Titan and Enceladus Mission Feasibility Study

K. Reh

November, 2006

Titan & Enceladus Mission Study (NASA Funded)

Overview

- SMD-Planetary Science Division requested 3-month concept studies be done to look at Titan and Enceladus missions:
  - Determine the feasibility of conducting missions to Titan and Enceladus within a $1B cost cap $FY'06 (excluding technology costs)
  - Assume as much existing technology as possible
- NASA established science teams drawn from the outer planet community, namely Outer Planet Assessment Group (OPAG) to:
  - Establish prioritized science objectives and measurement requirements
  - Identify straw man payloads
  - Work with mission designers to define candidate mission architectures
  - Support mission cost assessment
- Missions are required to leverage from and achieve accomplishments well beyond what Cassini can do in its extended mission, i.e.
  - Build upon scientific accomplishments of the Cassini-Huygens mission
  - Fly more capable and/or different instruments
  - Accomplish new measurement and/or better coverage
- Study targets launch dates between 2015 and 2018

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Team

- Titan Science
  - Ralph Lorenz (lead), APL
  - Elizabeth Turtle, APL
  - Frank Crary, SwRI
  - Hunter Waite, SwRI
  - Eric Wilson, JPL
  - Rosalie Lopes, JPL
- Enceladus Science
  - John Spencer (lead), SwRI
  - Andy Ingersoll, Caltech
  - Amy Simon-Miller, GSFC
  - Bill McKinnon, WUStL
  - Chris McKay, ARC
  - Rich Terrile, JPL
- Mission Architecture, System Engineering, Costing
  - Kim Reh - Study Leadership, JPL
  - Ed Jorgensen, JPL/Andrew Dantzler, APL - Cost engineering, input and analysis
  - Tom Spilker - Mission Architectecture, JPL
  - John Elliott - Project/Flight System Engineering, JPL
  - Theresa.D.Kowalkowski, JPL/TBD, APL - Mission Design/Engineering
  - Navid Dehghani - MOS, GDS, DSN utilization, JPL
  - Norm Beck – LV services, KSC
- Expert Review/Advisory Group
  - Gentry Lee, JPL
  - Duncan MacPherson, JPL
  - Glen Fountain, APL
  - John Niehoff, SAIC
  - Bob Pappalardo, JPL

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Approach

- Science Requirements and Payload
- Candidate Missions and Scenarios
- Mission and System Parameters
- Cost Assessment (Outer Planet mission model)
- Science Value Characterization vs Investment
- Risks

Guided by Cassini science, previous studies and experience with cost-capped outer solar system missions - New Horizons-Pluto, Juno

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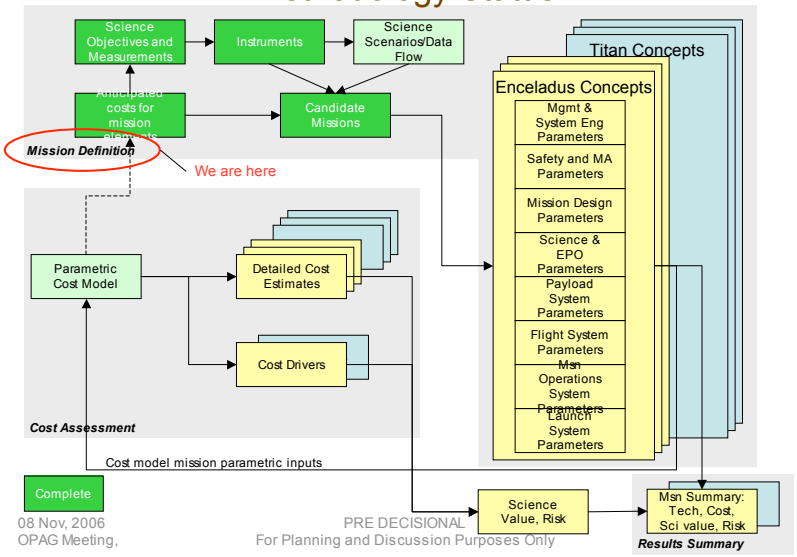
Methodology/Status



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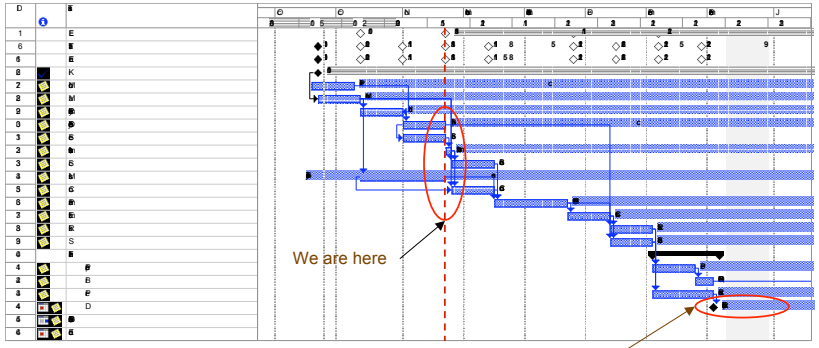
Schedule



- Final Report due to HQ NLT December 31, 2006
- Report results to OPAG after 1st of the year
- End date is March 15, 2007

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Products

- Preliminary report to NASA HQ (.ppt presentation)
  - To be presented to NASA HQ in time to support subsequent presentation at *OPAG Meeting in 2007
- Narrative final report due NLT December 31, 2006
  - Includes cost breakdown by mission element, assessment of cost data fidelity, evaluation by the science teams of the value and acceptability of final mission concepts, and (if desired by JPL) response to findings from the external review
  - Will be made available to the public
- Briefings as requested
  - If deemed necessary by NASA, the results of the study will undergo independent external review.

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Synopsis of Work To Date

Titan & Enceladus Mission Study (NASA Funded)

Status of Work To Date

- Completed
  - DRAFT Science Objectives and Payload
  - Mission Trade Space definition
  - Quantification of JUNO and NH-Pluto Costs
  - Outer Planet cost model familiarization
- In-Work
  - Preliminary Science Trace Matrix, payload parameters and Ops Scenario
  - Trajectory assessment and definition
  - Mission and system design quantification
  - Cost model modifications

Architectural Elements Identified

Building Blocks for Mission Concepts

Titan
1 SEP Stage
2 Chem. Propulsion Stage
3 Aeroshell
4 Cruise Stage
5 Flyby S/C
6 Orbiter
7a Atmospheric Probe
7b Lander
7c Rover
8a Constant-altitude balloon
8b Vertically maneuverable balloon
8c Airship
9 Sample Return
12 Nuclear power source
13 Solar/battery Power Source

Enceladus
1 SEP Stage
2 Chem. Propulsion Stage
3 Aeroshell
4 Cruise Stage
5 Flyby S/C
6 Orbiter
10a Inert Impactor
10b Instrumented Impactor
10c Hard Lander
10d Penetrator
10e Soft Lander
10f Rover (hopper)
11 Orbi-lander
12 Nuclear power source
13 Solar/battery Power Sourc

Fly-by, Orbiting, In Situ, Sample Return Architectures

Mission Design Techniques
A Propulsive Capture
B Aerobraking
C Aerocapture
D Saturn Aerocapture at Titan
E Tidal Effects for orbit adjustment
F Saturn system gravity assist
G Jupiter Gravity Assist
H Inner Solar System Gravity Assist
I Cycler Orbits

Mission Architecture Trade Space Established

Many Candidates Considered

In-Situ Elements	*In-Space Elements* Moon Orbiter	Saturn Orbiter	Single-Flyby S/C	Cruise Stage
Lander	T: *1*,**2 or 3C**,*3*,*4*,**6**,**7** Enc: *1*,**2**,*3D*,**6+10 or 11**	T: *1*,**3**,**3D+5 or 5A**,**7** Enc: *1*,**2**,**3D+5 or 5A**,**10**, **10b**	T: *1*,**3**,**4**,**7** Enc: *1*,**4**,**10**	T: *1*,**3**,**4**,**7** Enc: *1*,**4**,**10**
Aerobot	T: *1*,**2**,**3**,*4*,**6**,**8**	T: *1*,**3**,**3D+5 or 5A**,**8**		T: *1*,**3**,**4**,**8**
Sample Return		T: *1*,**3D+5 or 5A**,**9** Enc: *1*,**2**,*3D*,**5**,**9**	T: *1*,*2***5**,**9** Enc: *1*,*2***5**,**9**	
none	T:*1*,**2** or **3C**,*4*,**6** Enc: *1*,**2**,*3D*,**6**	T:*1*,**3D+5 or 5A** Enc: *1*,**3D+5 or 5A**	T: *1*,**5**,**3D** Enc: *1*,**5**,*3D*	

Key
T: Titan mission
Enc: Enceladus mission
1,2, etc.: Architectural element as coded above
Bold entry: Element is necessary for all mission design options
Italic entry: Element is necessary for some but not all mission design options

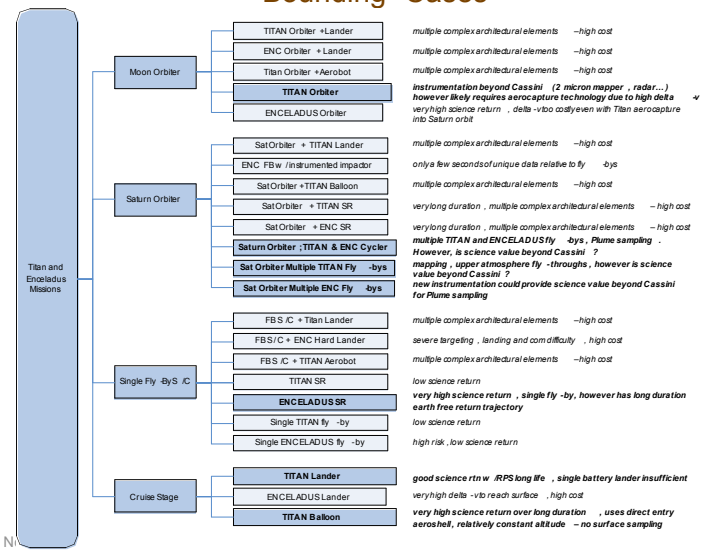
Probably technically achievable, but likely a Strategic class mission
Candidate for further consideration
Not applicable
Subset for further consideration

Architectures build upon Cassini results and enable more focused investigations of Saturn's icy moons.

POINTS:
1) The green areas of the chart indicate the potentially **least expensive** options of architecture space examined by the team however one cannot yet conclude that these mission candidates will fit into a one billion dollar budget.
2) Because these candidates represent the potentially least expensive architectures, they warrant further examination to determine if a viable scientific mission could fit into a $1B budget class.
3) A cost analysis of selected options is planned as well as characterization of science value versus investment.

Candidate Missions Identified for Further Study

"Bounding" Cases



Dark shading identifies missions that remain under consideration

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Summary

- Titan and Enceladus concept studies were initiated to determine the feasibility of conducting missions to Titan and Enceladus within a $1B cost cap $FY'06
- Science requirements and mission architectures have been established for further study and are undergoing more detailed definition (following presentations)
- Costing is planned to be complete by end of November
- Study is planned to be complete by end of calendar year

BACKUP

Titan & Enceladus Mission Study (NASA Funded)

WBS Based Cost Model

	Phase A/B	Phase C/D	Phase E	Total ($FY06M	Description
01 Project Management					**Wrap**
02 Project System Engineering					**Wrap**
03 Safety & Mission Assurance					**Wrap**
04 Science					**Scaling Rule with Science Input**
05 Payload System					
Instrument Complement					NICM
Lander					Analogy
Microprobe					Analogy
06 Spacecraft System					
06.01 S/C Management					**Wrap**
06.02 Spacecraft System Engineering					**Wrap**
06.03 Spacecraft Product Assurance					**Wrap**
06.04 Power SS					By Analogy/PMCM/Team X
Radioisotope Power Source as applicable					
06.05 C&DH SS					By Analogy/PMCM/Team X
06.06 Telecom SS					By Analogy/PMCM/Team X
06.07 Mechanical SS					By Analogy/PMCM/Team X
Aeroshell Mechanical (e.g., Structures, TPS)					By Analogy/PMCM/Team X
06.08 Thermal SS					By Analogy/PMCM/Team X
Aeroshell Thermal (e.g., Radiators)					By Analogy/PMCM/Team X
06.09 Propulsion SS					By Analogy/PMCM/Team X
06.10 GN&C SS					By Analogy/PMCM/Team X
06.11 Harness					By Analogy/PMCM/Team X
06.12 F-SW					By Analogy/PMCM/Team X
06.13 SC M&P					By Analogy/PMCM/Team X
06.14 SC Testbeds					By Analogy/PMCM/Team X
06.15 SC Other (SEP, Huygens Probe, Aerial Vehicle)					By Analogy/PMCM/Team X
07 Mission Operations System + 09 Ground Data System					By Analogy/PMCM/Team X
08 Launch System + Launch Support					**LV cost provided by NASA**
10 Project System Integration & Test					By Analogy/PMCM/Team X
11 Education and Public Outreach					**Wrap**
12 Mission Design					By Analogy/PMCM/Team X
Reserves					**30% Phase B/C/D, 15% Phase E**
Total ($FY06M)					

- All costs reported by development phase and $FY06M
  - Will inflate and time phase by fiscal year as needed
- All cost reported using JPL WBS Version 4
- Scaling factors (wraps) based upon recent proposals and JPL historic cost
- The new NASA Instrument Cost Model (NICM) will be used for instruments
- Analogy cost data will be used as a check on model estimates