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Advanced Radioisotope Power System Enabled Titan Rover Concept with Inflatable Wheels

by

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Introduction (1 of 2)

- In-situ exploration of Titan was given high priority in the:
  - Solar System Exploration (SSE) Decadal Survey (NRC, 2003), and in the
  - SSE Roadmap (NASA, 2005) included missions concepts for Titan exploration
  - The Cassini-Huygens mission further increased scientific interest in Titan
- In-situ exploration could be achieved through multiple mission architectures, ranging from New Frontiers (~$700M) class to Flagship class ($1.4B+)
  - **NF class**: may utilize a single element (e.g., an orbiter or an in-situ explorer)
  - **Flagship class**: may use multiple elements, including both an orbiter and in-situ elements, or a larger in-situ element.
- In-situ concepts could be (with increasing complexity):
  - Probe / Static lander: similar in functionality to Huygens, but may vary in size;
  - Balloon: only vertical control for surface access, its mass (and thus payload mass) would be limited, compared to a surface based asset.
  - Surface rover: significant traversing, similar to MER / MSL
  - Aerobot: all axis control and good surface access, but again, limited in payload mass compared to a surface based mission.
  - Helicopter: possibly the highest complexity
- Further trade options:
  - in-situ only vs. in-situ/orbiter combination
  - telecom with orbiter relay vs. Direct-To-Earth

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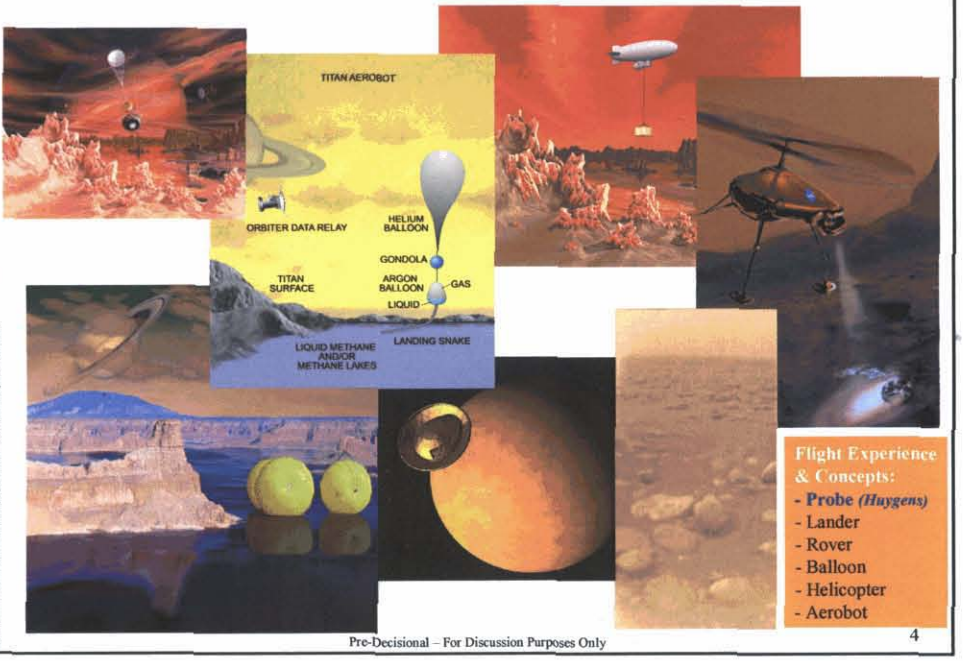
Introduction (2 of 2) – Examples



Flight Experience & Concepts:
- **Probe *(Huygens)***
- Lander
- Rover
- Balloon
- Helicopter
- Aerobot

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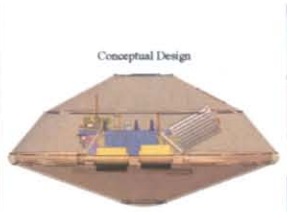
Study Objectives & Assumptions

- Demonstrate a simple, credible & affordable rover mission concept for Titan in-situ exploration, enabled by an Advanced RPS
- Mission class: Target small Flagship class *(2xNF)* or if possible New Frontiers class *(Note: with Delta IV-H architecture: large Flagship; ~4xNF)*
- Use flight & design heritage when possible *(e.g., MSL (rover); Viking (aeroshell/landing); Team-X fetch rover sampling mechanism)*

- Launch date: 2015 *(with technology cutoff in 2012)*
- Launch vehicle: Atlas 501 w/5m fairing *(Delta IV-H was also assessed, but resulted in an oversized mission)*
- Aeroshell: 4.5 m *(Viking heritage)*
- Delivered mass to Titan: ~780kg *(w/ Delta IV-H ~4200kg)*
- Trip time: 7.6 years *(with EJ gravity assist)*
- MSL class rover with inflatable 4 wheels *(D_{wheel}=1.5 m)*
- Surface operation: 3 years
- Double string design
- 30% contingency on mass allocation



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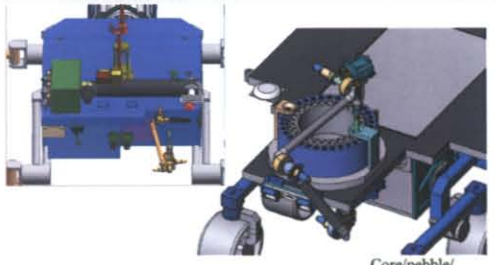
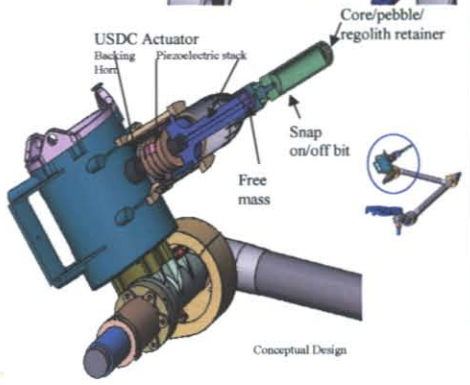
Science Goals and Objectives

- Objective 1: Determine the composition of Titan's surface materials
- Objective 2: Characterize the organic chemistry taking place at Titan's surface
- Objective 3: Describe the interactions between the surface materials and the atmosphere
- Objective 4: Describe the morphology of Titan's surface
- Objective 5: Describe the surface meteorology





Ref: J. Shirley, JPL, 2005

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Mission Architecture Trades – 1 of 3:

Trajectory options with a Delta IV Heavy L/V

Launch Date	Gravity Assists	Trip-time (years)	C3 (km^2s^{-2})	DLA (deg)	Launch Mass (kg)	DSM (ms-1)	9.5 AU Mass (kg)	Entry Speed (kms^{-1})	Entry Mass (kg)	Payload Mass (kg)
2012	VEEJ	8.7	10.6	15	7730	--	7600	8.2	~6800	~1600
2013	E	7.0	47.9	-22	3500	650	2800	6.6	~2000	~480
2013	E	8.0	47.7	-22	3500	550	2900	5.5	~2100	~550
2013-14	--	6.1	105.2	10	500*	--	480	4.9	~280	~75
2015	EJ	7.6	25.7	-12	5730	706	5000	5.9	~4200	~1050
2016	J	6.9	80.8	15	1200*	--	1150	4.6	~950	~240

Ref.: R. Haw, JPL, 2005

- **Initial calculations for a Delta IV-H L/V** (shown above);
- It is higher than the mass allocation requirement calculated for a single rover;
- The delivered mass is **scaled for an Atlas 501** (based on assumptions on cruise phase mass fraction, deep space maneuver mass fraction and an added conservative 30% contingency on the total mass);
- (It is recommended to recalculate these mass values for this smaller L/V case in future analyses.)

- The entry velocity is comparable to that at Mars, therefore, **the same TPS could be used for the aeroshell as on the Mars In-situ landers**.

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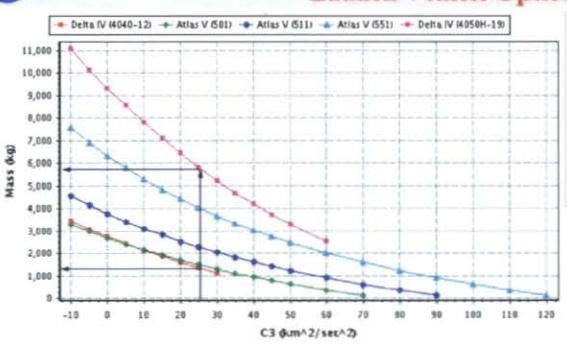
Mission Architecture Trades – 2 of 3:

Launch Vehicle Options



4.5 m aeroshell

Design concept

Design concept

- Atlas 501 (w/ 5 m fairing) could deliver ~800 kg to Titan (baselined option)
  (note, corresponding to the mass after being adjusted for cruise phase, DSM etc.)
  - This would allow for direct entry with a Viking type (4.5 m) aeroshell, which is sufficient for the required 778 kg entry mass *(including aeroshell, lander, palate, EDL system)*.
  - The smaller L/V would not only provide significant savings for the L/V compared to Delta IV-H, but the savings would cascade through the design potentially making the mission NF class.
- In comparison, Delta IV Heavy could deliver ~4200kg to Titan
  - This would result in a large Flagship class mission (estimated at over 4xNF cost cap).
  - This could include a larger orbiter up to ~3400 kg and the same lander as above; or could use multiple landers

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Mission Architecture Trades – 3 of 3:

Study Trade Space and Selected Options

Trade Element *(with decision driver)*					
Launch vehicle *(lower cost)*	Delta IV-H	**Atlas 501**			
Trajectory *(mission timeframe)*	High thrust direct	**HT Gravity Assist**	Low thrust direct	LT GA	
Launch opportunity *(program/ARPS)*	2012 VEEJ-GA	2013-14 direct	2013 E-GA	**2015 EJ-GA**	2016 J-GA
Architecture *(lower cost)*	Orbiter only	**In-situ only**	Orbiter & In-situ		
Orbiter *(lower cost)*	With Orbiter	**Without Orbiter**			
In-situ Architecture *(mobility)*	Static Lander (Huygens probe)	**Surface Rover**	Balloon	Aerobot (Vision Missions study)	Helicopter
Rover Size *(heritage/lower cost)*	Pathfinder class	MER class	**MSL class**	Larger than MSL class	
# or in-situ assets *(lower cost)*	**Single In-situ Asset**	Multiple In-situ Assets			
Telecom Architecture *(lower cost)*	Orbiter Relay Telecom	**Direct-to-Earth Telecom**			
Power options Architecture *(study obj.)*	Standard RPS	**Advanced RPS**	Small Fission	Solar	
RPS options *(space proven static conv.)*	**Adv.RTG** ↔	TPV ↔	Stirling ↔	Brayton	

Key drivers for this technology-focused study were: lower cost (trying to fit the mission into the New Frontiers category), missions and design heritage, RPS availability, science goal

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Strawman Instrument Suite for the Titan Rover Concept

Instrument	Mass	Volume	Power	Data	Heritage	Comments
Met Package	**0.7 kg**	11x16x6cm	800mW	57.4 kbit/day	Marsnet Study	Including wind sensor, pressure, temperature
Radiation Monitor	**2 kg**	20x10x5	3 W	10 kbit/day	MARIE	Scaled down. Energy resolution needs to be specified to measure 13C
Acoustic Monitor	**0.1 kg**	5x5x1	150 mW	100 kbit/day	MPL Mars Microphone	Assumes slightly larger capability than mars microphone
Sampling Camera/ Microscope	**0.5 kg**	5x5x5	200 mW	1 Mbit/analysis	MPL RAC	Could be extended to MECA-type AFM
Chemistry Package (GCMS/ES-IMS /CE etc.)	**20kg**	50x50x30	40W for 5 hrs/analysis		WAG - based on Huygens GCMS	Exact mix of techniques tbd
Raman Spectrometer	**1.5 kg**		3 Whr; 2-5 min/sample			Replaced Miniature Chemistry Package on original list
Panoramic Camera	**5 kg**		3W		IMP	
LIBS	**1.4 kg**		2 W			
Ultrasonic Corer	**6.8 kg**		20 W			Taken from Wayne Zimmerman's MSR Fetch Rover study

Total instrument payload: ~38kg, not including the 30% contingency required by design principles; nor the mast, drill & sample collection system mass

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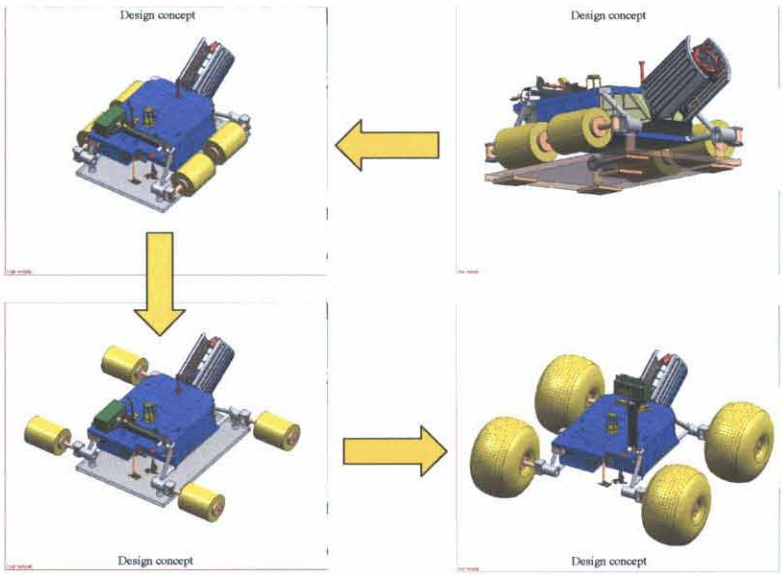
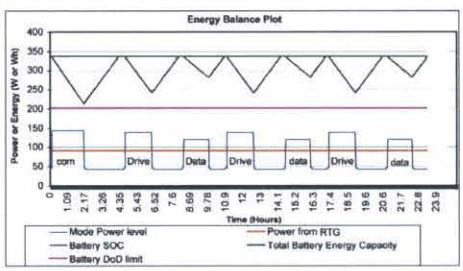
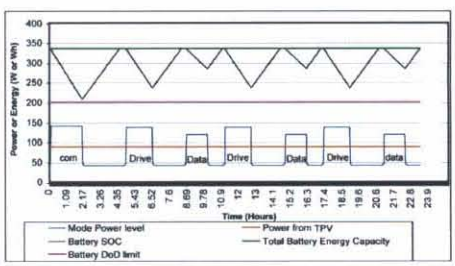
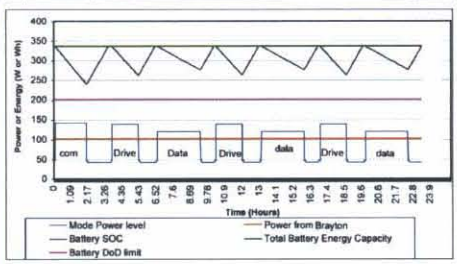
Deployment of the Inflatable Wheels



Titan Rover Concept Operations: ARPS Duty Cycle







- ARPS would provide continuous power over the mission lifetime with a slight degradation (~1.5%/year – RPS type dependent). Power after 10 years:
  - Adv. RTG power: ~90 We (after 10 years) **(baseline)**
  - Brayton: ~101 We (after 10 years)
  - TPV power: ~88 We (after 10 years)
  - Three Stirlings: ~207We (after 10years) (not shown) (two Stirlings to cover the Advance RTG power level +1 redundant unit)
- Hybrid power system with secondary batteries (12Ah)
- Peak Power is High Science mode: 147 We
- 3 x 1.7 hrs drive sessions & 3 x 1.55 hrs science & 2 hrs telecom (per day with and advance RTG)
- The other two RPS options (TPV; Brayton) would allow for similar operations, 3 Stirlings even better

Baseline Advanced RPS (assumptions):
5 GPHS modules; Mass: 25.5kg; $\eta \sim 9\%$
Power (BOM): 112We/1250Wt; Spec.power: 4.4W/kg
Operates in atmosphere: 1.5bar N_2; T_{amb}=94K

Titan Rover Concept Operations and Design Considerations

Item	Comments
Traverse	1.5 m diameter wheels (4) with inner tire; Material: PBO (polybenzoxaxole)/Xylon; Could traverse up to ~150 m/hrs; up to ~0.5 km/day; & up to ~500 km/3-years (dependent on science and mission requirements; surface environments; and navigation/autonomy):
Data volume	Rover Science Data Volume: ~28.8 Mbits of science data is downlinked per day
Communications	On rover: 8.4 GHz X-band 0.5 m 2 axis articulated HGA; Emergency LGA; Direct-to-Earth comm. thus landing location limited to the pole region; Assumed 180x12m DSN antenna array:
Autonomy & Navigation	Requires autonomous hazard avoidance; HGA pointing for DTE; Trajectory request uploaded from Earth (direction/distance), rover follows suit and avoids obstacles; No orbiter; All-sky camera; Pointing requires 3600 arcsec of control & 1800 arcsec knowledge to DTE comm.; Use input from IMU/PanCam/accelerometer and cameras to navigate
Structures	MSL chassis; Sampling arm with drill and sample carousel; Arm would carry ultrasonic corer inside a rotatable pod; PanCam style 1.5m mast, stereo+2 nav.cam; all-sky cam
Thermal design	7.6 year cruise phase – RPS excess heat removal from aeroshell (5GPHS, 1250Wt) Virtually finless RPS on surface (94K); Utilize RPS waste heat for WEB
Extreme environments	Radiation: Jupiter flyby 30-200 kRad w/o shielding; Ionizing Dose: 10 kRad TID behind 100 mils of aluminum with an RDM of 2 Cold: 94K on the surface; flexible materials / actuators / joints on arm, mast Tholin: could stick to lens, optics
Planetary protection	Not addressed in this limited scope / small budget study

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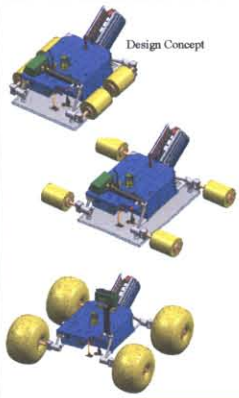
Mass Breakdown

Element	Mass (kg)	w/30% contingency (kg)
Structures & Mechanisms)	128	167
Power	35	46
Thermal	31	40
Cabling	21	27
Telecomm	19	25
Attitude Control	13	17
Command & Data	+ 3	+ 4
Total Bus	251	326
Total Instrument Payload	+ 38	+ 49
Total Rover (Dry)	289	**376**
Pallet Lander		+ 130
Total Landed Mass		506
Aeroshell Mass		+ 272
Total Entry Mass		**778**

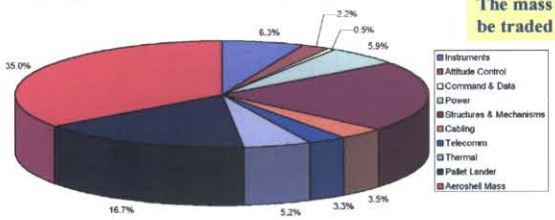


Note: Changing the type of ARPS would not significantly impact the **total rover mass**:

With ARTG:	376 kg
With TPV:	366 kg
With Stirling:	392 kg
With Brayton:	380 kg

ARPS are only enhancing;
Advanced RTG mass: ~25.5 kg
MMRTG mass: ~43.0 kg
thus using it causes a 17.5 kg rover mass increase (more impact on cruise stage thermal design)

The mass advantage with advanced RPS's could be traded against additional payload mass



Launch mass ($C3=25.7\ km^2/s^2$):
On an Atlas 501: 1455 kg
Cruise stage+DSM: 677 kg
(conservative estimate from trajectory calculations for aDelta IV-Heavy)

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Conclusions and Recommendations

- Demonstrated the feasibility of an MSL class Titan rover concept, enabled by a single Advanced Radioisotope Power System:
  - ARTG (baselined for this study); TPV; Brayton; or three Advanced SRGs (due to required redundancy)
- When launched on an Atlas 501 class L/V, the system could be sized to potentially fit into Small Flagship or maybe into New Frontiers cost cap
- Technology challenges could include:
  - Direct to Earth communication (assumed the upgraded DSN with 180x12m)
  - Extreme environments issues, such as materials for the cold (94K) surface operations incl. inflatable wheels, actuators, joints; sticky tholin deposits on imaging systems
  - Development of advanced RPSs (technology investment)
  - Autonomy and Navigation issues
- Advanced RPSs are enhancing:
  - using an MMRTG would increase the rover mass by less than 5%.
  - However, the mass savings with an Advanced RPS could be traded for additional payload, thus enhancing science return.

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The opinions expressed in the presentation are those of the authors alone and do not reflect official NASA policy.

Further details on this and other advanced RPS enabled studies can be found in (Abelson et al, 2005).

Note that this study was performed on a small budget. Therefore, a further detailed point design analysis is recommended on a suitable configuration, driven by science objectives (static lander / rover / balloon / aerobot etc.) in order to better understand the trade space and the size and affordability of such a mission

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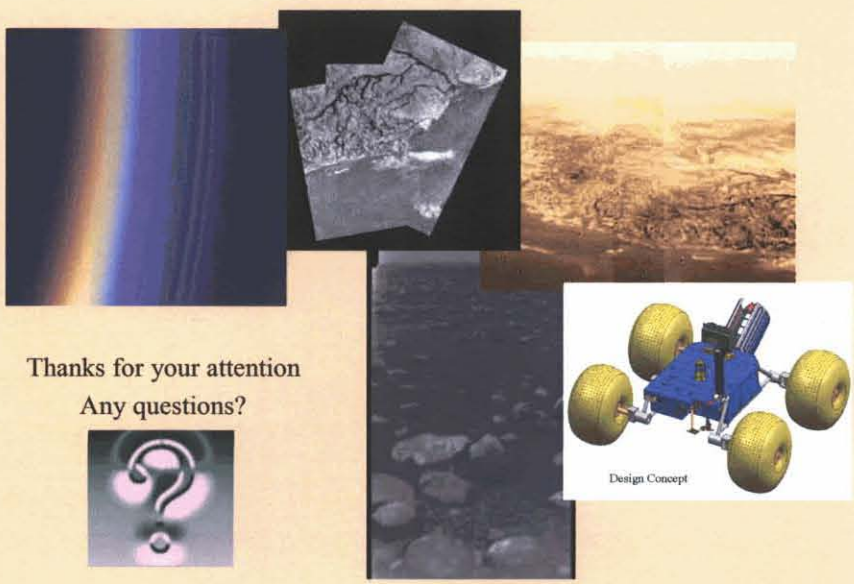

Thanks for your attention

Any questions?