National Aeronautics and Space Administration

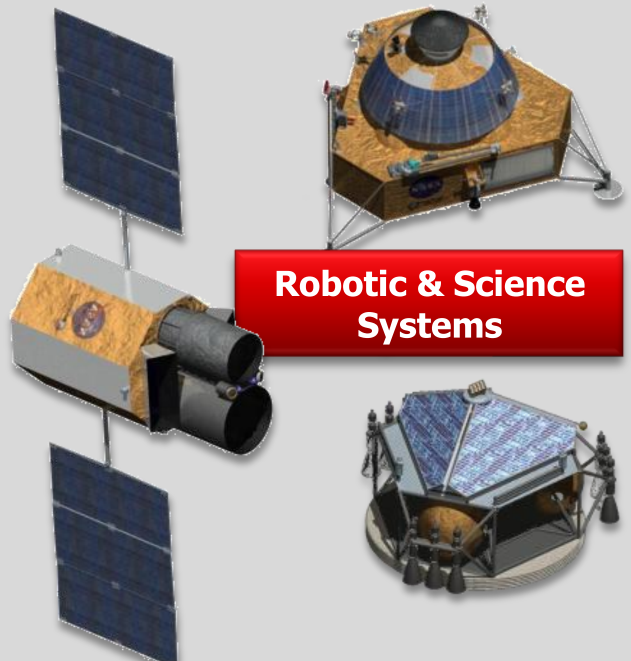
MSFC Advanced Concepts Office

Defining the future of space exploration

Advanced Concepts Overview

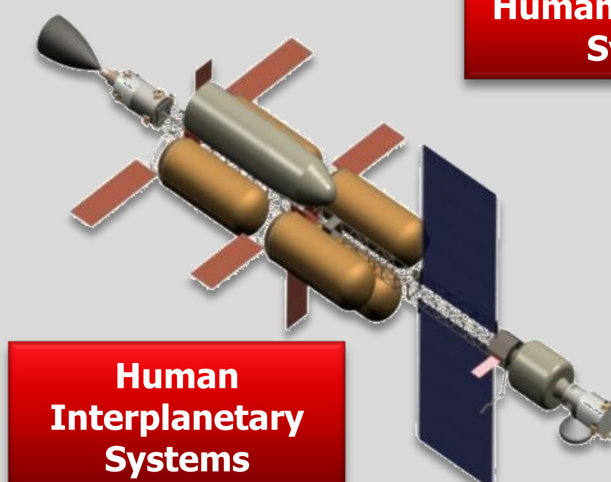
We Are An Office Specializing In Pre-Phase A & Phase A Concept Definition For Space Exploration Elements

Launch Vehicle Systems



Robotic & Science Systems

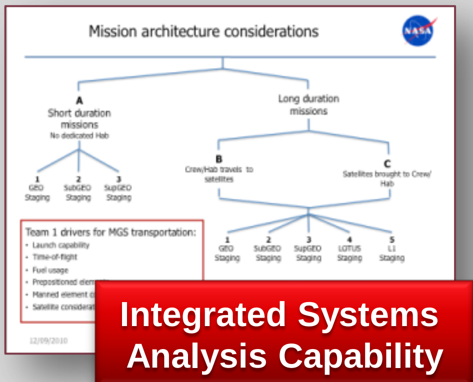
Human Exploration Systems

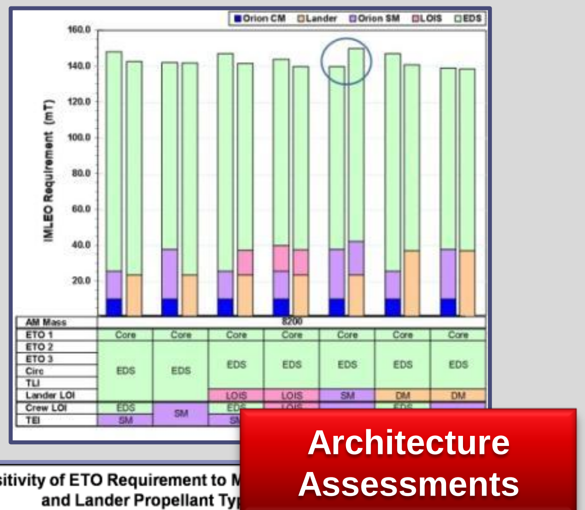


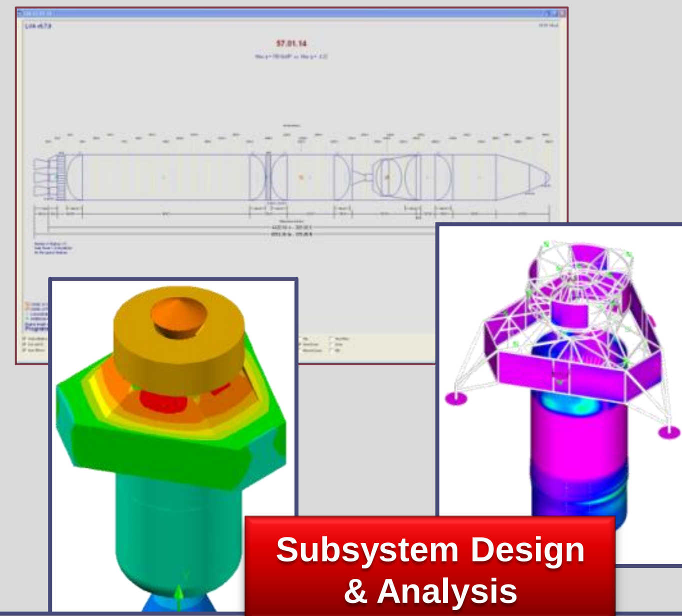
Human Interplanetary Systems

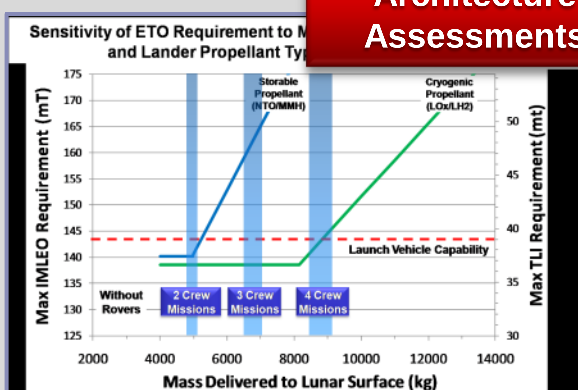
Advanced Concepts Overview

We Utilize Multi-Disciplined Teams Within the Office to Provide Fully Integrated Assessments of Missions and Their Elements









Project & Study Highlights

Science & Robotic Exploration

- Advanced X-ray Timing Array (AXTAR)
- Small Orbital Debris Detection And Tracking (SODDAT)
- Cryogenic Propellant Storage & Transfer (CPST) Technology Demonstration Definition
- Nano-Energetic Propellants
- Space Solar Power

Human Exploration

- Space Launch Systems (SLS) Definition
  - Launch Vehicle Trades & Analysis
  - Architecture Definition
- Human Spaceflight Architecture Team (HAT)
  - Cryo Propulsion Stage Definition
  - Lunar Lander Definition
  - Deep Space Habitat Definition
- Manned GEO Servicing

ACO Contributions to the Agency

HEOMD

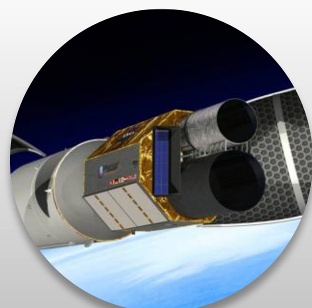
HAT

MSFC Center Development

MSFC Engineering Directorate

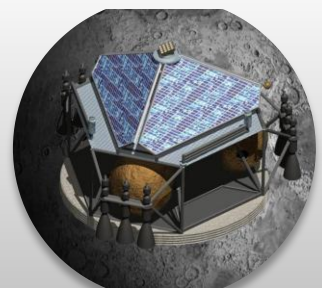
MSFC Science & Mission Systems

Earth-to-Orbit Transportation System Definition



Earth & Planetary Science Concept Definition

Human Exploration Architecture Definition



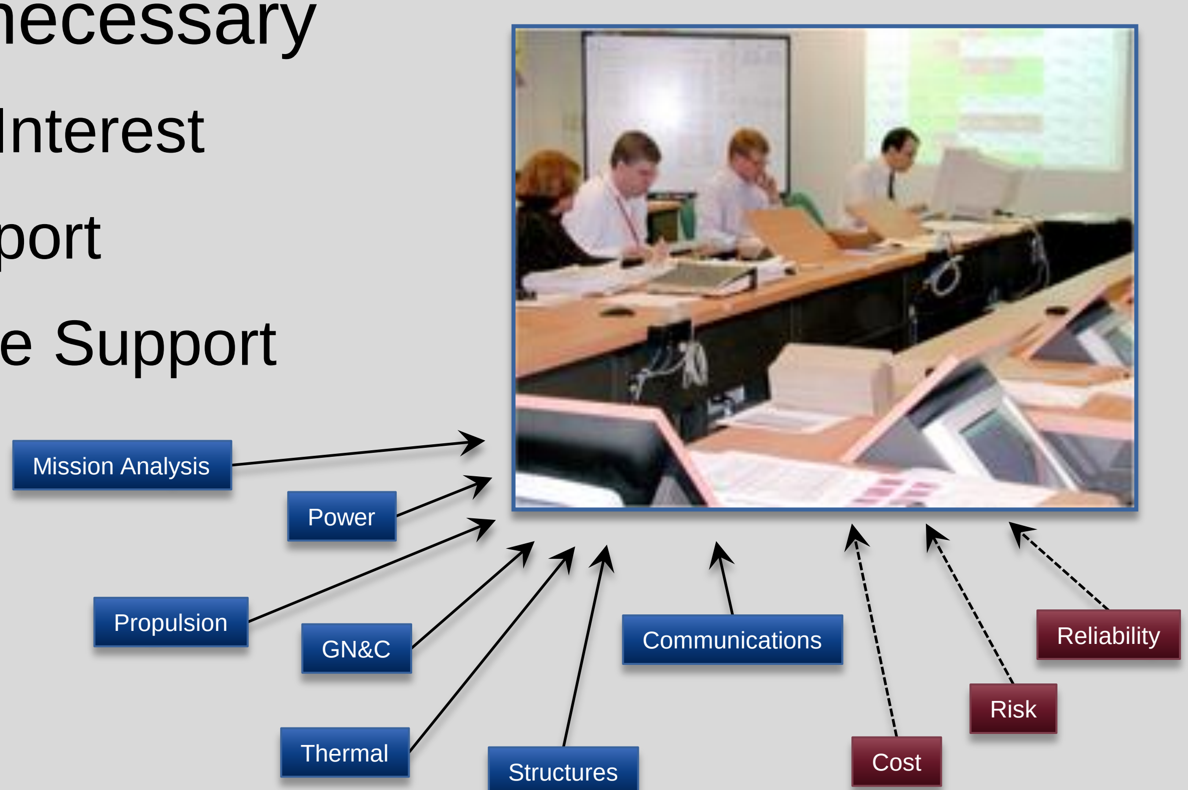
Scientific & Robotic Exploration

In Space Element Definition

Advanced Concepts Products Influence NASA Programs

Collaborative Design Team

- The ACO Design Teams are established, co-located teams of systems and design engineers
- Other disciplines or specific expertise are matrixed into the team as necessary
  - Scientific Areas of Interest
  - Programmatic Support
  - Additional Discipline Support



Design & Analysis Tools

Advanced Concepts uses a suite of industry standard and in-house developed tools to perform analysis

INTROS

ProEngineer

Thermal Desktop

Copernicus

LVA

3D Studio

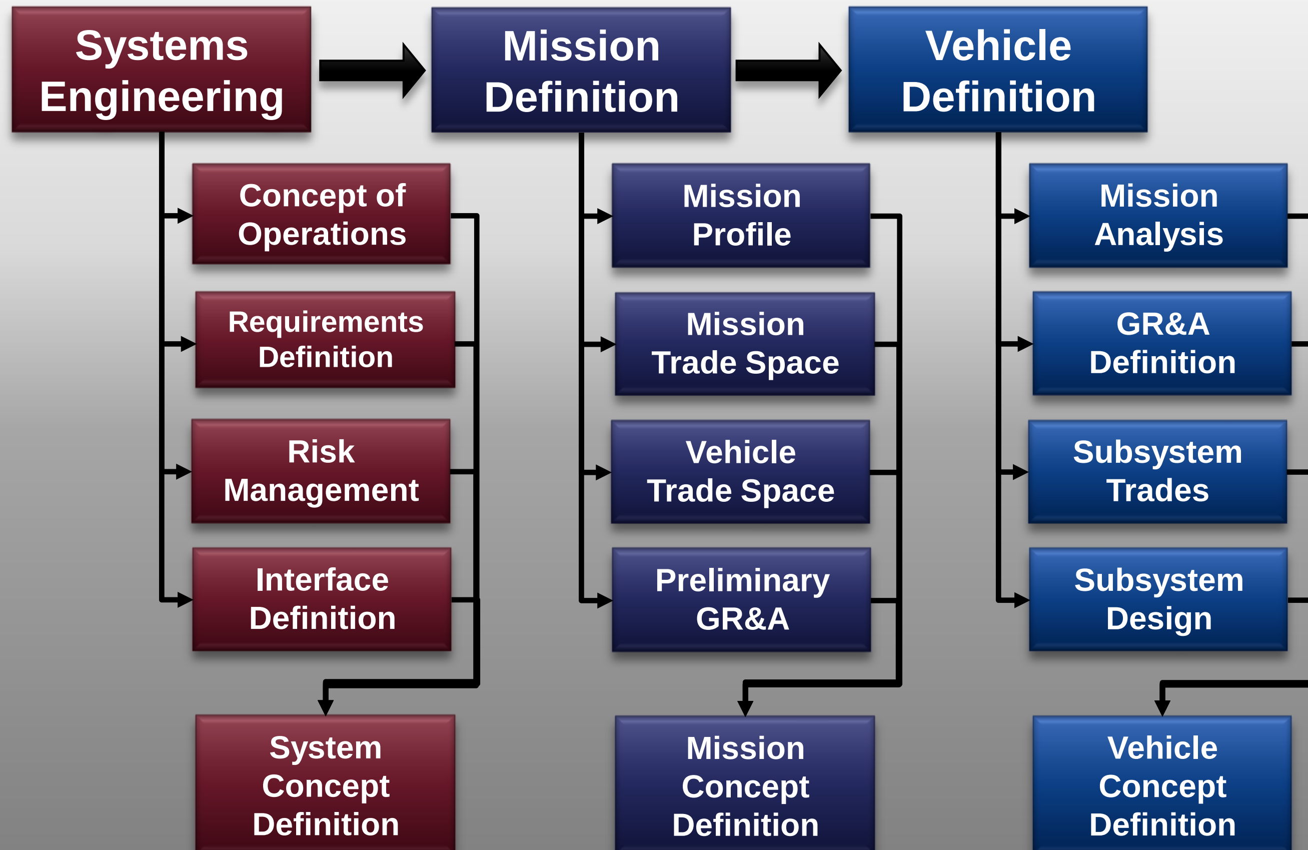
POST

COPA

FEMAP w/NX NASTRAN

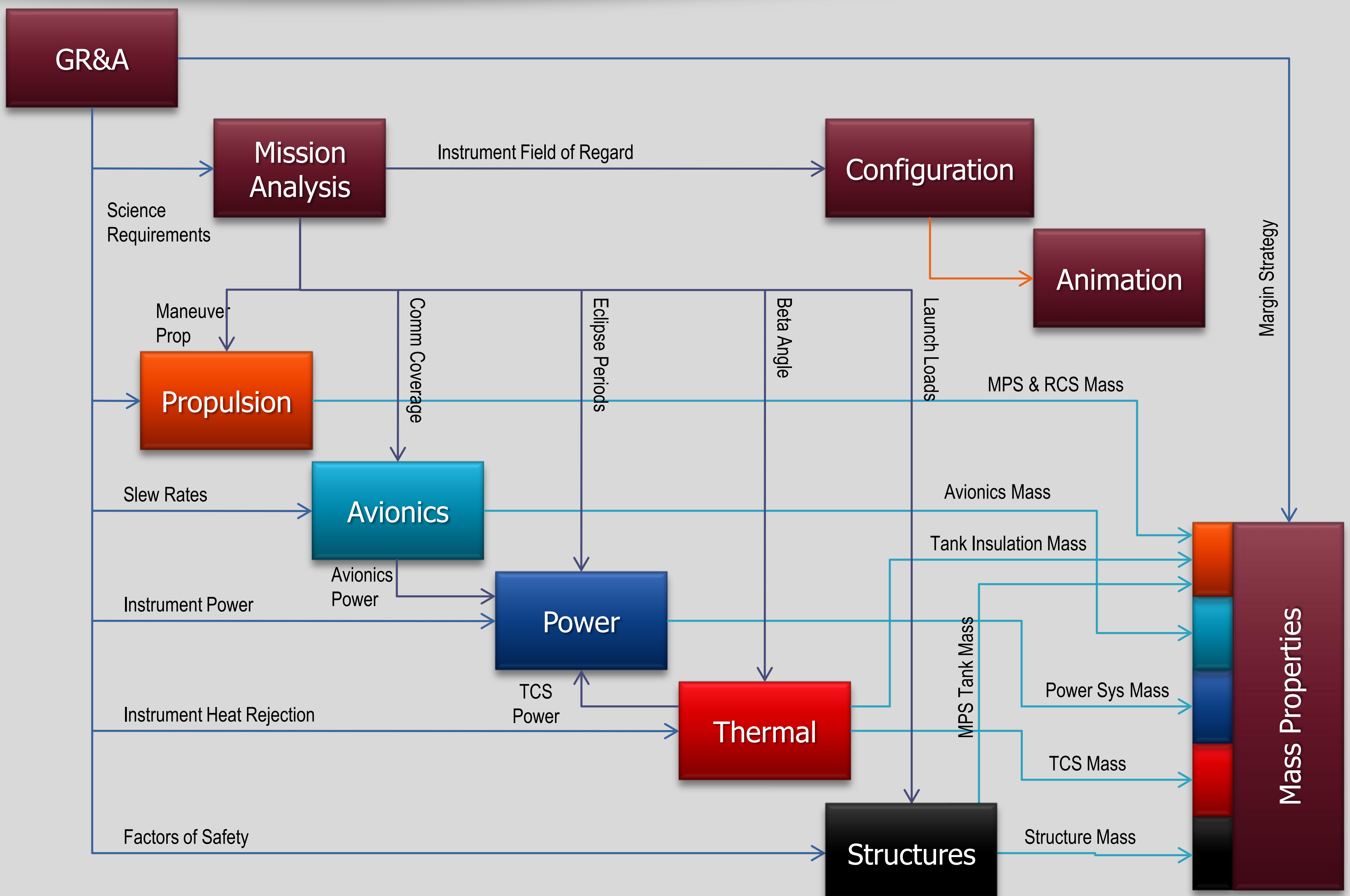
Collaborative Design Process

Engineering Directorate Collaborative Pre-Phase A Design Process



Consistent with NASA NPR 7120 System Engineering Principles

Simplified Vehicle Definition Process



Summary

- Advanced Concepts Performs Rapid Pre-Phase A & Phase A Conceptual Design and Analysis for Space Exploration Elements
  - Collaborative Engineering Processes
  - Diverse Toolset

Vdot's implementation will greatly enhance the capabilities of the Advanced Concepts Office

STUDY EXAMPLES

Example: AXTAR Spacecraft Study

AXTAR: Introduction

- **Customer**
  - Colleen Wilson-Hodge (VP62) and the AXTAR science team
- **Mission Description**
  - The Advanced X-ray Timing Array (AXTAR) is an X-ray observatory concept combining very large collecting area, broadband spectral coverage, high time resolution, highly flexible scheduling, and an ability to respond promptly to time-critical targets of opportunity.
  - It's mission is to probe the physics of ultra-dense matter, strongly curved space-times, and intense magnetic fields.
  - Instruments: (1) the Large Area Timing Array (LATA) is for timing observations of accreting neutron stars and black holes; (2) the sensitive Sky Monitor (SM) acts as a trigger for pointed observations of X-ray transients and also provides sensitive monitoring of the X-ray sky.
- **Mission Class: MIDEX science mission.**

Goals and Responsibilities

- **Study Goal**
  - Complete a conceptual spacecraft design to support the AXTAR science mission and determine the maximum number of LATA supermodules and Sky Monitor cameras that can be accommodated on a feasible configuration
- **Responsibilities**

Advanced Concepts Office

Spacecraft
- Communications
- Electrical Power
- Trajectory / GN&C
- Propulsion
- Thermal
- AR&D
- Launch Stack Shroud Integration
- Cost

Instruments
- Propose method to transfer heat from LATA to spacecraft thermal control system
- Determine max number of LATA modules and Sky Monitors for feasible configuration.

VP62

Instruments
- Design
- Power
- Mass
- Data requirements
- Cost (ED04/CS50 will also cost the instruments)

Bus structure

AXTAR: Mass Properties (Falcon 9 Concept)

4.0	**Avionics/Control**			**422.53**
4.1	ACS (includes Reaction Wheels and Torque Rods)	1	308.98	308.98
4.2	CDS (includes Flight Computers and Data Recorders)	1	20.00	20.00
4.3	Instrumentation	1	15.00	15.00
4.4	Communications System	1	38.55	38.55
4.5	Avionics Cabling	1	40.00	40.00
5.0	**Thermal Control**			**53.90**
5.1	Multilayer Insulation/Thermal Tape	1	42.00	42.00
5.2	Thermal Filler	1	2.10	2.10
5.3	Paint/Thermal Coatings	1	9.10	9.10
5.3	Heaters/Thermostats	1	0.70	0.70
6.0	**Contingency**			**620.35**
6.1	Structure	30%		382.50
6.2	Propulsion	30%		28.40
6.3	Power	30%		66.53
6.4	Avionics/Control	30%		126.76
6.5	Thermal	30%		16.17
Dry Mass				**2688.19**
7.0	**Non-propellant Fluids**			**4.09**
7.1	Residual Hydrazine	1	2.09	2.09
7.2	Pressurant (GN2)	1	2.00	2.00
8.0	**Payload/Science Instruments**			**1797.20**
8.1	LATA	42	30.00	1260.00
8.2	SM	27	2.00	54.00
8.3	IDS	1	30.00	30.00
8.4	Payload Contingency (30%)		403.20	403.20
8.5	Instrument Cabling	1	50.00	50.00
Inert Mass				**1801.29**
Total Less Propellant				**4489.48**
9.0	**Propellant (Hydrazine)**	1	405.25	**405.25**
Gross Mass				**4894.7268**

Backup

Example: Cryostat

CRYOSTAT Mission Overview

DESCRIPTION

- This project will demonstrate the technologies needed to store, monitor, access, pre-position and transfer cryogenic propellants for large cryogenic propellant storage and transfer systems that will support future space mission and commercial market opportunities

APPROACH

- Critical technologies are demonstrated in one mission utilizing one vehicle

APPLICATIONS

- Human exploration missions beyond LEO utilizing:
  - Large cryogenic stages w/ long duration space exposures
  - Propellant transfer for the earth departure stages (EDS)
- Supporting infrastructure for commercial space options (e.g., for satellite servicing, propellant transfer, refueling depots, tourism, etc.)

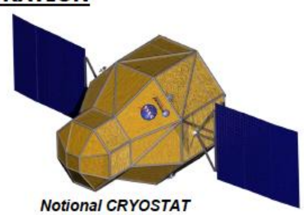
BENEFITS

- Enabling large cryogenic propulsion stages for Human exploration
- Options for use of commercial operations to support explorations missions (through use of multiple propellant transfers)

TECHNOLOGY ELEMENTS

- Tank Thermal Control
- Tank Pressure Control
- Cryogenic Propellant Transfer
- Liquid Acquisition
- Mass Gauging
- Leak Detection

CONFIGURATION



Notional CRYOSTAT Configuration

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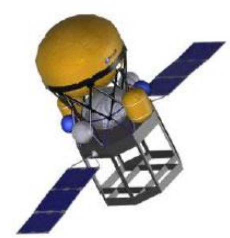
YOSTYAT Concepts

Lite Maximum Size
on Falcon 9 Capability)

:	4.6 m
	4 m
ass:	316 kg
ass:	2000 kg
CFM System	3816 kg
Bus	3020 kg
Total Mass:	**6836 kg**

CPS-Lite Minimum Size
(Based on 2 Month Mission)

Length:	4.2 m
Dia.:	2 m
LH2 Mass:	250 kg
LOX Mass:	580 kg
CFM System	2350 kg
Bus	1300 kg
Total Mass:	**3650 kg**



CPS-Pathfinder
(2 Month Mission)

Element	Mass
LH2	250 kg
Total CFM Payload	791 kg
Spacecraft Bus	471 kg
Launch Mass	**1262 kg**

Spacecraft Size
Length = 2.4 m
Dia. = 1.9 m

4

Example: HEFT CryoPropulsion Stage

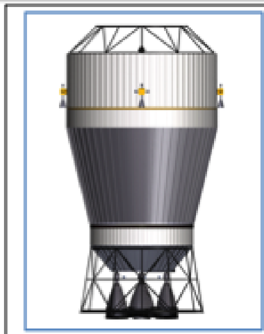
Groundrules & Assumptions

- Provides ΔV for circularization of the launch vehicle 30x130 nmi delivery orbit to the LEO 220 nmi circular orbit for itself and any other payloads manifested with it on the launch vehicle.
- CPS includes avionics, propulsion, and attitude control for automated rendezvous and docking. When rendezvous and docking with other elements the CPS can play either the active or passive role.
- CPS structure will provide adequate load bearing strength to account for its own fully loaded mass, plus the mass of any attached payloads through all phases of the mission, including launch, loiter, docking, and active thrusting.
- While loitering in-space, the CPS provides required attitude control for itself plus any attached payloads utilizing on-board RCS (storable, bi-prop system).

Groundrules & Assumptions

- CPS has a power generation and storage system capable of providing the necessary power for itself, plus any required attached payloads (quantity TBD) for all phases of flight. The full power generation capability of the CPS can be transferred to other elements through the forward docking iDSS/payload interface.
- The CPS Block 2 includes a long duration cryogenic fluid management system that provides 0.5%/month liquid hydrogen loss (by mass), and 0%/month liquid oxygen loss.
- During high thrust maneuvers where a Solar Electric Propulsion (SEP) stage is connected, the CPS engines must maintain a thrust to weight of the assembled elements of less than 0.1g.

Cryo-Propulsion Stage – Block 1



Design Constraints/Parameters

Propellants	O2/H2
Stage PMF	0.8
Stage Diameter	7.5 m
Stage Length	18 m
# Engines / Type	4 / Altair DME
Engine Thrust (100%)	18,627
Engine Isp (100%)	448.6 sec
RCS Propellants	NTO/MMH
# RCS Thrusters / Type	16 / Press-fed
RCS Thruster Isp	300 sec

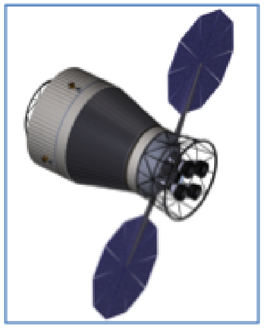
Passive Thermal Control of Propellants

Category	Mass, kg
Structure	2,913
Propulsion	3,023
MPS (including tanks)	2,761
RCS (including tanks)	262
Power	147
Avionics	455
Thermal	1,091
Active CFM	-
Passive CFM	364
Vehicle TCS	728
MMOD Protection	-
Growth (30%)	2,289
Dry Mass	9,918
Inert Mass*	2029
MPS Fuel Boiloff	49
MPS Oxidizer Boiloff	96
Non-Usable MPS Prop	1,716
Non-Usable RCS Prop	31
Pressurants	136
Total Less Usable Prop	11,947
Usable Propellant	67,897
MPS Fuel	10,286
MPS Oxidizer	56,572
RCS Fuel	392
RCS Oxidizer	647
Total Stage Wet Mass	79,844

* Mission specific values

The Block 1 Cryo Propulsion Stage (CPS-B1) is delivered to a 30 x 130 nmi insertion orbit by the launch vehicle where the CPS is then responsible for raising and circularizing itself and any payload to an orbit of 220 nmi. The non-reuseable CPS-B1 utilizes passive thermal control techniques to limit cryogenic propellant boiloff during its operation. The CPS-B1 includes avionics, propulsion, and attitude control for automated rendezvous and docking. Inert propellants are mission specific and are affected by mission duration, number of engine burns, and other mission parameters.

Cryo-Propulsion Stage – Block 2



Design Constraints/Parameters

Propellants	O2/H2
Stage PMF	0.8
Stage Diameter	7.5 m
Stage Length	18 m
# Engines / Type	4 / Altair DME
Engine Thrust (100%)	18,627
Engine Isp (100%)	448.6 sec
RCS Propellants	NTO/MMH
# RCS Thrusters / Type	16 / Press-fed
RCS Thruster Isp	300 sec

0.5% per month H2 Boiloff
0% per month O2 Boiloff

2 x UltraFlex Arrays (28.7 kW total power)

Category	Mass, kg
Structure	2,913
Propulsion	3,023
MPS (including tanks)	2,761
RCS (including tanks)	262
Power	1,003
Avionics	455
Thermal	4,057
Active CFM	2,965
Passive CFM	364
Vehicle TCS	728
MMOD Protection	382
Growth (30%)	3,550
Dry Mass	15,383
Inert Mass*	2,229
MPS Fuel Boiloff	336
MPS Oxidizer Boiloff	-
Non-Usable MPS Prop	1,716
Non-Usable RCS Prop	31
Pressurants	136
Total Less Usable Prop	17,602
Usable Propellant	67,897
MPS Fuel	10,286
MPS Oxidizer	56,572
RCS Fuel	392
RCS Oxidizer	647
Total Stage Wet Mass	85,499

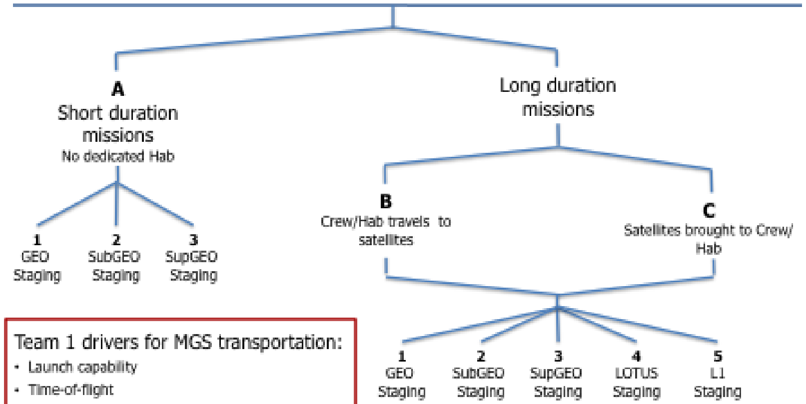
* Mission specific values

Description

The Block 2 Cryo Propulsion Stage (CPS-B2) builds upon the Block 1 CPS but includes a long duration cryogenic fluid management system that provides 0.5%/month liquid hydrogen loss (by mass), and 0%/month liquid oxygen loss. The CPS includes avionics, propulsion, and attitude control for automated rendezvous and docking. Inert propellants are mission specific and are affected by mission duration, number of engine burns, and other mission parameters.

Example: Manned GEO Servicing

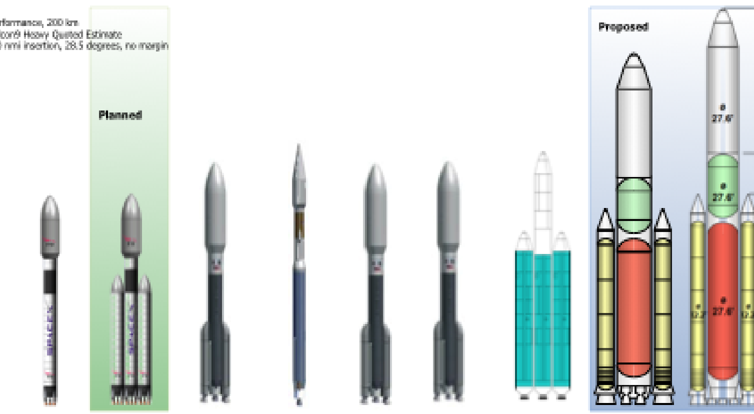
Mission architecture considerations



Team 1 drivers for MGS transportation:
- Launch capability
- Time-of-flight
- Fuel usage
- Prepositioned elements
- Manned element considerations
- Satellite considerations

Potential launch vehicles for MGS missions (1 of 2)

1 – KSC ELV performance, 200 km
2 – SpaceEx Falcon9 Heavy Quoted Estimate
3- 30 nmi X 130 nmi insertion, 28.5 degrees, no margin



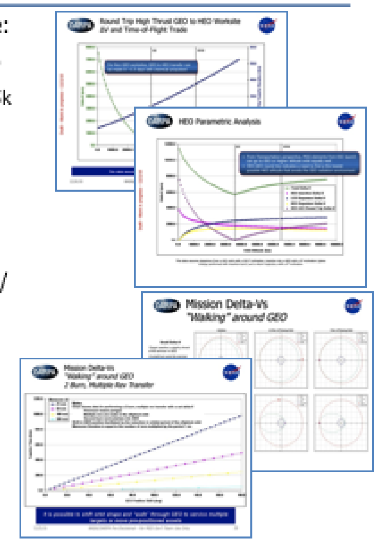
Launch Vehicle	Falcon 91	Falcon 9 Heavy2	Atlas 5011	Atlas 4011	Atlas 5411	Atlas 5511	Delta IV Heavy1	In-line Shuttle C3	HEFT SDV3
LEO pyld (kg)	9,115	32,000	8,140	9,695	15,930	17,415	23,060	79,900	108,600
GTO pyld (kg)	3,475	19,500	3,860	4,740	7,850	8,540	12,575	~37,800	51,395
GEO pyld (kg)	~1,750	~9,750	~1,930	~2,375	~3,925	~4,270	6,160	~21,735	29,556

Potential launch vehicles for MGS missions (2 of 2)

Launch Vehicle	DIVH w/ACES US	Atlas V Phase 2	Atlas V Phase 2 w/Ares 1 2nd stage ACES 3rd	Atlas V Phase 3 w/Ares 1 2nd stage/ACES 3rd	Ariane 5 ECA (A5 w/blkII cryo US)	Proton K	Proton M
LEO pyld (kg)	35,000	77,900	80,000	120,000	20,000	20,800	22,000
GTO pyld (kg)	19,500	43,200	~40,000	~60,000	10,500 (12,000 with SECB upgrade)	5,100	6,000
GEO pyld (kg)	~9,750	24,100	~23,000	~34,500	~5,250	2,600	3,500

Astrodynamic mission architecture trades

- Radiation environment, ΔV vs. orbital altitude:
  - EVA radiation environment improves above GEO
  - Elements transiting from LEO to GEO or HEO-65k require minimal increase in fuel usage
- Chemical propulsion vs. electric propulsion:
  - Chemical propulsion provides lower time-of-flight, electric propulsion provide better fuel economy
- Round trip ΔV and time-of-flight, LEO to GEO/HEO-65k
- Maneuvering within GEO:
  - Relevant to ability to reach multiple satellites with either rapid response (1 day) or fuel-efficient response (weeks)



Example: Nano-Energetic Propellants

Potential Vehicle Benefit

Monopropellant Mission Matrix

Mission	Propellant Load (kg)	ΔV (m/sec)	NEPP Propellant Candidates	Science Payload Increase (%) O2/H2	HAN/H2O
Mars Astrobiology Explorer	596	419	O2 / Metalized Gelled H2 (MGH) HAN / H2O / FGS-nDiamond	60.0	50.3
Mars Sample Return Lander	470	389		18.9	16.2
Mars Geophysical Network	132	296		34.4	38.6
Io Observer	989	1124		110.5	89.4
Saturn Probe	252	675		113.4	106.3

Game-Changing

1

Bipropellant Mission Matrix

Mission	Propellant (kg)	ΔV (m/sec)	NEPP Propellant Candidates	Science Payload Increase (%) O2/H2	HAN
Mercury Lander	1969	1238	O2 / Metalized Gelled H2 (MGH) HAN / H2O / FGS-nDiamond	51.8	-2.6
Venus Mobile Explorer	370	280		15.5	4.6
Venus Intrepid Terresa Lander	351	270		9.5	3.0
Venus Climate Mission	1432	1734		22.8	-0.4
Lunar Polar Volatiles Explorer	216	254		3.5	2.0
Mars Sample Return Orbiter	1573	3690		21 kg	-0.6
Jupiter Europa Orbiter	2681	2260		27.1	-2.1
Ganymede Orbiter	2664	2662		65.5	-5.0
Trojan Tour	557	1933		18.3	2.5
Titan Saturn System	2528	2377		32.8	-2.3
Enceladus Fly-by	2000	2000		55.8	-2.9
Enceladus Orbiter	2434	2881		60.9	-4.2
Titan Lake Lander	2255	2590		54.4	-3.4
Uranus Orbiter and Probe	1161	2500		23.5	0.3
Chiron Orbiter	840	2166		28.6	1.9

Game-Changing

2

Solid Propellant Mission Matrix

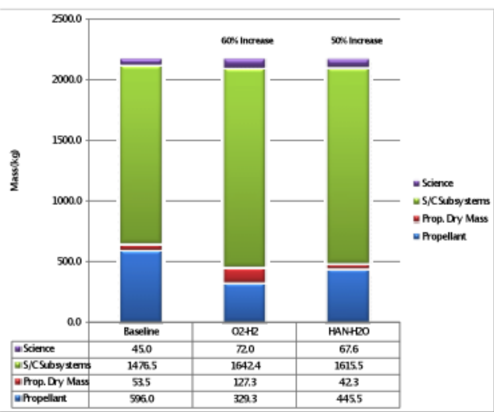
Mission	Baseline Motor	Propellant Load (kg)	ΔV (m/sec)	NEPP Propellant Candidates	Science Payload Increase (%) (1)	(2)	(3)	(4)	(5)
Mercury Lander	Star 48V	2076	4426	(1) DCPD / AP / nAl (2) High Solids HTPB (3) HAN/HTPB/Al (4) HAN/GAP/Al (5) HAN/DCPD/Al	-62.8	13.8	-9.1	13.8	-21.3
Lunar Geophysical Network	Star 30BP	457	2450		-19.3	17.7	1.2	15.7	-7.7
Lunar Polar Volatiles Explorer	Star 48V	2010	2455		-41.0	10.1	-5.2	10.1	-13.3
Mars Sample Return Lander	Star 17A	145	1857		-1.6	1.0	0.2	1.0	-0.2

3

Subsystem Specific Benefit

Mars Astrobiology Explorer

•Evaluate paleoenvironmental conditions
•Characterize the potential for the preservation of biotic or prebiotic signatures, and
•Access multiple sequences of geological units in a search for possible evidence of ancient life and/or prebiotic chemistry



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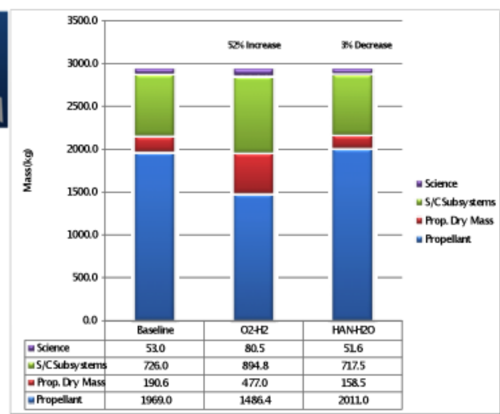
Mercury Lander

•What is the chemical composition of Mercury's surface (major and minor elements)?
•What is the mineralogy and structural state of the materials at Mercury's surface?
•What is the magnitude and time dependence of Mercury's
•magnetic field, at least for a point on the surface?
•What is the character of geological activity at scales ranging from regional to local
•What is the rotational state of Mercury?



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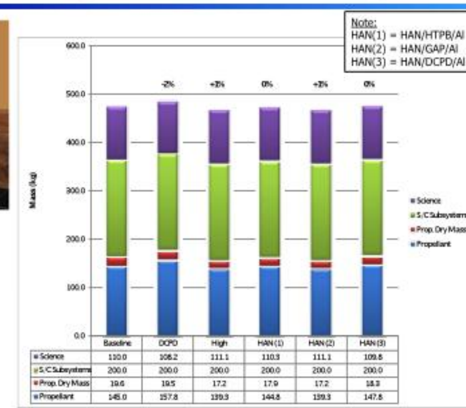
Mars Sample Return Lander

•Collect and return several samples of regolith to add to the rock-core cache collected by the MAX-C rover.
•Collect an atmospheric sample.



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