	N/A	N/A	N/A	Data recorded for post aerocapture playback
Titan Science	X-Band	N/A	HGA: 44.3 dBi 2.4m dish Fixed Mount inside aeroshell	70m	75 kbps (2.3 Tbits total return: 8hr per day)
Lander Science Relay	UHF	LGA 0.38m Omni -3db at 60° half angle Fixed Mount	LGA: MRO UHF -3db at 30° half angle Fixed Mount inside aeroshell	N/A	64 kbps (16 Gbits total: 30min per 8days)

Aerocapture Systems Analysis Review
S/C Design: Orbiter Propulsion



Aerocapture Systems Analysis Review
S/C Design: Power Profiles

Peak Power

		Mission Phase												
ient	Peak	Launch	Deploy	Cruise	Prop Sep	Lander Sep	Radiator Sep	AeroCap	Aero Sep	Camera Science	Lander Relay	SAR Science	Earth Comm	Recharge
Margin		81.8%	34.5%	34.8%	32.5%	20.9%	67.6%	66.5%	75.2%	36.0%	45.3%	-15.5%	21.8%	74.3%
Available	252	252	252	241	241	228	228	222	222	214	214	214	214	214
Totals		***45.90***	***165.00***	***157.00***	***162.50***	***180.50***	***74.00***	***74.20***	***55.00***	***137.10***	***117.10***	***181.10***	***167.60***	***55.00***

Average Power

		Mission Phase												
ient	Duty Cycle	Launch	Deploy	Cruise	Prop Sep	Lander Sep	Radiator Sep	AeroCap	Aero Sep	Camera Science	Lander Relay	SAR Science	Earth Comm	Recharge
Margin		81.8%	42.8%	43.4%	41.1%	37.9%	67.5%	66.5%	75.2%	36.0%	45.3%	48.0%	31.4%	74.3%
Available		252	252	241	241	228	228	222	222	214	214	214	214	214
Totals		***45.90***	***144.27***	***136.27***	***141.77***	***141.52***	***74.02***	***74.20***	***55.02***	***137.12***	***117.12***	***111.42***	***146.87***	***55.02***

- **Very preliminary analysis**
- **Peak power profile suggests the need for batteries**
- **Average power profile indicates 2 MMRTGs capable of meeting mission needs**
  - Lander Separation Phase assumes UHF lander relay and Earth telecom
  - Aerocapture and Aerocapture Separation Phase assume no Lander or Earth telecom
  - Camera science mode assumes concurrent operation of Microwave Spectrometer and Mutlispectral Camera
  - Worst Case is Telecom with Earth
- **Liens**
  - Science instrument design maturity
  - Addition of Reaction Wheels
  - MMRTG capability

Aerocapture Systems Analysis Review
S/C Design: New Technology Development

- **Enabling Technologies**
  - No new technology required
- **Strongly Enhancing Technologies**
  - TPS Material Testing
    - TPS materials proposed and other TPS options exist today, but are not tested against expected radiative heating at Titan
- **Enhancing Technologies**
  - No new technology required
- **The following technologies provide significant benefit to the mission but are already in a funded development cycle for TRL 6 by 2006**
  - MMRTG (JPL sponsored AO in proposal phase, First flight in '09)
    - Solar array/battery combo would add at least 3.5x the MMRTG mass
  - SEP engine (Glenn Research Center engine development, TRL6 in '06)
    - Allows mission to fit on smaller launch vehicle
  - Second Generation AEC-Able UltraFlex Solar Arrays (175W/kg)
    - Triple Junction cells on existing UltraFlex structural design
    - Conventional arrays double already large array mass

Aerocapture Systems Analysis Review
S/C Design: Work For Next Study Phase - Orbiter

- **MIT vs Reaction Wheel Trade**
  - Current design uses MIT (0.7N) thrusters for attitude control
    - Increases NAV dispersions for Lander eject and aerocapture FPA
    - Reaction wheels deleted from original design because of mass and power issues
  - Could be 33kg to 73kg mass lien
- **Conceptual Design For Deployable HGA**
  - Current design uses 2.4m fixed HGA
  - 6.0m Deployable HGA slightly heavier, but provides opportunities for
    - Reduced backshell height (mass opportunity)
    - Reduced aeroshell diameter (mass opportunity)
    - 500 kbps to70m ground station, 15 Terabit total science return capability (75kbps to 70m for 2.4m fixed HGA, 2.3TBit total return)
    - 6 bit depth for SAR data (5 bit for 2.4m fixed)
- **Conceptual Designs For Science Instruments**
  - Current designs are WAGs by experts based on existing instruments that need be be repackaged for this mission
  - Could be significant lien or opportunity for Mass, Size, Power (Survival, Peak, Average), EMI, data volume, etc.
- **Power Profile Analysis / Battery Definition**
  - Current analysis is high level and indicates performance close to margins
  - Need better detail to size batteries for proper peak power load, duration and frequency
- **Payload Deck Configuration**
  - Current design not concerned with placement of equipment on payload deck
  - Effects EMI between components, thermal balance, center of mass location (critical for aerocapture), cabling mass, and aeroshell diameter/height
- **RCS engine thermal control**
  - Current addressing heating in the cold case, but does not address cooling in the hot case.
  - Current analysis does not address thermal control for hydrazine lines
- **Aerocapture heatshield / backshell instrumentation**

Aerocapture Systems Analysis Review
S/C Design: Work For Next Study Phase - System

- **Concepts for "Holes" in the Aeroshells**
  - Current design ignores issues associated with routing structure, visible FOV, and thruster exhaust through aeroshell and heatshield
  - Could be mass lien or opportunity
  - Could be new technology need
- **Concepts for Structural Separation Planes**
  - Current design does not define separation planes, structure, or equipment between the truss elements
  - Could be 20kg+ mass lien
- **Launch Vehicle**
  - Determine opportunity for 4m Fairing on Delta 4450
    - Current design uses 5m fairing
    - Possible launch mass opportunity of 100kg
- **SEP Prop Module**
  - Change Design to Glenn Research Center 10kW engines
    - Current design utilizes unfunded JPL 5kW engines
    - GRC engines TRL 6 by 2006
  - Define Solar Array Deployment Sequence and Mechanism Concept
    - Current design largely ignores the reality of deploying the solar arrays and of SEP engine plume effects on arrays
    - Could be opportunity or lien of 10kg
- **Lander**
  - Define Lander separation concept
    - Current design ignores spin stabilization before ejection and MMRTG radiator separation with Lander
    - Could be mass liens high on launch stack which effect structural mass needs
  - Determine Orbiter to Lander visibility from Lander Separation to Lander EDL
    - Current design sizes Lander EDL UHF link, but assumes correct visibility between Lander and Orbiter antennas during Lander EDL
    - Visibility realities could relax or eliminate need for EDL specific relay antenna

Aerocapture Systems Analysis Review
S/C Design: Work For Next Study Phase – System (cont)

- **Telecom**
  - Possible use of KA Band to improve Science return
  - Possible use of KA Band to improve navigation
  - Addition of Orbiter LGA/MGA for immediate post aerocapture and Titan Orbit emergency/safing communication
    - Current design has HGA as only post-aerocapture Earth comm antenna
  - Lander EDL and Orbiter Aerocapture geometries/attitudes for real-timed relay and Earth communication
    - Current link budgets assume relative geometry feasibility
  - Lander EDL and Orbiter Aerocapture link budgets for real-time relay and Earth communication
    - Data returned to Earth (carrier signal lock, bps) as a function of Lander EDL timeline and Orbiter aerocapture timeline