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Titan Explorer:

The Next Step in the Exploration of a Mysterious World

Presentation based on the Final Report for NASA Vision Mission Study per NRA-03-OSS-01 (Submitted on 6/10/2005)

Presented by: William Edwards, NASA Langley Research Center
william.c.edwards@nasa.gov

Principal Investigator: Dr. Joel S. Levine, NASA Langley Research Center
Study Lead: Henry S. Wright, NASA Langley Research Center

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- Goal
- Science Questions
- Science Payload
- Data Collection Strategy
- Titan Environment
- Platform Comparison
- Baseline Description - Airship
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  - Deployment
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Goals of the “Vision Mission”

- The first goal is to sharpen understanding of a subset of possible future missions for scientific and programmatic planning. These vision missions represent approaches to extending the current and near term flight programs to future, more advanced capabilities.

- A second and equally important goal for improving our understanding of implementation of long term objectives is to support integration of long range Agency-wide planning. (i. e., use of astronauts, nuclear power, and other “high-dollar” technologies).

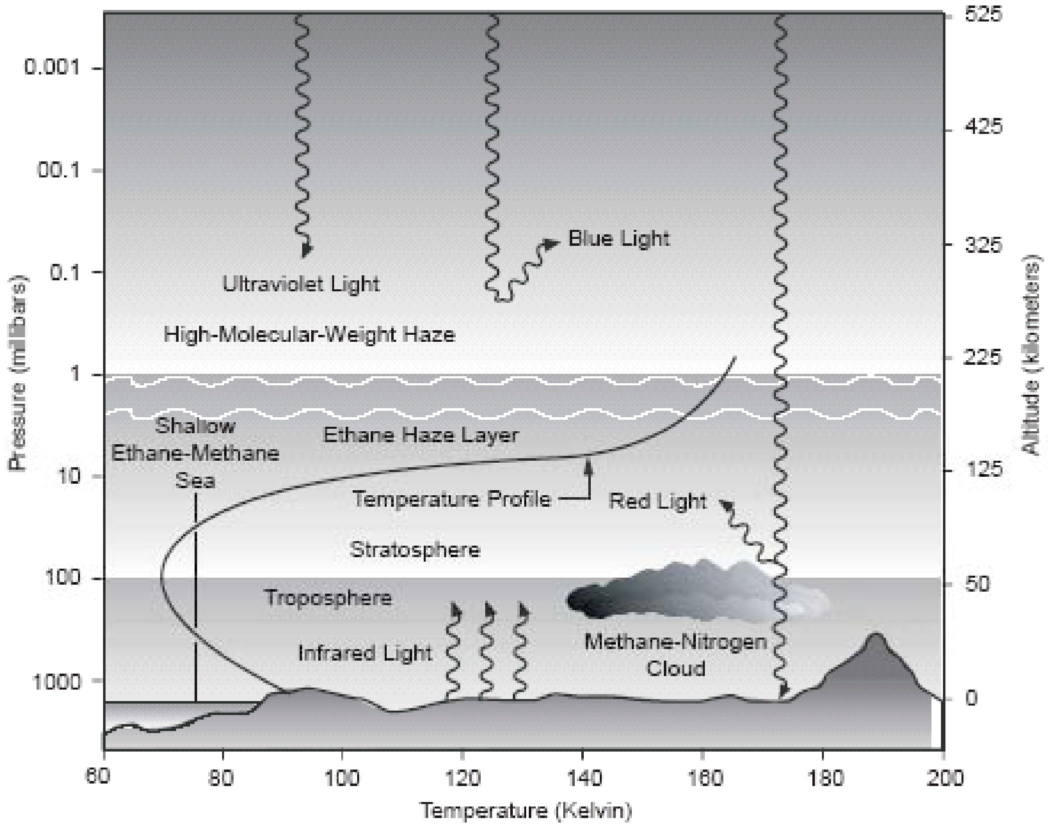
Titan Explorer Science Questions

- What is the chemical composition of the atmosphere, including the trace gases?
- What is the isotopic ratio of the gases in the atmosphere?
- What pre-biological chemistry is occurring in the atmosphere/surface of Titan today and what is the relevance to the origin of life of Earth?
- What is the nature, origin, and composition of the clouds and haze layers?
- What is the nature and composition of the surface?
- Are there oceans of liquid hydrocarbons on the surface of Titan?
- What is the nature of the meteorology and dynamics of the atmosphere?
- What is the processes control the meteorology and circulation of the atmosphere?
- What is the nature of the hydrocarbon “hydrological cycle” on Titan?
- What are the rates of escape of atomic and molecular hydrogen from the upper atmosphere of Titan and what impact does this escape have on the atmospheric chemistry?
- How does the atmosphere of Titan interact with the solar wind and Saturn itself?
- How have the atmosphere and surface of Titan evolved over its history?

Scientific Rationale - 1

Investigation Area 1: Atmosphere of Titan

- Determine chemical composition of the atmosphere, including trace gases
- Determine the isotopic ratio of the gases in the atmosphere
- Characterize nature of pre-biological chemistry occurring in the atmosphere and surface
- Determine rates of escape of atomic and molecular hydrogen from upper atmosphere
- Assess how Titan's atmosphere interacts with the solar wind and with Saturn
- Characterize evolution of the atmosphere



Credit: NASA/JPL - Cassini Arrival Press-Kit

Scientific Rationale - 2

Investigation Area 2: Meterology and Circulation

- Determine nature, origin, and composition of clouds and haze layer(s)
- Characterize nature of the meterology and dynamics of the atmosphere; including process which control meterology and circulation
- Determine nature of hydrocarbon hydrological cycle on Titan

Investigation Area 3: Nature of the Surface

- Characterize nature of pre-biological chemistry occurring in the atmosphere and surface
- Characterize nature and composition of the surface
- Determine if there are “oceans/lakes” of hydrocarbons on the surface of Titan

Mapping of Science Questions and Measurements

Platform	Measurement Type	Platform	Measurement Type
Orbiter	Solar occultation (SO)	Airship	Airship Imager System (AIS)
Orbiter	Radar Mapper (RAD)	Airship	Mass Spectrometer (MS)
Orbiter	Magnetometer (MAG)	Airship	Haze and cloud particle detector (HCP)
Orbiter	Ultraviolet Spectrometer (UVS)	Airship	Surface Composition Spectrometer (SCS)
Orbiter	Visual and Infrared Mapping Spectrometer (VIMS)	Airship	Sun-seeking spectrometer (SSS)

Science Questions	Orbiter Instruments					Airship Instruments				
	SO	RAD	MAG	UVS	VIMS	AIS	MS	HCP	SCS	SSS
What is the chemical composition of the atmosphere, including the trace gases?	■			■			■			
What is the isotopic ratio of the gases in the atmosphere?	■						■			
What pre-biological chemistry is occurring in the atmosphere/surface of Titan today and what is its relevance to the origin of life on Earth?	■			■			■			
What is the nature, origin, and composition of the clouds and haze layers?					■	■		■		■
What is the nature and composition of the surface?		■	■		■	■			■	
Are there oceans of liquid hydrocarbons on the surface of Titan?		■			■	■			■	
What is the nature of the meteorology and dynamics of the atmosphere?					■	■		■		■
What processes control the meteorology and circulation of the atmosphere?					■	■		■		■
What is the nature of the hydrocarbon "hydrological cycle" on Titan?	■	■		■	■	■	■	■	■	■
What are the rates of escape of atomic and molecular hydrogen from the upper atmosphere of Titan and what impact does this escape have on atmospheric chemistry?	■			■			■			
How does the atmosphere of Titan interact with the solar wind and Saturn itself?			■	■						
How have the atmosphere and surface of Titan evolved over its history?	■		■	■			■			

Science Payload

Platform	Meas. Type	Baseline	Mass (Kg)	Power (W)	Science Objective
Orbiter	Solar Occultation	ACE-SCISAT Instrument (Canada)	18	25	Determine atmospheric composition and isotopic ratios
Orbiter	Radar Mapper	Magellan & Cassini	15	200	Determine nature of the surface
Orbiter	Magnetometer	MGS/ STEREO	8	2	Search for planetary dipole and surface magnetism
Orbiter	Ultraviolet Spectrometer	Cassini UVIS	8	6.5	Measure atomic and molecular hydrogen escape from the upper atmosphere of Titan
Orbiter	Vis. & Infrared Mapping Spectrometer	Cassini VIMS	34	27	Measure cloud layer, haze layer, and surface characteristics (IR)
Aerial	Imaging System (2 imagers)	Clementine (UVVIS)	1.3 (2.6)	5 (10)	Investigate surface features, clouds, and haze
Aerial	Mass Spectrometer	Cassini INMS	10	28	Measure atmospheric composition and isotopic ratios
Aerial	Haze and cloud particle detector	Pioneer Venus (LCPS)	2.5	20	Determine aerosol abundance and characterization
Aerial	Surface composition spectrometer	Messenger (MASCS)	5	5	Determine nature and composition of the surface
Aerial	Sun-seeking spectrometer	Galileo (Net Flux Radiometer)	3	33	Measure the opacity of the atmosphere of Titan
Aerial	Surface Science Payload	Beagle-2/Huygens	3	-	Determine nature and composition of the surface

Key Study Assumptions

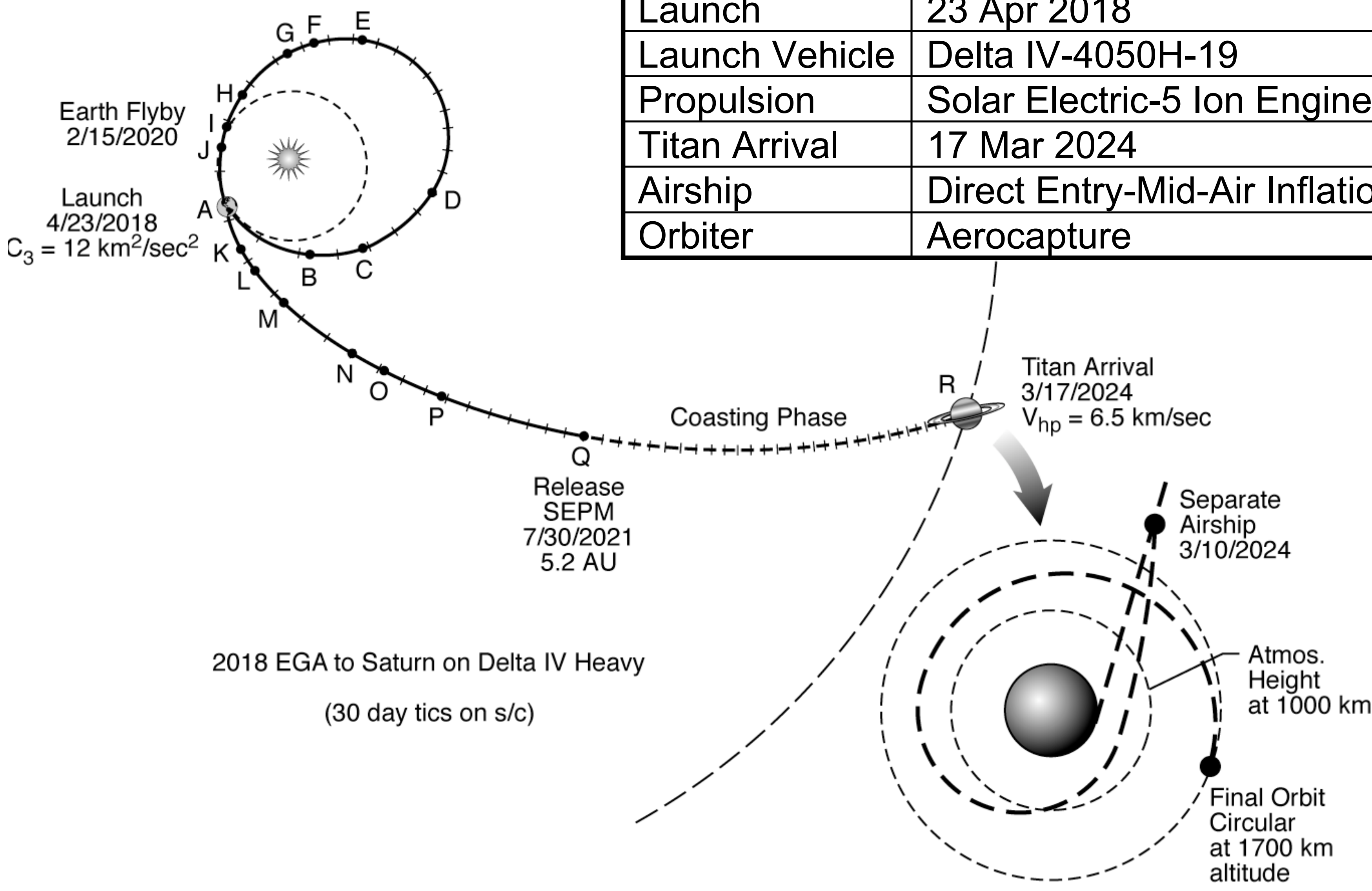
- NRA Assumptions
  - Flagship class mission - cost >$700M
  - Launch after 2015
  - No special planetary protection provisions required

- Study Team Assumptions
  - Use existing expendable launch vehicle
  - Aerial vehicle life time >3 months
  - Orbiter life time >39 months after entering orbit

Mission Architecture Assumptions

Titan Explorer

Launch	23 Apr 2018
Launch Vehicle	Delta IV-4050H-19
Propulsion	Solar Electric-5 Ion Engines
Titan Arrival	17 Mar 2024
Airship	Direct Entry-Mid-Air Inflation
Orbiter	Aerocapture

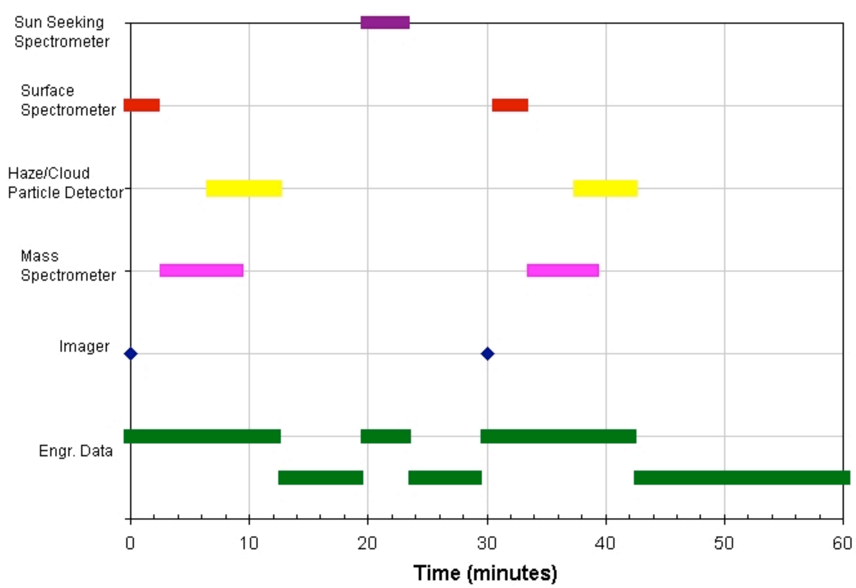


Orbiter Measurements

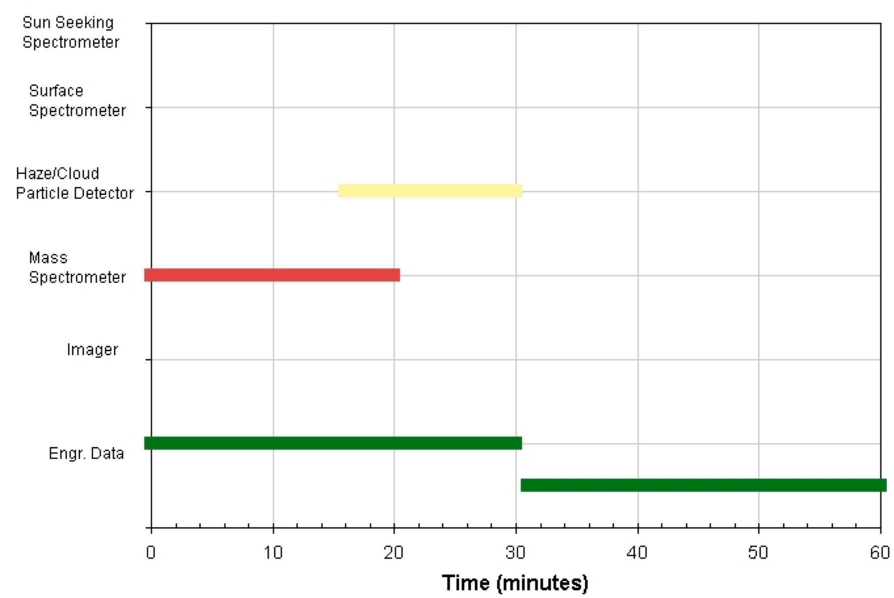
Instrument	**Radar Altimeter**	**Visual & Imaging Spec.**	**UV Spectrometer**
Desired % Global Coverage	90%	60%	20% at 6x64
FOV	Antenna: 1 degree beamwidth	32 x 32 mrad	1 x 64 mrad 2 x 64 mrad 6 x 64 mrad
Swath Width	30 km	54 km	1x64: 3.4 km 2x64: 6.8 km 6x64: 20.4 km
Ground Track per Pass per Orbit	15% of orbit 4000 km	5% of orbit 1400 km	5% of orbit 1400 km
Minimum Number of Orbits	713	754	665
Number of Over Samples	3	3	3
Number of Orbits Required	2138	2263	1996
Required Mission Duration (based on operating scenario in Table 72)	3.0 years	2.2 years	1.9 years
Orbiter Instruments	**Operation Time**	**Data Rate**	**Data Volume**
Solar Occultation Instrument	6000 Occult. @ 14 min. each:	115 kbps	575 Gbits
Magnetometer	5600 Orbits @ 60% per orbit:	4 kbps	256 Gbits
UV Spectrometer	1996 Orbits @ 5% per orbit:	32 kbps	57.6 Gbits
Visual & Imaging Spectrometer	2263 Orbits @ 5% per orbit:	182 kbps	382 Gbits
Radar	2138 Orbits @ 15% per orbit:	1400 kbps	8400 Gbits
Orbiter Engineering Data	3.3 yrs = 1 x 10^8 sec	5 kbps	520 Gbits
Total Uncompressed Data Volume			**10,190 Gbits**

Aerial Vehicle Data Collection Strategy

- Correlate science data with location on Titan and vehicle state (altitude, orientation, speed, etc.)
- Orbiter is out of sight for up to 6 days - all science and engineering data stored on-board aerial vehicle for later transmission
- Sun Seeking Spectrometer and Surface Composition Spectrometer data only collected on “Sun-Side”



Day-Side Operational Scenario



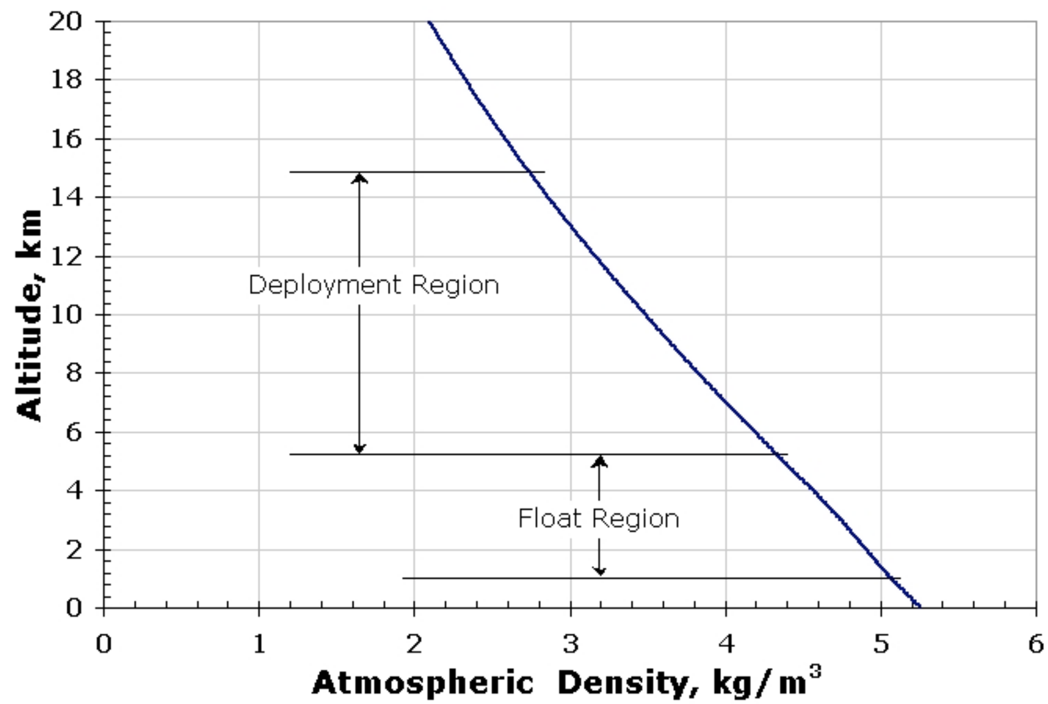
Night-Side Operational Scenario

Titan Environment

Parameter	Earth	Titan
Gravity	9.8 m/s^2	1.35 m/s^2
Average Surface Temperature	288 K	93 K
Average Surface Pressure	1 bar	1.5 bars
Average Surface Speed of Sound	319 m/s	181 m/s
Primary Atmospheric Constituents	N_2 - 78%; O_2 - 21%	N_2 - 97%; CH_4 - 3%

Low gravity and high density make it an ideal locale "to fly"!

Cryogenic conditions increase design complexity



Platform Comparison - 1

- Assessed three platforms - Airplane, Airship, and Helicopter
- Each platform had to carry the baseline science payload
- Each platform had a “similar” operating strategy
  - Data collection and return
  - Surface interactions and flight paths were platform dependent
- Assessment balances
  - Implementation feasibility
  - System mass
  - Implementation risk
  - Fault recovery
  - Potential for surface interactions

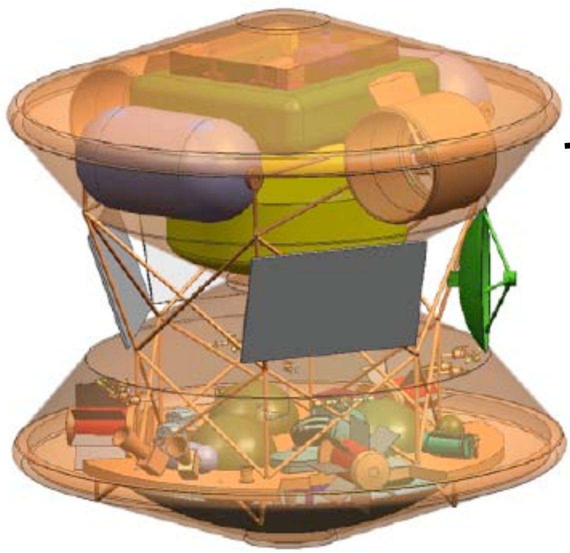
Platform Comparison - 2

- Qualitative and quantitative comparisons have been made
- Key operational drivers for all platforms
  - Power for propulsion
  - Navigation strategy
  - Robustness to faults

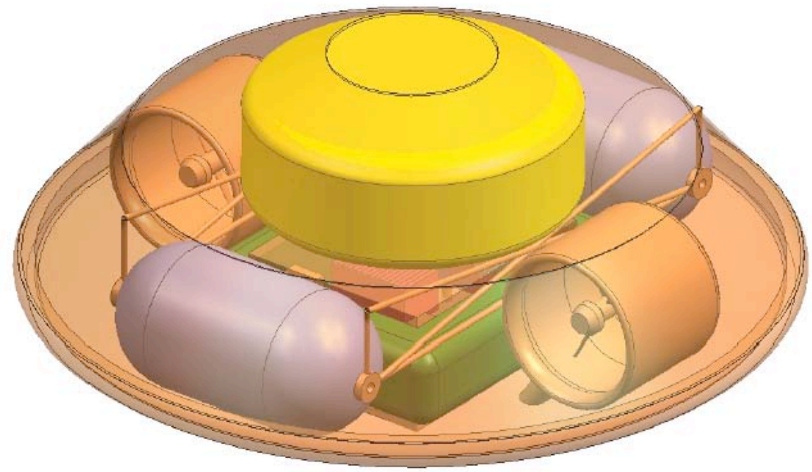
Category	Airplane	Helicopter	Airship
Mass	390 kg	320 kg	490 kg
Implementation Feasibility	Medium	Medium	High
Operational Risk	High	Medium	Low
Development Risk	Medium	High	Medium
Fault Tolerance	Low	Medium	High
Surface Interaction Capability	Low	High	Medium

Airship is preferred recommendation for Titan.
Helicopter may be feasible, (propulsion system development needed)
Airplane not recommended for use at Titan

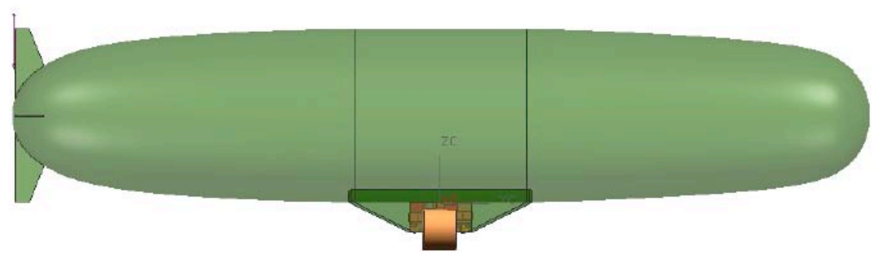
Aerial Vehicle



Orbiter and Aerial Vehicle During Post-SEP Separation

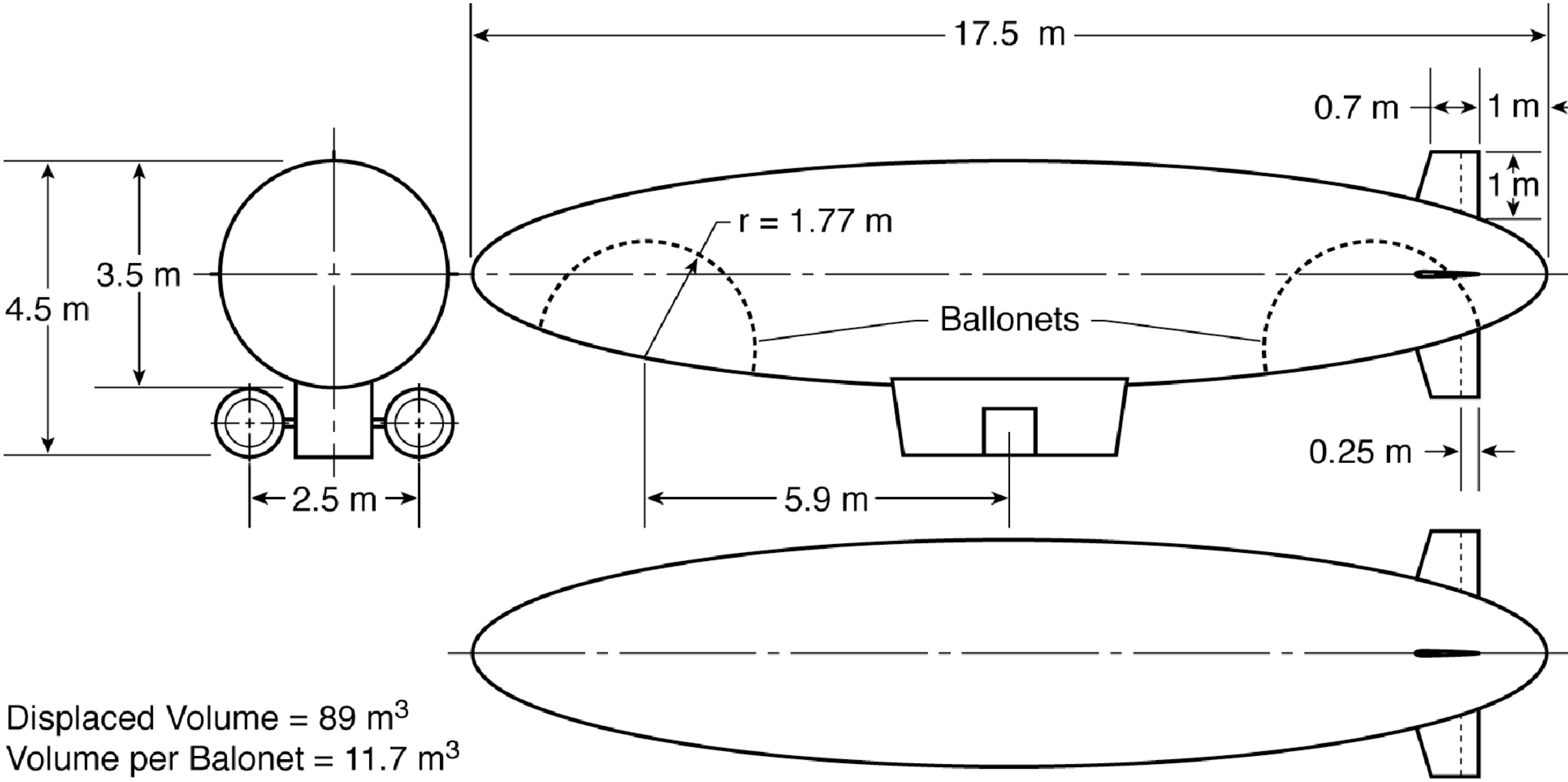


Aerial Vehicle During Release, Before Atmospheric Entry



Aerial Vehicle During Deployment

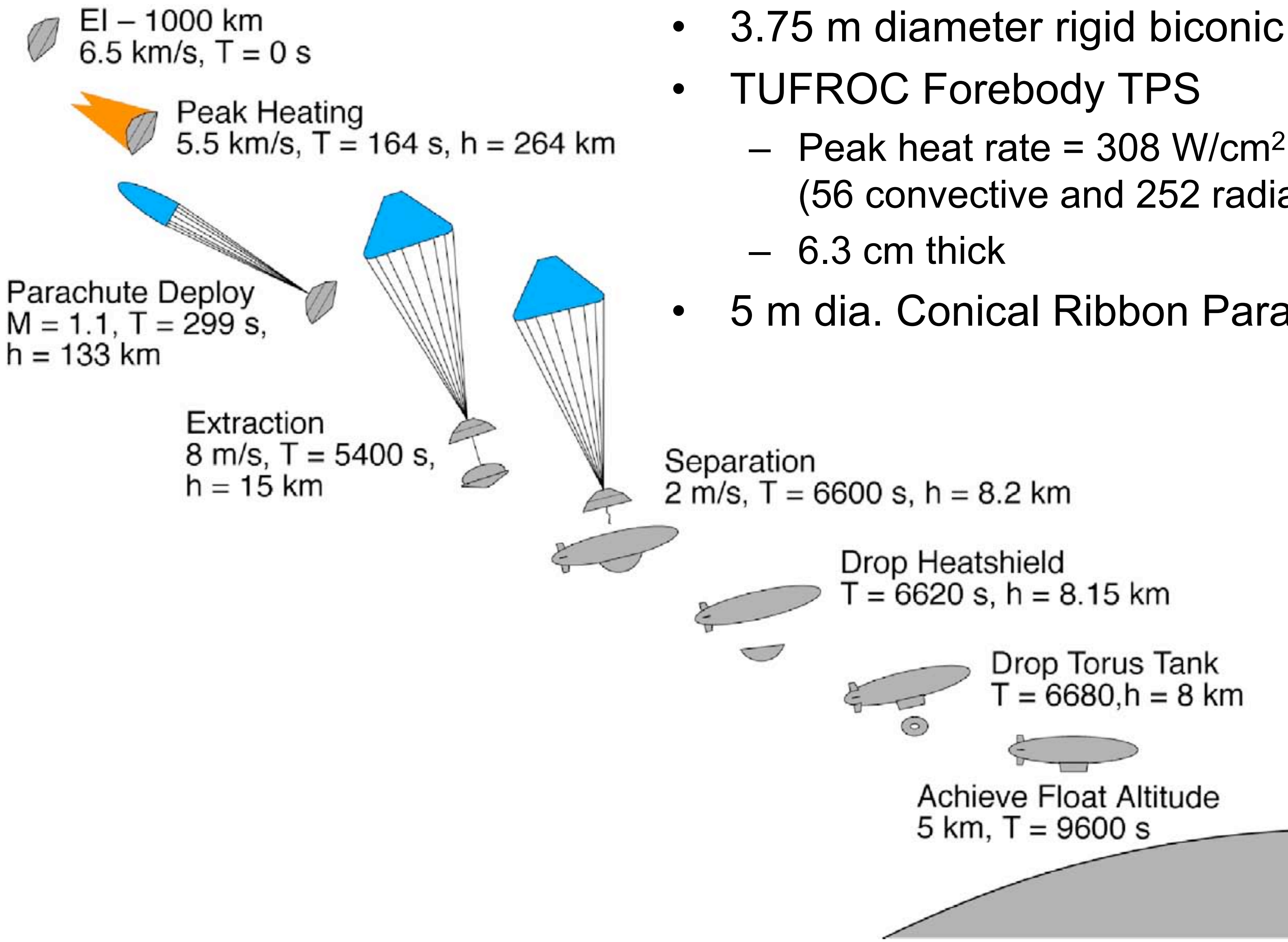
Airship Configuration



Displaced Volume = 89 m^3
Volume per Balonet = 11.7 m^3

Lift Gas	Helium	Elec. Power	4 SRG's (EOL = 95 W each) & 12 A-hr Li-Ion Battery
Altitude Range	0 - 5 km	Airship Hull Mat'l	4 layer composite (Kapton, Kevlar, Mylar, Tedlar: 20 g/m^2)
Descent Rate	<25 m/minute	Propulsion	2 Propulsors-each with single 0.7 m diameter 2 bladed propeller
Cruise Speed	3-4 m/s	Data Return	UHF Relay to Orbiter

Deployment Strategy



- 3.75 m diameter rigid biconic aeroshell
- TUFROC Forebody TPS
  - Peak heat rate = 308 W/cm^2 (56 convective and 252 radiative)
  - 6.3 cm thick
- 5 m dia. Conical Ribbon Parachute

Mission Operational Strategy

- Goals
  - Maximize surface area investigated
  - Extensive investigation of atmosphere - latitude coverage
- Autonomous operations
- Data collected, stored, and relayed (UHF) to orbiter.
- Science team to evaluate data and provide periodic mission tasking - desired location, extent of data
- Surface interactions - descent - only occur when in continuous communication with orbiter

Technology Development

Enabling Technologies	Enhancing Technologies
Orbiter Instrument: Miniaturized solar occultation instrument	**Orbiter Instrument: Magnetometer, radar mapper,** need to be modified for required resolutions.
Airship Instruments: Haze and cloud particle detector, sun seeking spectrometer	**Airship Instruments: Imager, mass spectrometer and surface composition spectrometer** need to be modified for required resolutions.
Aerocapture: A key technology will allow 2.4 times more payload to be delivered to Titan.	**Orbiter Data Relay:** Baseline is X-band. Ka allows 1.5 orders of magnitude increase in returned data.
Airship Envelope Materials: Gasbag and ballonets operating in the cryogenic temperature range.	**Aeroshell-Heatshield Radiator Concept:** Waste heat from RTG's needs to be managed during cruise from Earth.
Orbiter and Airship Power-Use of Second Generation RTG's: New RTG's would have specific powers which are 2x that of current MMRTG's or SRG's which will soon be available.	**Optional Aerial Vehicle-VTOL-Turbo-Expander:** The VTOL vehicle could use nuclear powered gas turbine engine.
Spacecraft Propulsion-Next Generation Ion Engines: Engines now implemented in DAWN mission may be suitable.	
Aerial Vehicle (Airship & VTOL)-Autonomy and Navigation: Position and attitude determination is essential for flight and correlating science data.	

Summary & Conclusions

- Aerial measurements provide a unique perspective
- Aerial exploration of Titan is feasible using either existing or near-term technological solutions
- Airship is preferred platform
- Helicopter has merit and should not be ignored
- Enabling technologies
  - Aerocapture
  - Mid-Air inflation - demonstration test
  - Autonomous operations - sensors, processors, and software
  - Cryogenic, flexible, hull materials
  - Improved efficiency RTG's
- Mission Pull exists - single largest impediment is funding (development and implementation)

Back Up Slides

Data Return

Parameter	Value
Airship to orbiter – number of relay passes per Titan orbit about Saturn	28
Airship to orbiter – relay pass duration	35 to 75 minutes
Airship to orbiter – link capacity per Titan orbit about Saturn	1.1 Gbits
Airship to orbiter – elevation mask; link margin	15 degrees; 10 dB
Airship to orbiter – total link volume during 4 month life	8.3 Gbits
Airship to orbiter – total uncompressed data returned	21 Gbits
Orbiter to Earth - % of time available for downlink	45%
Orbiter to Earth – downlink data rate from Titan (orbiter HGA to 34m BWG)	50 kbps
Orbiter to Earth – downlink data rate from Titan (orbiter HGA to 70m) Orbiter to earth – link margin Orbiter to Earth – total link volume during 40 month life (if only path is orbiter HGA to 34 m BWG)	250 kbps 3 dB 1578 Gbits
Orbiter to Earth – total returned uncompressed data volume during 40 month life (if only path is orbiter HGA to 34m BWG) Orbiter to Earth - total link volume during 40 month life (if only path is orbiter HGA to 70 m)	4 Tbits 7889 Gbits
Orbiter to Earth – total returned uncompressed data volume during 40 month life (if only path is orbiter HGA to 70m)	20 Tbits
Baseline Science and Engineering Data Volume Required	10.3 Tbits
Data Return Margin	~100%

Mass Story

Element	CBE Mass (kg)	Contingency (%)	Max. Expected Mass (kg)
Science Payload – Aerial Vehicle	26.1	24.10%	32.4
Baseline Aerial Vehicle – Airship	282.9	29.70%	366.8
Helium Lift Gas	69.2	30%	90
Total Aerial Vehicle Mass (Float Mass)	**378.2**	**293%**	**489.2**
Entry Aeroshell & Systems	**559.4**	**30.50%**	**730**
Total Entry Mass	**937.6**	**30.00%**	**1219.1**
Science Payload – Orbiter	77.9	19.20%	92.8
Orbiter – Dry	444.6	23.10%	547.3
Orbiter Propellant	55.8	15%	64.2
Orbiter Total at Titan	**578.3**	**21.80%**	**704.3**
Aerocapture Aeroshell & Systems	716	29.50%	927.1
Aerocapture Propellant	80.2	15%	92.2
Total Aerocapture Mass	**1374.5**	**25.40%**	**1723.6**
Orbiter to Aerial Vehicle Truss	181.8	13.70%	206.7
Divert & TCM Propellant	213.1	15%	245.1
SEP Prop Module to Orbiter Aeroshell Truss	69	30%	89.7
SEP Propulsion Module	955	29.80%	1240
SEP – Propellant	1057	0%	1057
Total Injected Mass	**4788**		**5781.2**
Launch Vehicle Adaptor	150	20%	180
Total Launch Mass	**4938**		**5961.2**
Delta IV-4050H-19 Capability at C3 = 12			**7525**

Relay Link Availability