EAGLE

Enceladus Astrobiology and Geophysics Lander Expedition

2006 NASA Academy
at Goddard Space Flight Center :

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Mission Overview

OPAG Meeting

November 8th, 2006

Ryan Anderson & Daniel Calvo

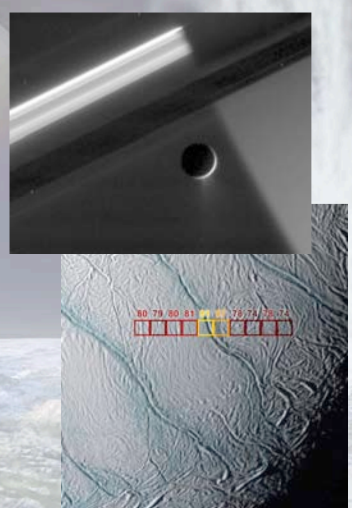
Cornell

EAGLE: Study Goals

- **Develop a set of science goals for a flagship mission to Enceladus**
- **Investigate mission architectures that can satisfy those goals**
- **Prove the economic and technological feasibility of such a mission**
  - **Heritage**
  - **Low-Risk primary mission**

EAGLE: Science Goals

- Determine if liquid water is present and map its distribution
- Determine surface chemical composition, identify any organic compounds and biomarkers.
- Understand Enceladus' unusual geologic features, and the processes behind the surface activity seen by Cassini.

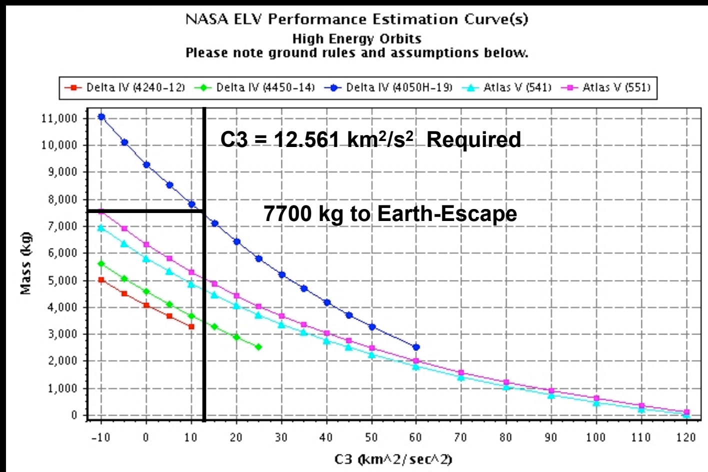


Mission Architecture Overview

The EAGLE spacecraft consists of three components:

- **Saturn Orbiter**
  - Orbit Saturn
  - Carry scientific instruments
  - Act as communications relay for Lander
- **Enceladus Orbiter/Lander**
  - Orbit and land on Enceladus
  - Contain a wide range of scientific instruments
  - Extended Mission
- **Propulsion Stage**
  - Provide thrust for Saturn and Enceladus maneuvers
  - Contain Enceladus orbiting instruments
  - Dependent on Lander systems and discarded after fuel is spent

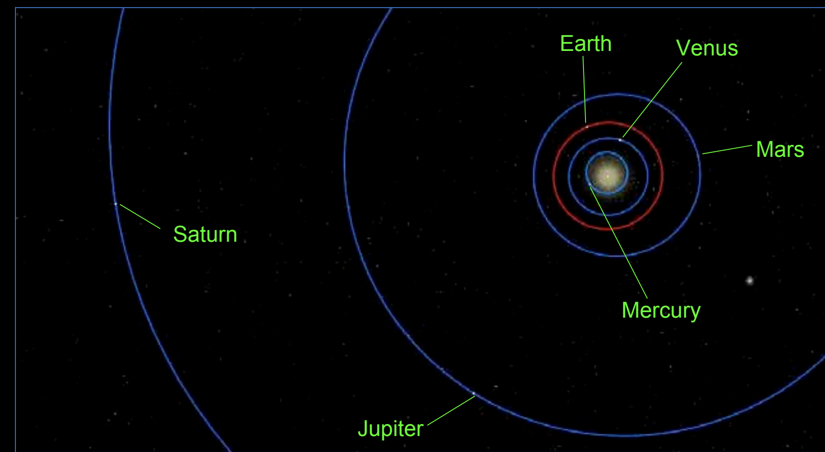
Launch Vehicle Selection



(http://elvperf.ksc.nasa.gov/elvMap/staticPages/launch_vehicle_info1.html)

- Launch Vehicle: Delta IV (4050H-19)

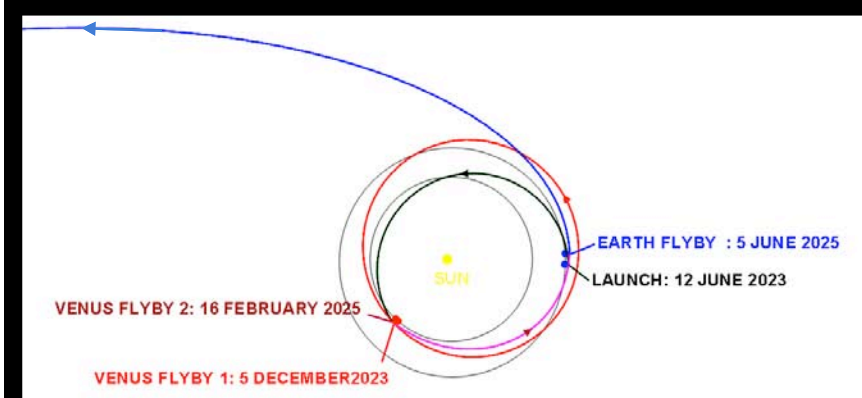
Can we Use Jupiter?



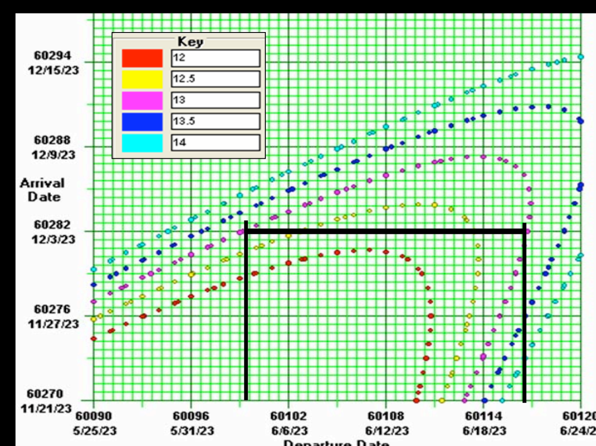
- For Launch in mid 2020's, Jupiter assist is NOT practical.

Interplanetary Trajectory

- Venus-Venus-Earth-Saturn trajectory
- Seven year transit time (SOI in June 2030)
- ΔV=4.47 km/s (Earth escape to Saturn capture)



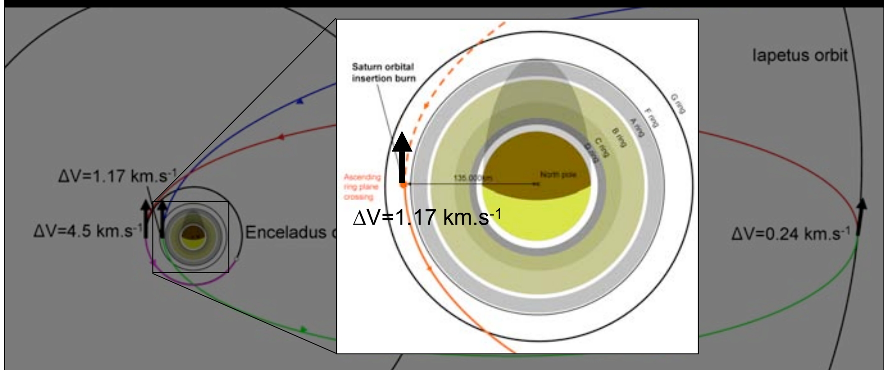
Nominal Launch Window



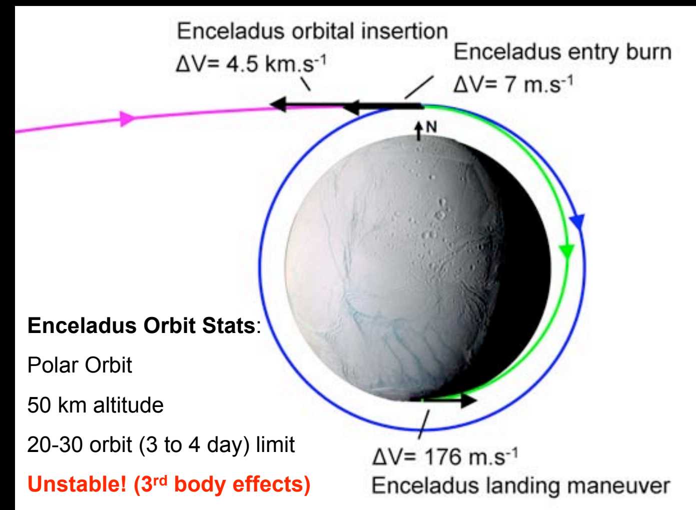
- Venus arrival must occur on 3 Dec 2023
- For a C3 < 13 km²/s² this constrains the launch date to the first three weeks of June 2023

Saturn Orbital Insertion

- Hyperbolic orbit slightly inclined with respect to Saturn's ring plane.
- Perigee between F and G rings minimizes ΔV Cost

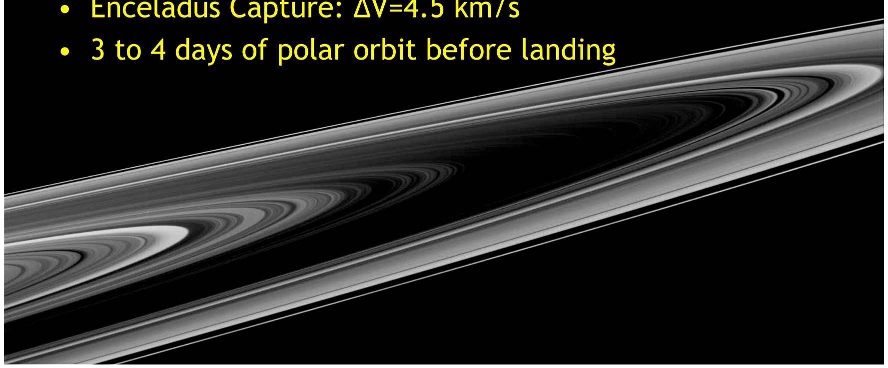


Enceladus Orbital Insertion



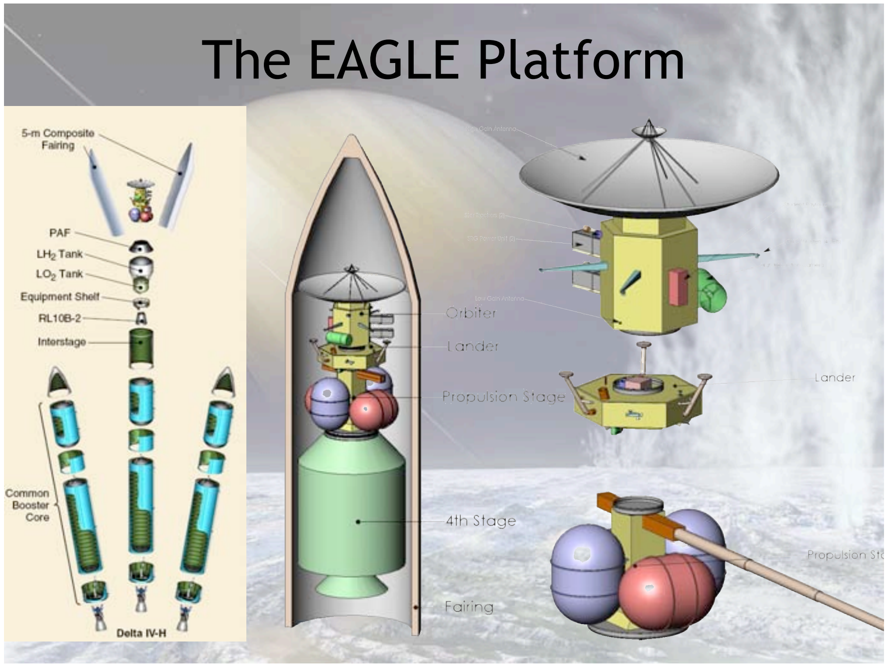
Trajectory Summary

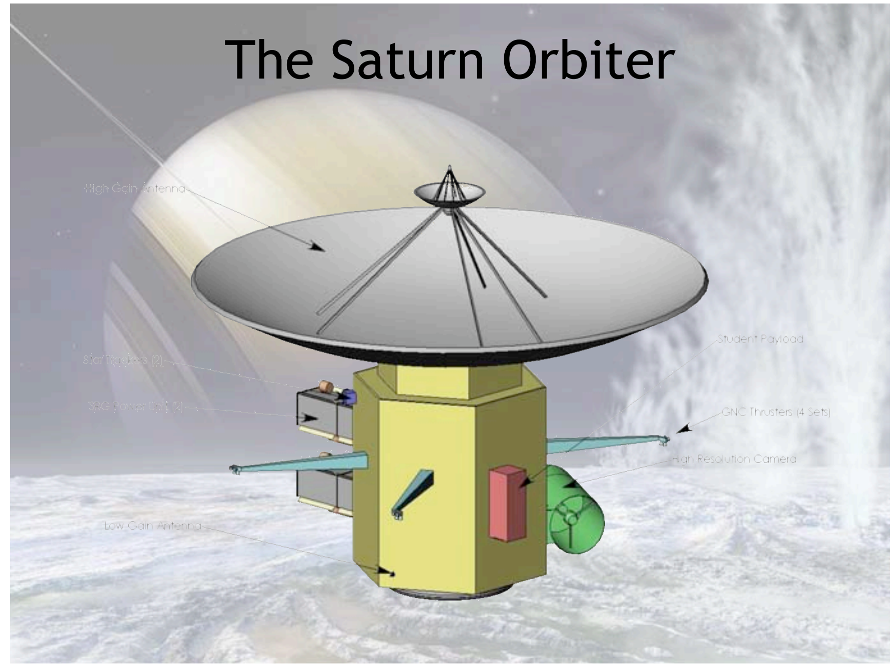
- Launch Vehicle: Delta IV(4050H-19)
- Launch date: 12 June 2023
- Venus-Venus-Earth-Saturn trajectory: ΔV=4.47 km/s
- Enceladus Capture: ΔV=4.5 km/s
- 3 to 4 days of polar orbit before landing



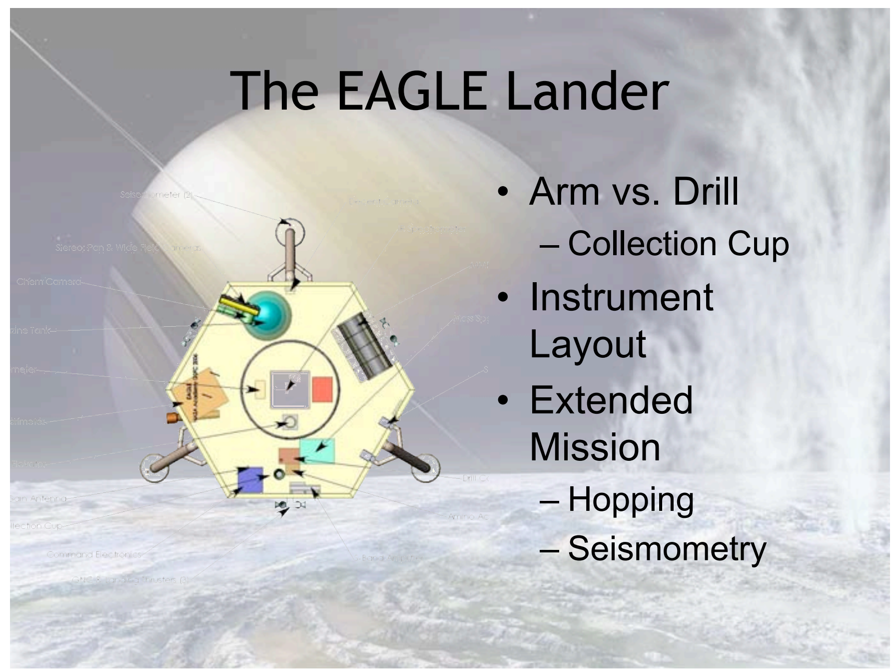
Science Payload Summary

Instrument	Mass (kg)	Data Rate (kilobits/sec)	Heritage
Orbiter			
Saturn Orbital Camera	25	29	MGS
Student Instrument	10	unknown	
Lander (orbital mode)			
Magnetometer	3	3.6	Cassini
Photopolarimeter	5	0.216	Galileo
Near-IR Mapping Spectrometer	18	11.52	Galileo
Laser Altimeter	7	---	Riegl
Descent Imager	0.6	unknown	MSL
Lander (surface mode)			
Wide-Field Cameras (2)	0.6	30 (200 Images per day)	MER
Amino Acid Analyzer	~10	unknown	ExoMars
GCMS	4	3	Rosetta
Seismometers (2)	0.4	8	JPL
ChemCam	6	0.14	MSL
APXS	0.6	9600	MER/MSL/Rosetta
Drilling & Sample Delivery System	5	---	Rosetta
	Total= 90.2		


The EAGLE Platform
5-m Composite Fairing
PAF
LH2 Tank
LO2 Tank
Equipment Shelf
RL10B-2
Interstage
Common Booster Core
Delta IV-H
Orbiter
Lander
Propulsion Stage
4th Stage
Fairing
Lander


The Saturn Orbiter


The EAGLE Lander


The EAGLE Lander
• Arm vs. Drill
– Collection Cup
• Instrument Layout
• Extended Mission
– Hopping
– Seismometry

Communications: Lander-Orbiter

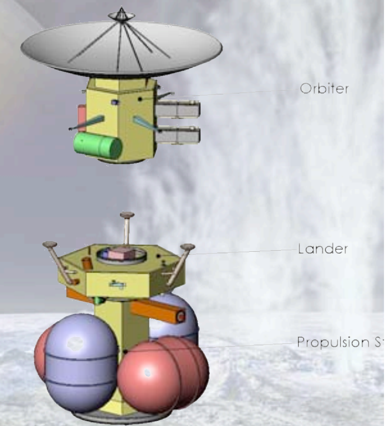
	LGAs
Gain	10 dB
Power	20 W
Frequency	2.30 GHz
Minimum data rate	1.5 kilobits/second
Bit error rate	10^{-5}
Link margin	3.55

Communications: Orbiter-DSN

	HGA	LGA
Gain	**48 dB**	**12 dB**
Power	**20 W**	**20 W**
Frequency	**8.40 GHz**	**8.40 GHz**
***Minimum* data rate**	**7 kilobits/second**	**100 bits/second**
Bit error rate	10^{-5}	10^{-5}
Link margin	**3.11 dB**	**3.21 dB**

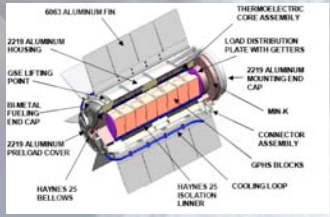
Radiation and Micrometeorite Shielding

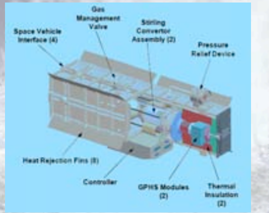
- Following radiation recommendations from Cassini, with ability to add polyethylene shielding for payload if necessary
- MLI with 0.050 mm layer spacing
  - Dust-sized particles in rings (0.01 g)
  - 4 – 10 km/s
- Honeycomb Aluminum structure
- High gain antenna directed as shield against larger particles



Thermo - Power

Time (years)	MMRTG Power Output (We)	SRG Power Output (We)
0	125	116
1	123.015915	115.0757021
2	121.0633228	114.1587691
3	119.1417234	113.2491423
4	117.2506249	112.3467635
5	115.3895433	111.4515749
6	113.558002	110.5635193
7	111.7555322	109.6825398
8	109.9816724	108.8085799
9	108.2359685	107.9415839
10	106.5179736	107.0814962
11	104.8272479	106.2282617
12	103.1633586	105.3818259
13	101.5258796	104.5421345
14	99.9143918	103.7091339





GNC - Propulsion

Component	Units	Mass/unit	Total Mass (kg)	Manufacturer	Heritage	TRL
Guidance Navigation and Control						
Lander:						
Monopropellant tank assembly	1	20	20	Pressure Systems, Inc	Cassini	9
Thrusters	12	0.8625	10.35	Olin Aerospace Corporation	Viking	9
Propellant Isolation Assembly (PIA)	1	10	10	Multiple	Cassini	9
Star Trackers	2	5	10	Officine Galileo	Multiple	9
Reaction Wheels	3	20	60	CTA Space Systems	Multiple	9
Orbiter:						
Star Trackers	2	5	10	Officine Galileo		
Thrusters	16	0.8625	13.8	Olin Aerospace Corporation	Multiple	9
Propellant Isolation Assembly (PIA)	1	10	10	Multiple	Cassini	9
Monopropellant tank assembly	1	10	10	Pressure Systems, Inc	Cassini	9
		Total Dry Mass:	**154.15**			
		Total max avg power consumption (W):	60			

Component	Units	Mass/unit	Total Mass (kg)	Manufacturer	Heritage	TRL
Propulsion						
Lander:						
Main Engine Assembly (MEA)	1	20	20	Lockheed Martin	Cassini	9
Bi-propellant tank assembly	1	200	200	Lockheed Martin	Cassini	9
Helium Tank Assembly	1	50	50	Lincoln Composites	Cassini	9
Pressurant Control Assemblies (PCA)	2	35	70	Multiple	Cassini	9
Propellant Isolation Assembly (PIA)	1	20	20	Multiple	Cassini	9
		Total Dry Mass (kg):	**360**			
		Total max avg power consumption (W):	50			

EAGLE Systems Summary

Lander Mass Budget

Subsystem	Flt Units	Total Mass (kg)	Contingency %	CBE + Contingency (kg)
Instruments	14	53.3	30.00%	69.3
Attitude Determination and Control System	5	70.0	30.00%	91.0
Command and Data System	5	8.8	30.00%	11.5
Power	1	44.2	30.00%	57.5
Propulsion 1	20	390.3	30.00%	507.4
Structures	2	145.0	30.00%	188.5
Telecomm	4	109.0	30.00%	141.7
Thermal	23	24.0	30.00%	31.2
System Total	**74**	**844.6**	**30.00%**	**1098.0**

EAGLE Mass Summary

	Mass (kg)	Contingency	Mass w/ Cont.
Orbiter	542	30%	705 kg
Lander	844.6	30%	1098 kg
Total Fuel	5052	15%	5809 kg
Total	**6168.6**		**7612 kg**
Total Available			**7700 kg**

'Off-the-Shelf' Cost

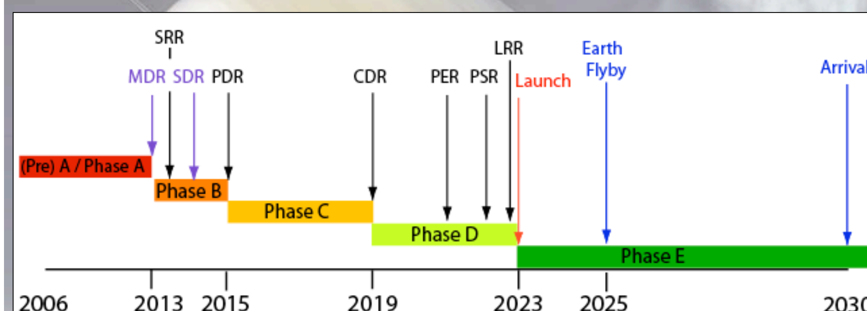
100 Project Management	$15,656.28
200 Project System Engineering	$23,484.42
300 Flight System	$425,061.75
310 Mission Design	$3,804.40
320 Structure	$32,981.83
330 Propulsion system	$56,830.99
340 ADCS	$38,790.13
350 Thermal Control Subsystem	$7,270.87
360 Power System	$166,801.41
370 Command & Data Handling	$2,626.36
380 Telecommunications Subsystem	$114,166.18
390 Science Instrument	$1,789.59
400 Flight and Ground Software	$31,348.24
410 Flight Software	$18,808.94
420 Ground Software	$12,539.30
500 Performance Assurance/Safety	$15,656.28
600 Assembly Test and Pre Launch Op	$12,401.90
700 Calibration	$10,910.93
800 Launch Vehicle	$269,875.00
900 Mission Operations	$25,676.87
1000 Educational Outreach	$8,402.95
Total	$838,474.62
Minus Mission Ops	$812,797.75

Cost and Schedule

	FY13	FY14	FY15	FY16	FY17	FY18
Phase A	$10,072.74	$10,311.55				
Phase B			$38,747.22	$39,685.41		
Phase C					$99,712.47	$136,020.40
Phase D						
ELV and Services						
DSN & Other Tracking Support						
Total Cost	$10,072.74	$10,311.55	$38,747.22	$39,685.41	$99,712.47	$136,020.40

	FY19	FY20	FY21	FY22	FY23-30	Total (Real Yr.)
Phase A						$10,311.55
Phase B						$78,432.63
Phase C	$104,318.13					$340,051.00
Phase D		$97,143.54	$132,322.23	$71,686.20		$301,151.97
ELV and Services	$73,352.03	$112,456.91	$114,885.79	$55,324.38		$356,019.10
DSN & Other Tracking Support					$43,368.24	$43,368.24
Total Cost	$177,670.15	$209,600.45	$247,208.02	$127,010.57	$43,368.24	**$1,129,334.49**

Schedule




Questions?
http://academy.gsfc.nasa.gov/2006/research/group/index.jsp