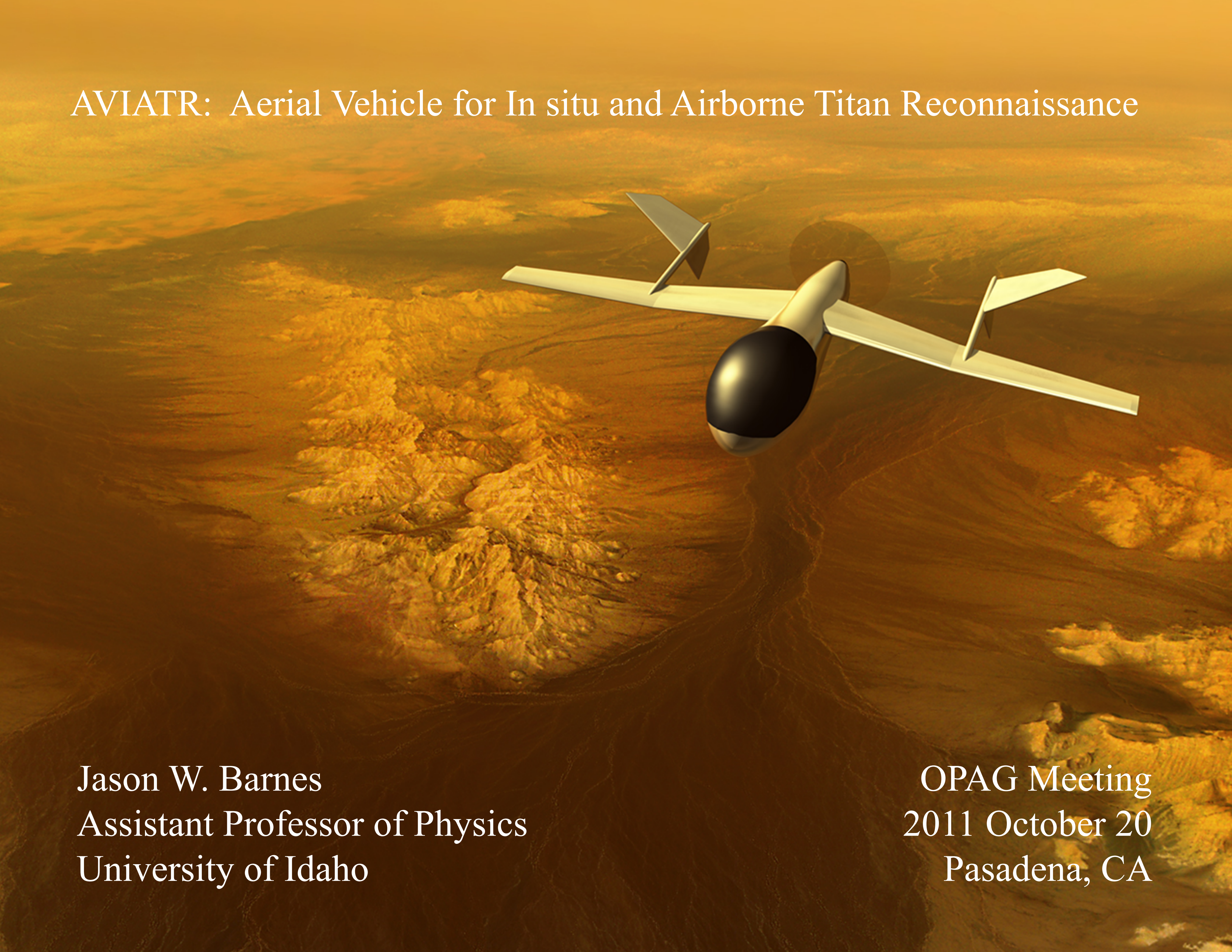
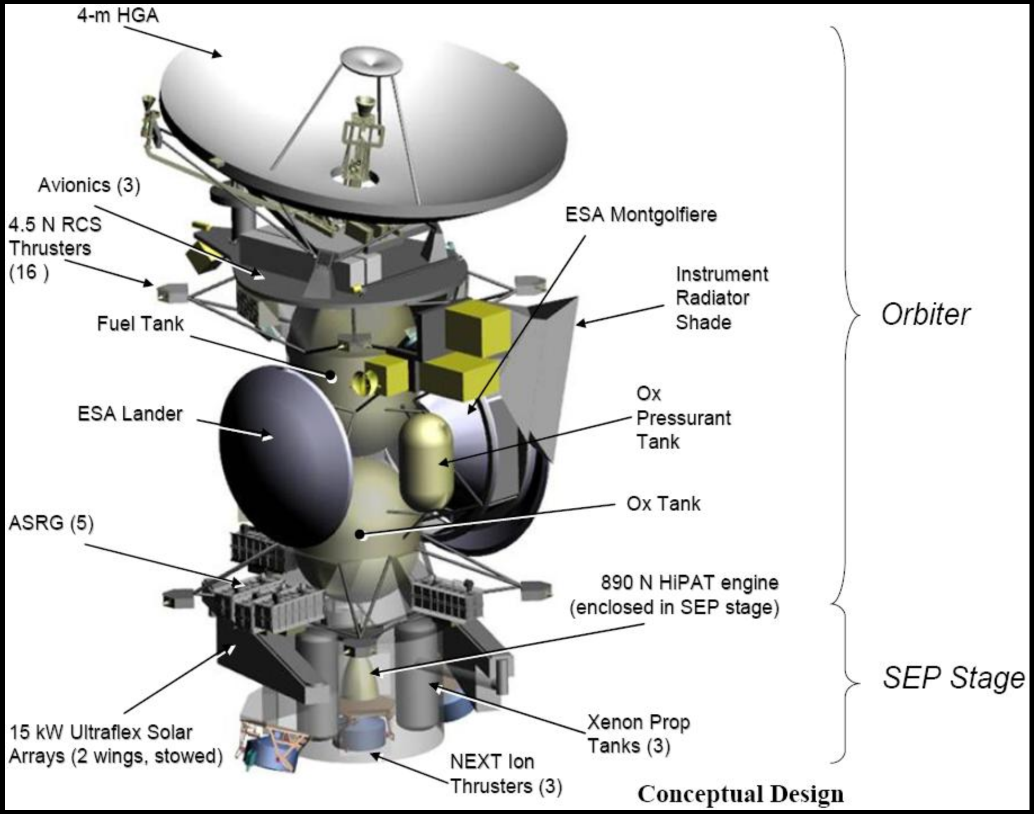
AVIATR: Aerial Vehicle for In situ and Airborne Titan Reconnaissance



Jason W. Barnes
Assistant Professor of Physics
University of Idaho

OPAG Meeting
2011 October 20
Pasadena, CA

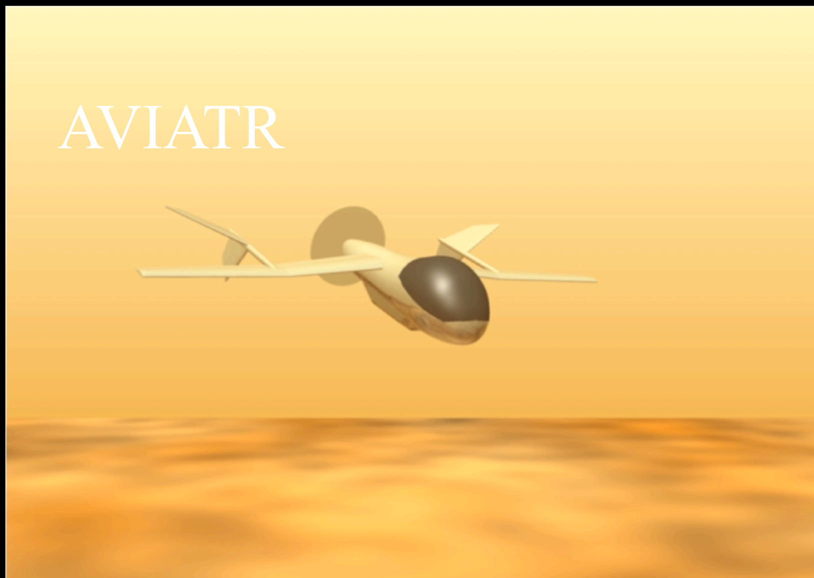
TSSM: Titan Saturn System Mission

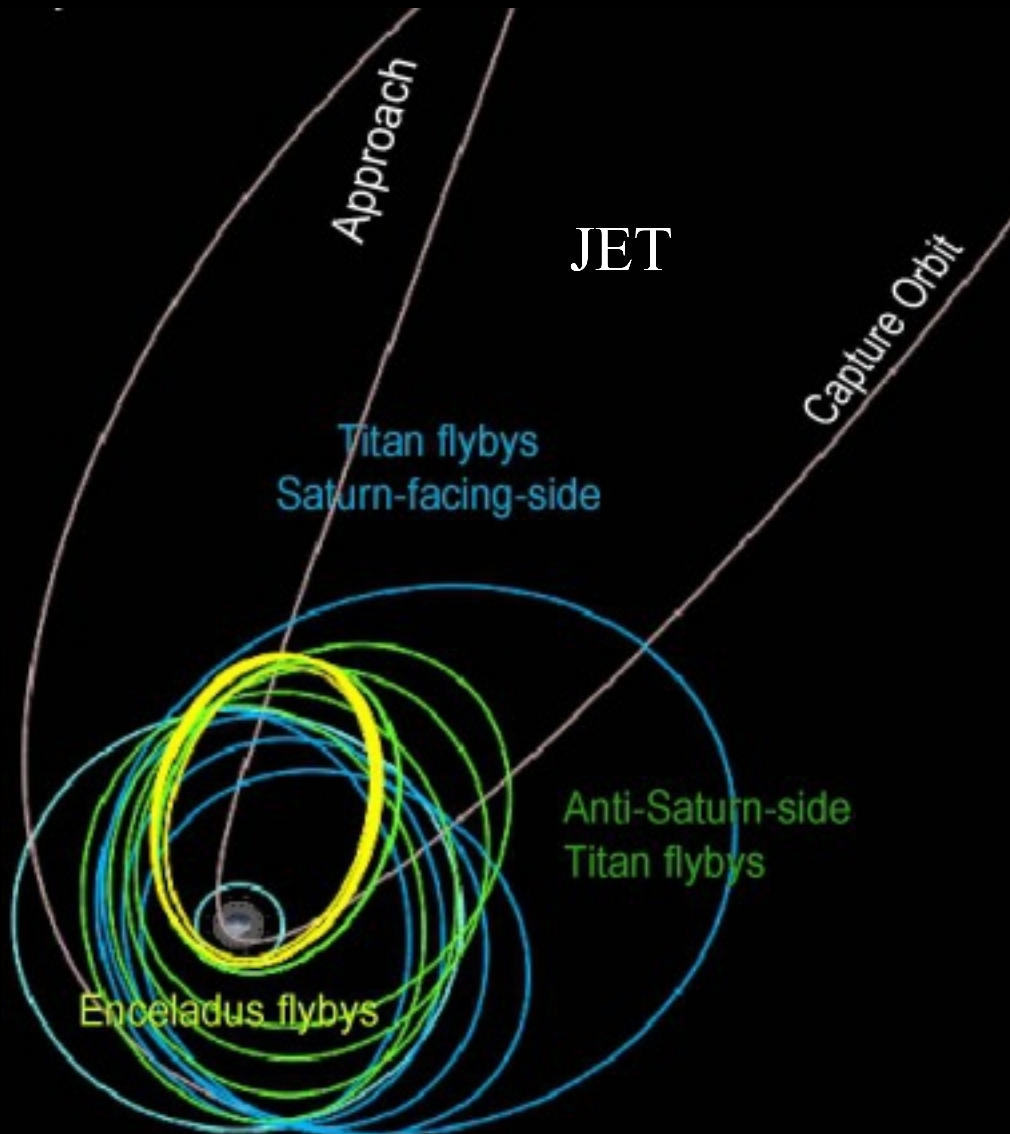


$~4-6 billion

TSSM

Titan Exploration Program





Titan Exploration Program

Mission Scope: Why not a balloon?

In general, either a balloon or an airplane is capable of achieving similar sets of scientific objectives. AVIATR is better suited to the task than a balloon:

BETTER SCIENCE: With go-to capability, stereo, repeat imaging, rapid altitude-change capability, remaining on the dayside, and direct-to-Earth communcations, a fixed-wing heavier-than-air plane can address more scientific objectives than a balloon and can be done on a New Frontiers budget.

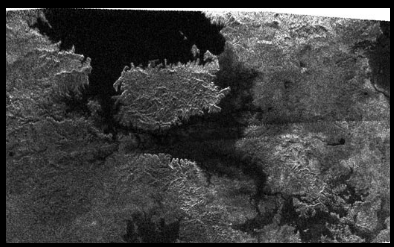
MORE EFFICIENT ^{238}Pu USAGE: Because a hot-air balloon uses MMRTG waste heat for buoyancy, it will not work with more efficient ASRGs. Conversely, MMRTG's are too inefficient in terms of Watts/kg to fly an airplane. Thus the ASRG is an enabling technology for a Titan Airplane.

Airplane vs. Balloon

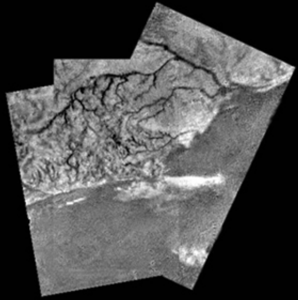
AVIATR Science Goals

Surface Geology: Ascertain, from above, the elements of Titan's geological processes and history, their relative levels of activity, and their global distributions and morphologies.

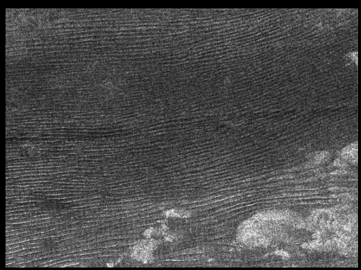
Lakes



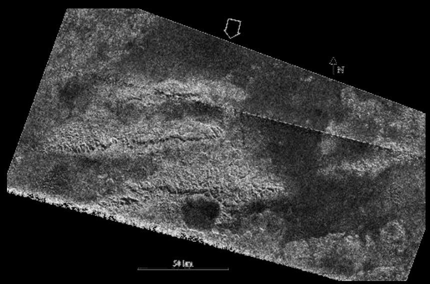
Channels



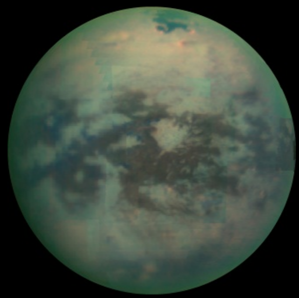
Dunes



Surface Activity

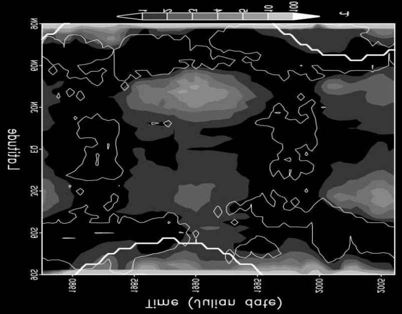


Exploration

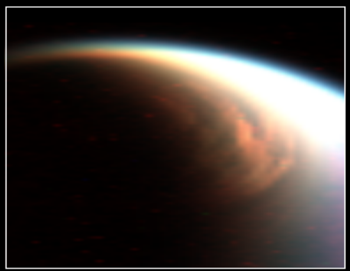


Atmospheric Science: Characterize, from within, the global diversity and local conditions of Titan's present-day atmosphere.

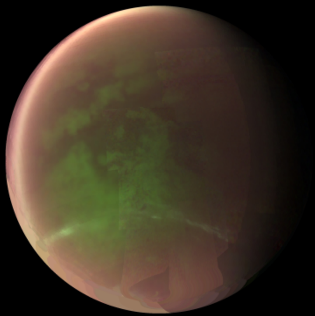
Winds



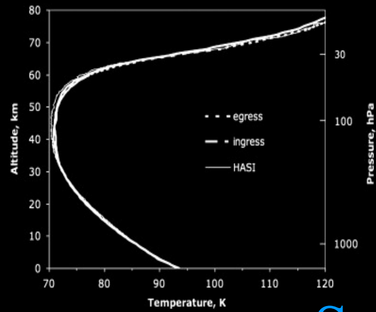
Clouds



Haze



Structure



Science

UAV Design

The power required for level flight, P_{flight}, is

$$P_{flight} = \frac{1}{2}\rho f V^3 + \frac{2(W/b)^2}{(\pi \rho e V)}$$

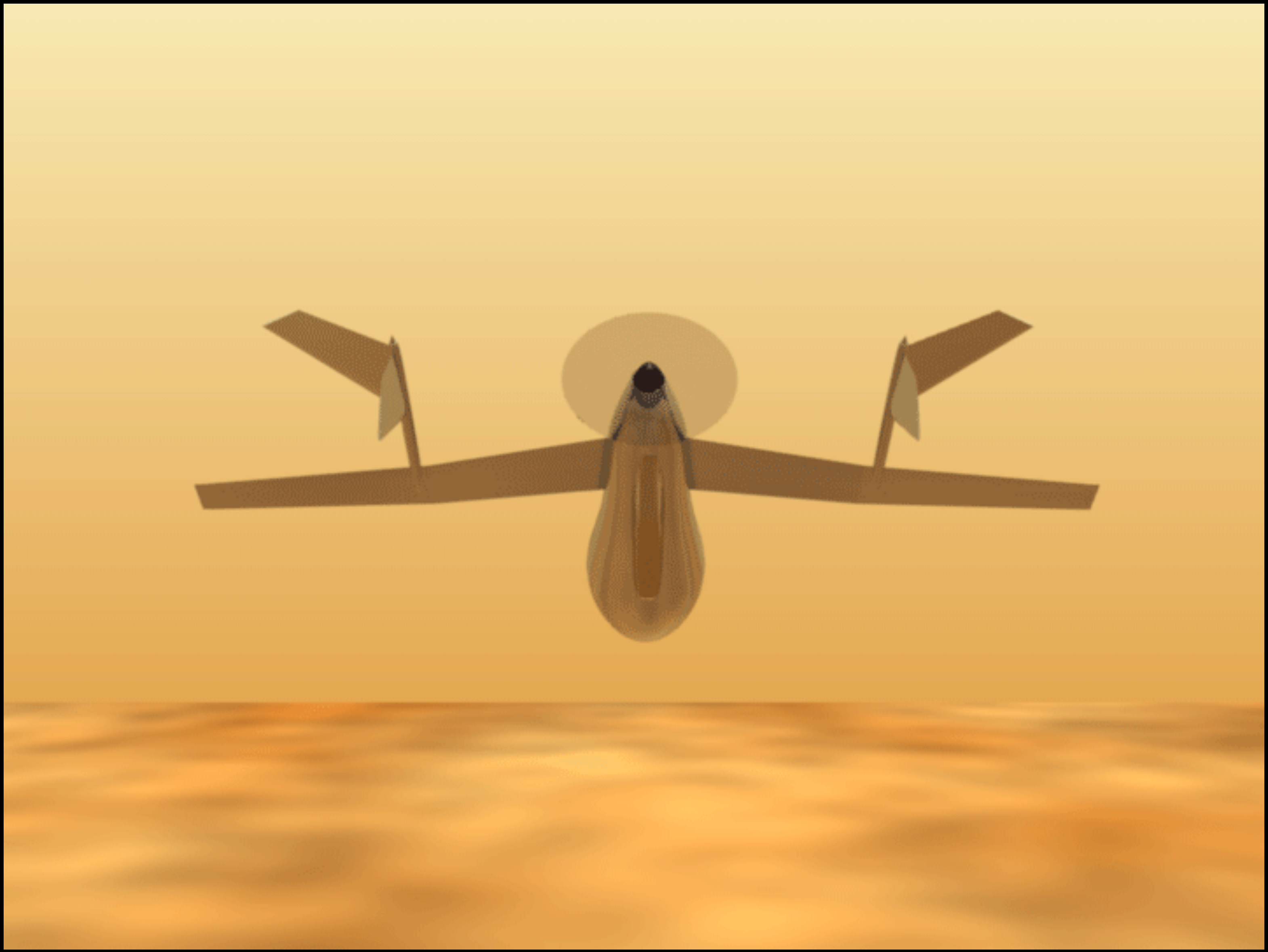
where ρ is the density, f the skin friction coefficient, V the velocity, W the weight, b the wingspan, and e the Oswald's efficiency factor.

Surface Gravity – 1.352 m/s^2 (0.138 x Earth)
Atmospheric Density – 3.9 kg/m^3 (at 10 km; E=1.2 kg/m^3)
Temperature – 85 K
Wind Speed at Flight Altitude – 0.0-3.0 m/s
Speed of Sound – 200 m/s
Specific Kinetic E for Flight – $^1/_{30}$*Earth, $^1/_{1200}$*Mars

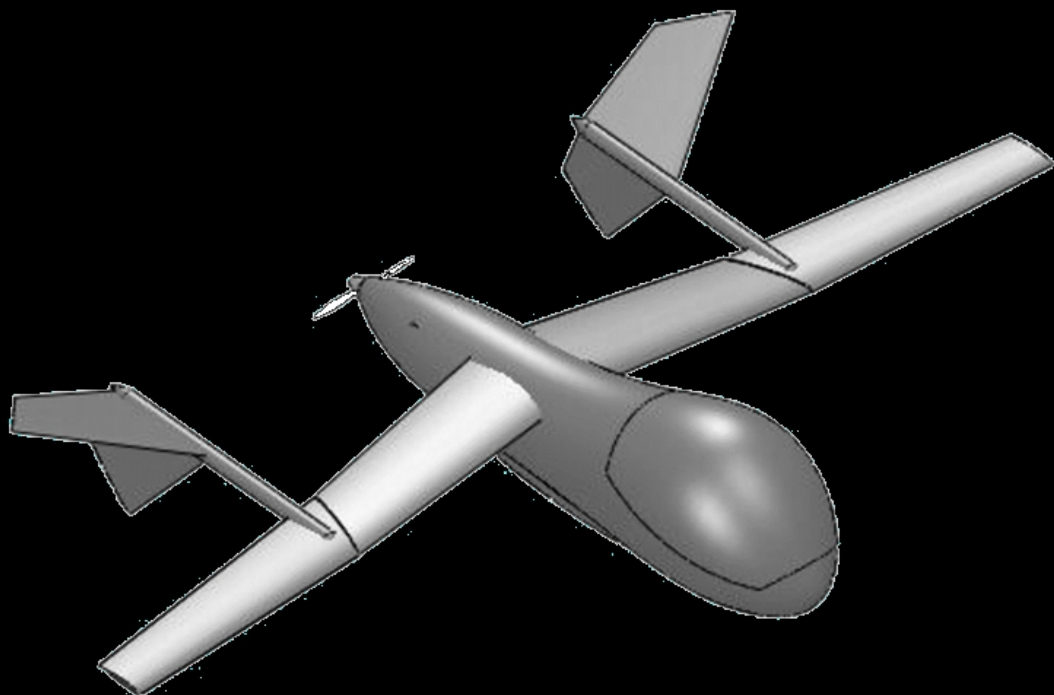
With 3.25 times more air and 7 times less gravity than Earth (or 500 times more air and 2 times less gravity than Mars), along with a workable thermal environment, heavier-than-air flight makes more sense on Titan than anywhere else in the solar system.

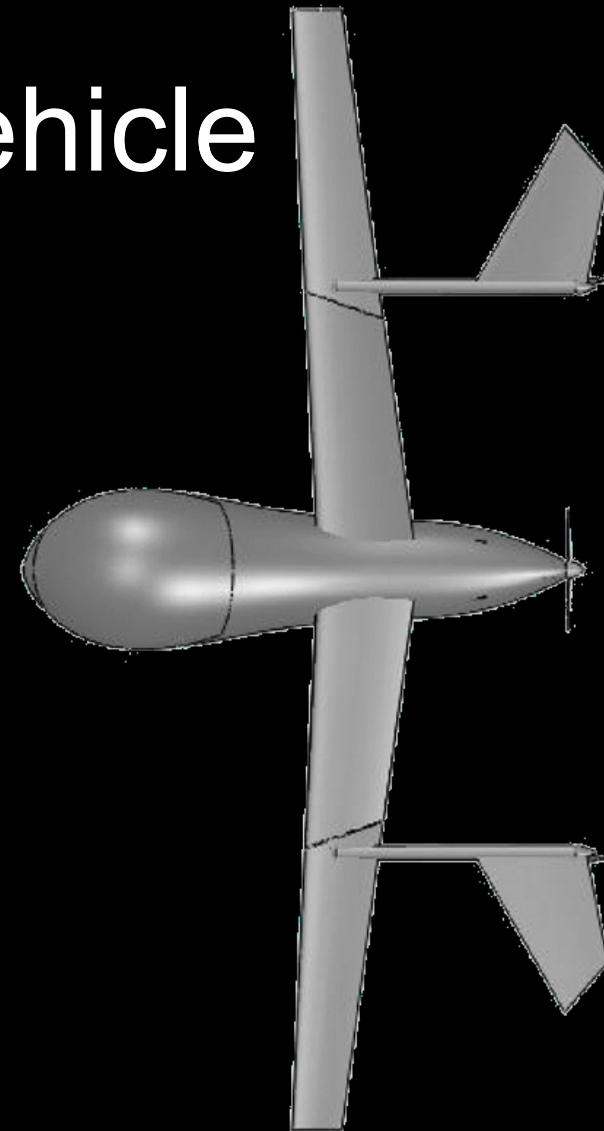
Titan Flight Parameters

UAV Design



AVIATR Air Vehicle

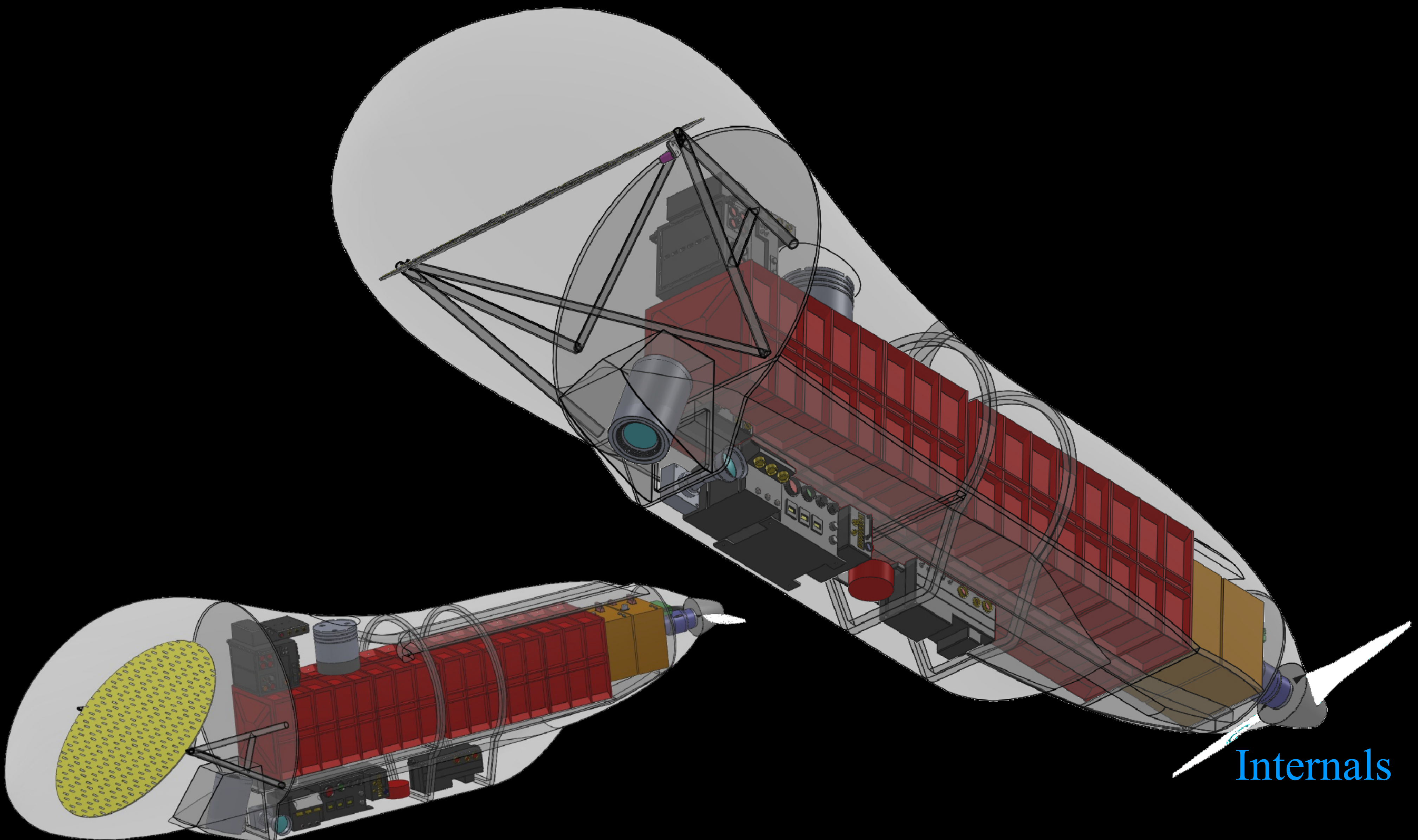




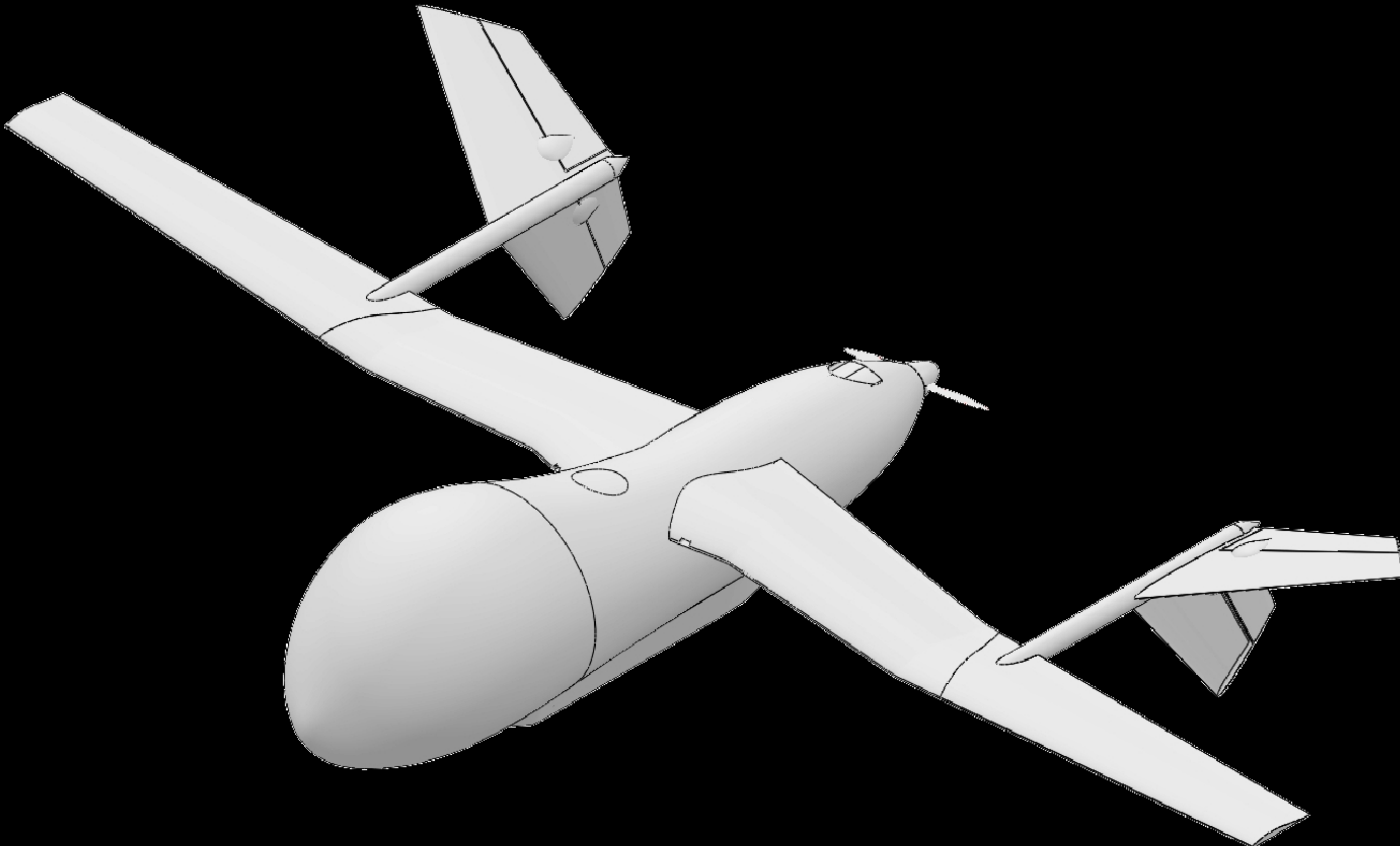
Air Vehicle

AVIATR Air Vehicle

Internal Layout

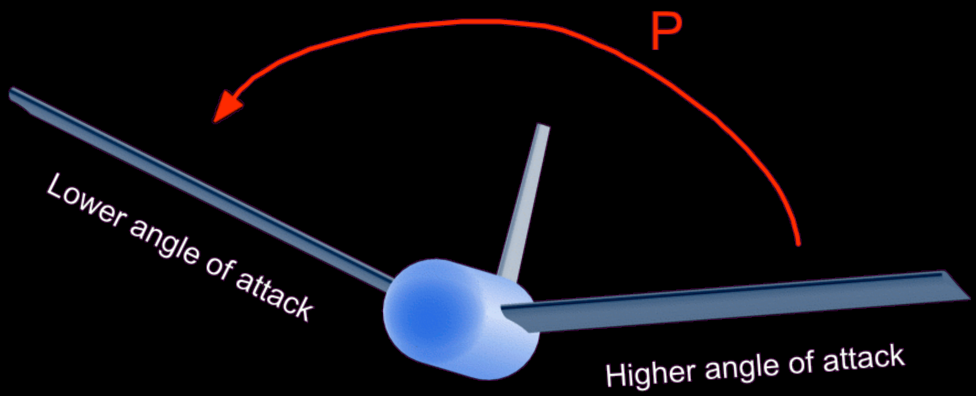


AVIATR Control Surfaces



Control Surfaces

UAV Design



- With wing dihedral angle (left), stable and consistent weight and balance without consuming fuel, and proper trim, the aerial vehicle is inherently stable. Without control inputs, will return to straight and level flight. Long-wavelength oscillations can build up over many hour timescales.

- AVIATR will have a built-in safe mode, just like any other modern interplanetary spacecraft. In safe mode the vehicle will fly so as to keep the solar zenith angle below a given value (say, 45°), and point the antenna toward the Sun for communication with Earth to wait for further instruction.

- Like safe mode for a vehicle in space: the AVIATR safe mode requires no prior knowledge of the vehicle's position or orientation.

Safe Mode

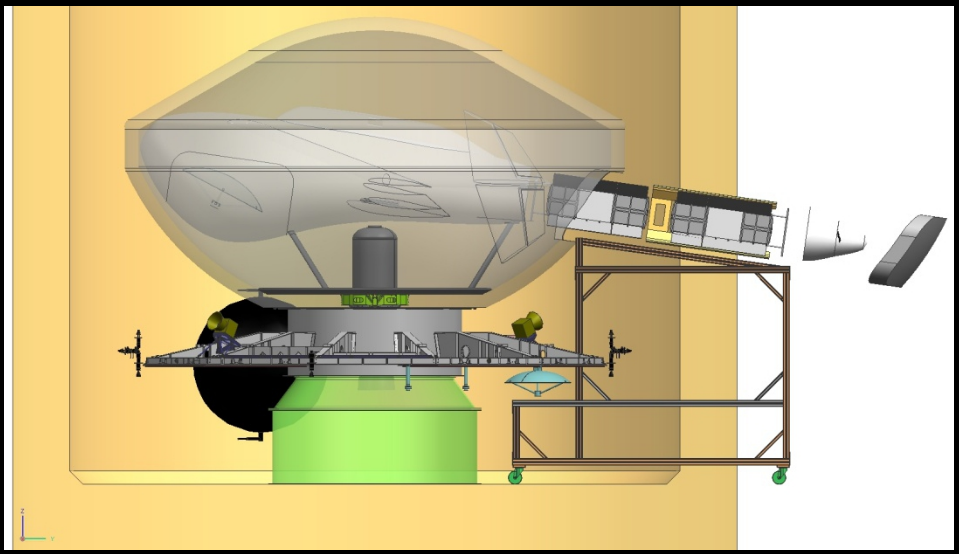
AVIATR Size Comparison

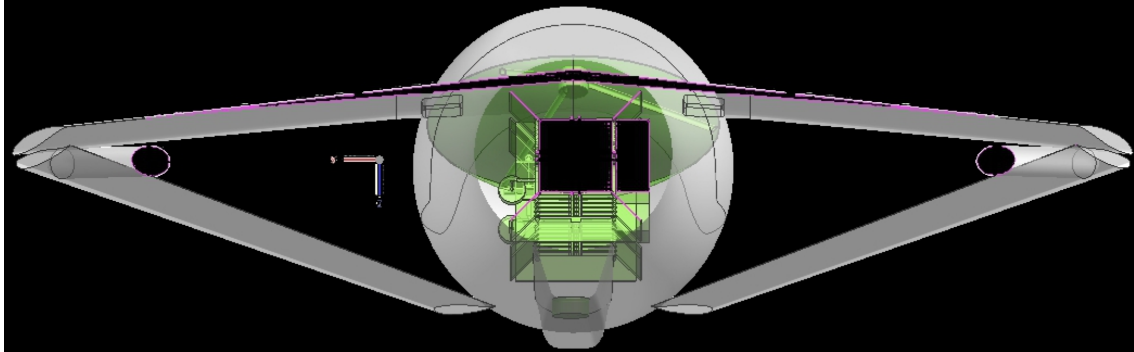
T38 Trainer Jet

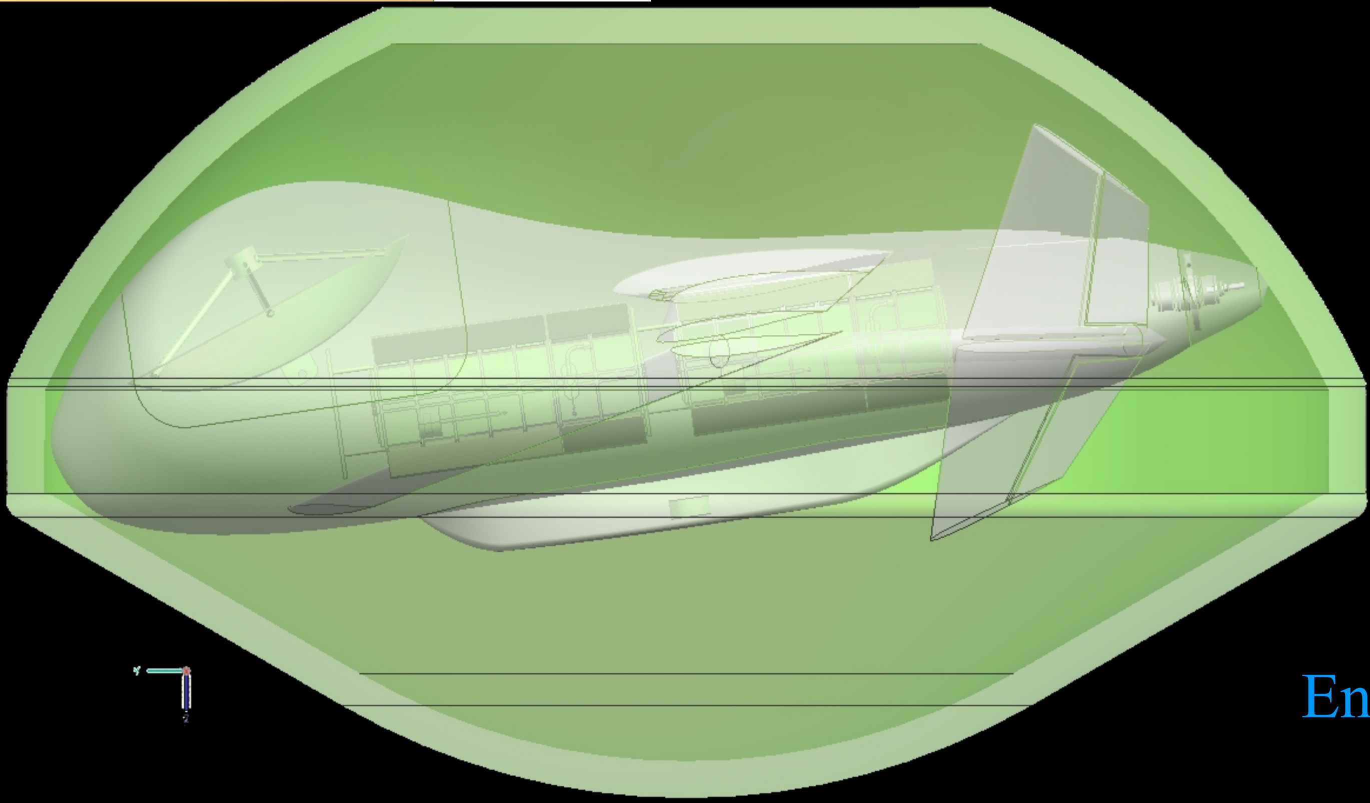
AVIATR

Size Comparison

AVIATR Entry Vehicle

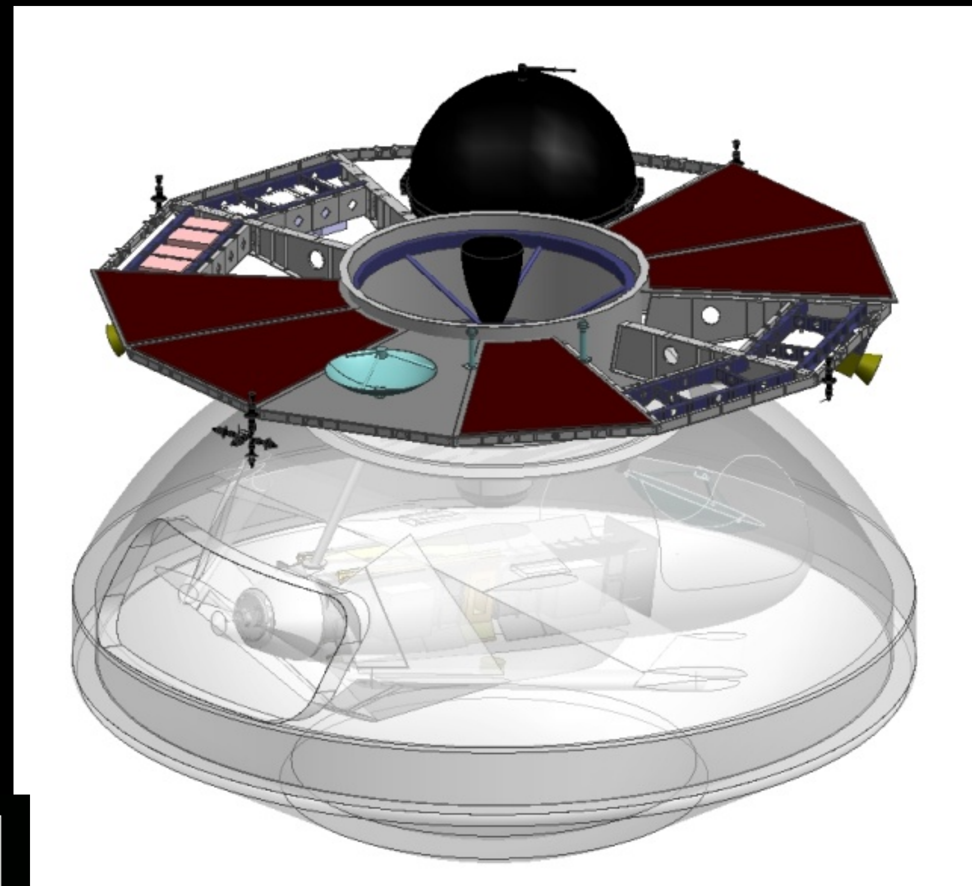


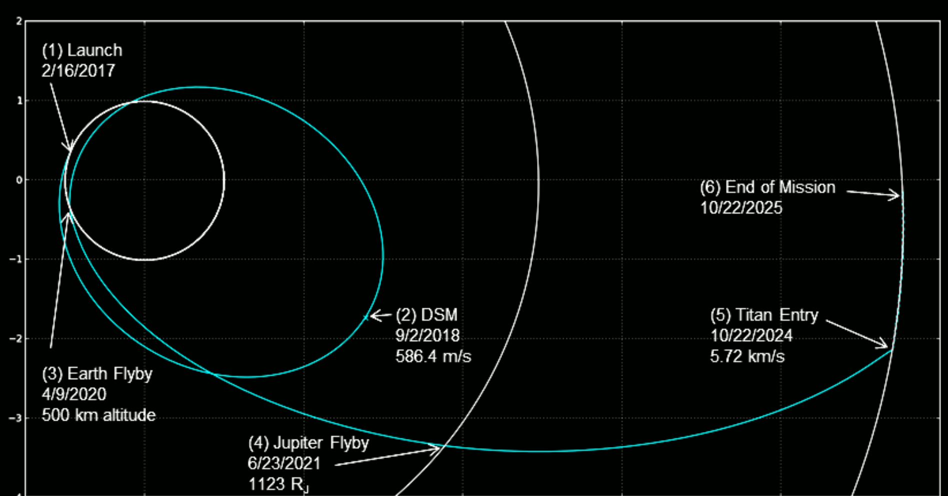


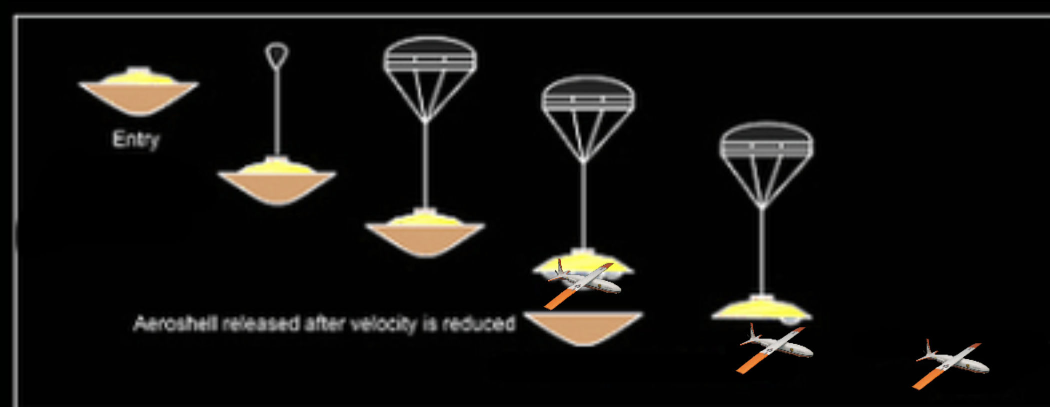


Entry Vehicle

Rocket and Spacecraft

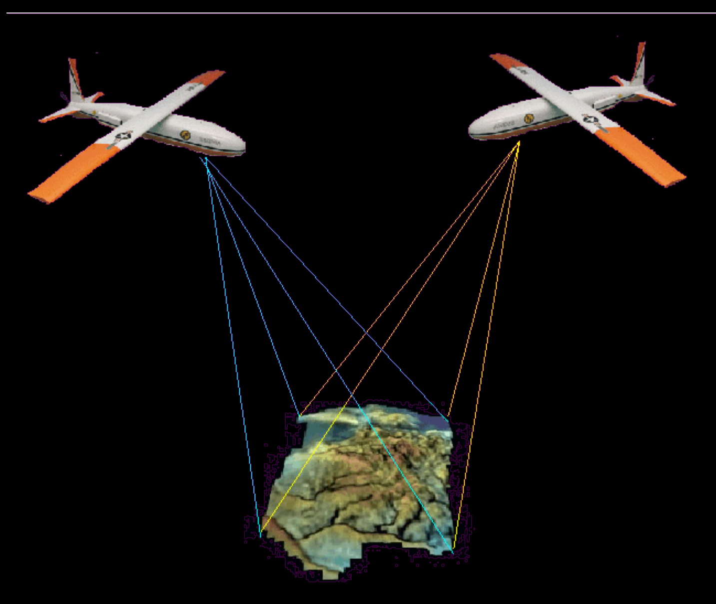






Science Instruments: Optical Remote Sensing Suite

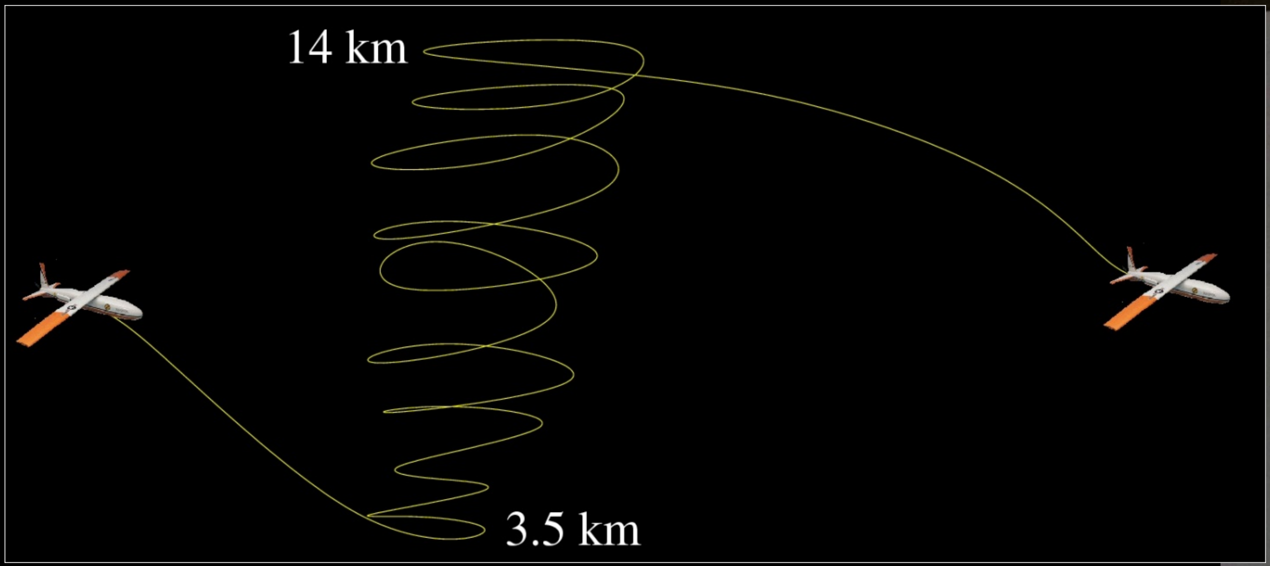
	High-Resolution Imager	Horizon-Looking Imager	Near-Infrared Spectrometer
Wavelength:	1.97 – 2.09 µm (2 micron methane window)	4.87 to 5.15 µm (5 micron methane window)	1.05 to 5.4 µm (with >=400 channels across this range)
Ground Scale:	0.5 m/pix at 3.5 km altitude (~2 m/pix at 15 km)	~15 to 34 m/pixel	3.5 to 8 m/pixel at 3.5 km alt (~15 to 34 m/pixel at 15 km)



ORS Instrumentation

Science Instruments: Atmospheric Suite

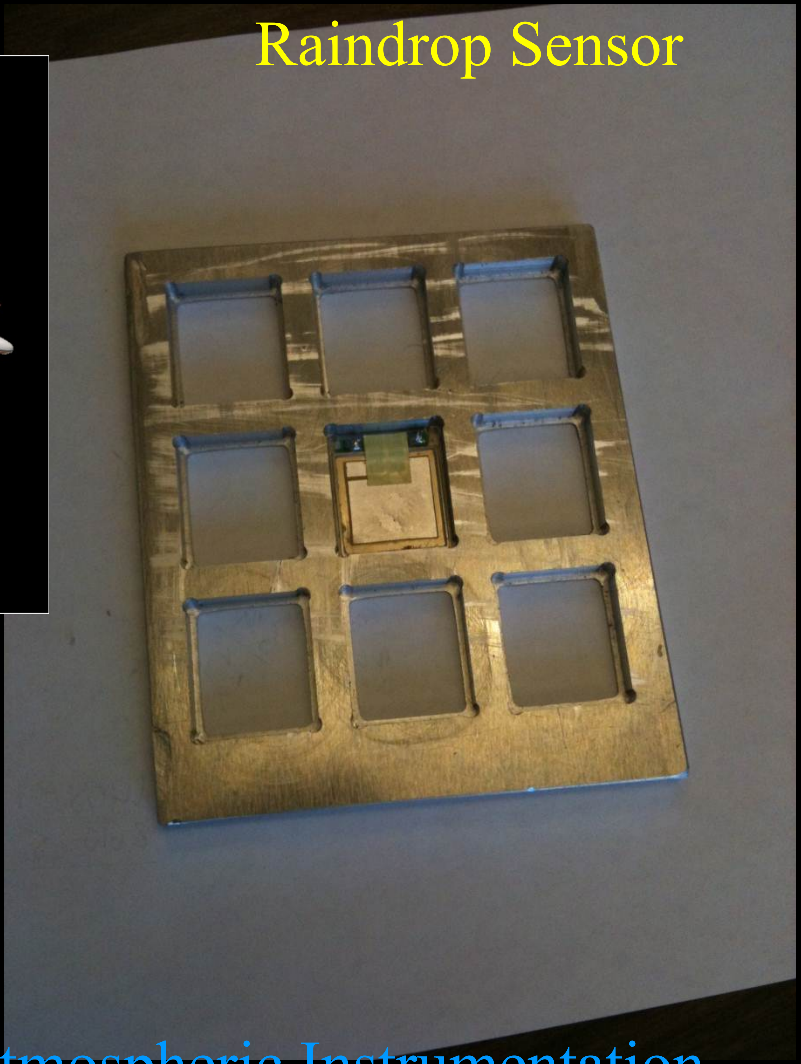
Atmospheric Structure: P, T, humidity, haze



Ultrastable Oscillator / Doppler Wind

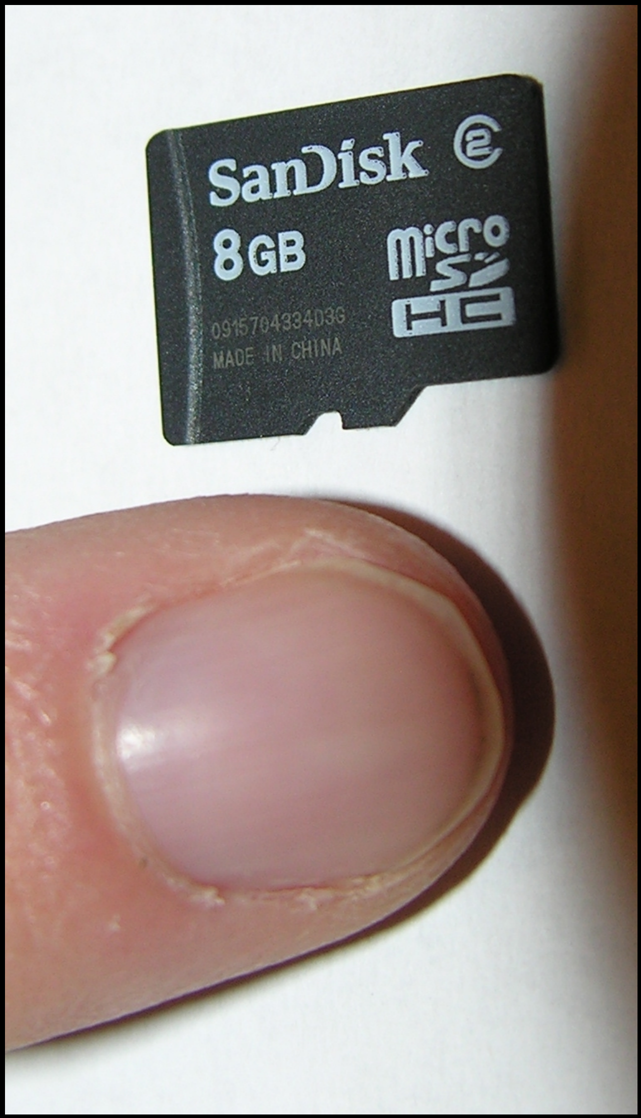
Radar Altimeter

Student
Raindrop Sensor



Atmospheric Instrumentation

Operations



Bandwidth is limited; storage is cheap, small, & low-mass. We will build in far more onboard storage than we will be able to return to Earth.

Downlink only those data thought highest priority, but keep the others. Download them from the aircraft if and when a request is made for them.

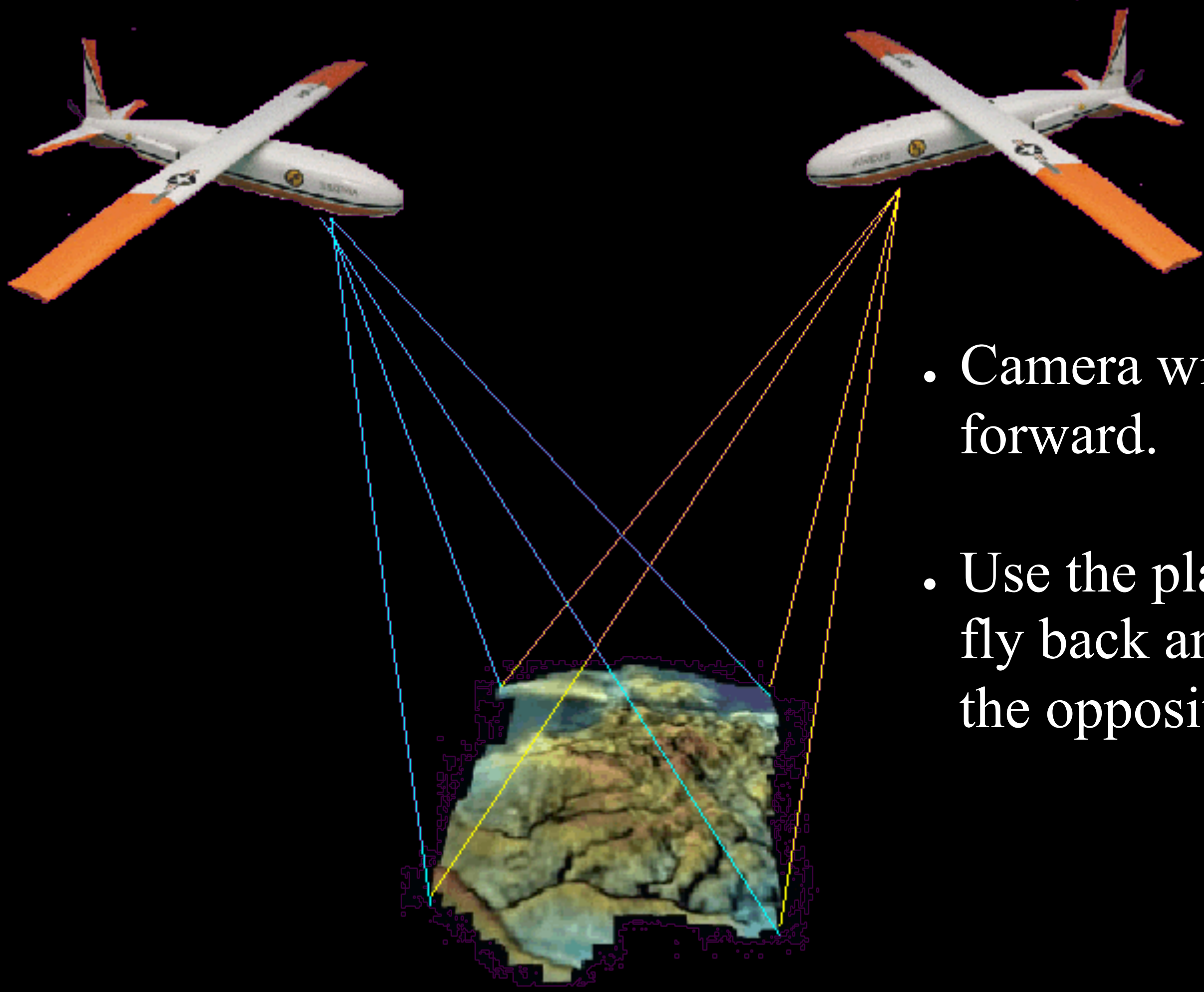
Send back meta-data and thumbnail-sized initial versions of images so that the science team can select which to return at full resolution

Both lossless and lossy compression available for science team to select on a per-image basis.

This approach and these abilities allow us to be highly efficient users of our limited bandwidth, in order to maximize the science return.

Data Management Strategy

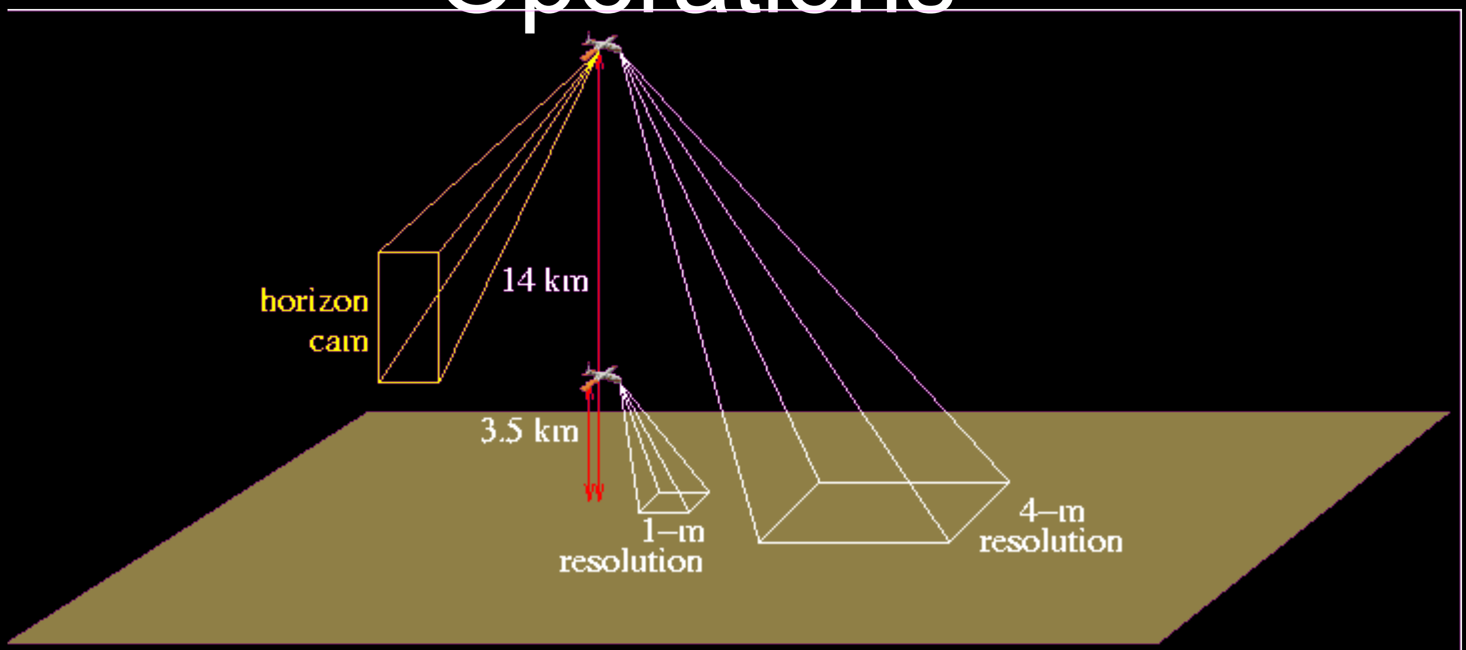
Operations



- We will achieve stereo imaging with a single, fixed camera.
- Camera will be angled ~15^{o} off nadir, forward.
- Use the platform's maneuverability to fly back and image the same area from the opposite look angle as desired.

Stereo

Operations



- Repeated experience from planetary missions has shown that high-resolution postage stamps require context for proper geologic interpretation.
- AVIATR will use both its horizon-looking camera and its altitude flexibility to gather contextual imaging
- Context mapping from 14-km altitude resulting in 4-m resolution; high-res at 3.5-km altitude with 1-m resolution.

Acquiring Context

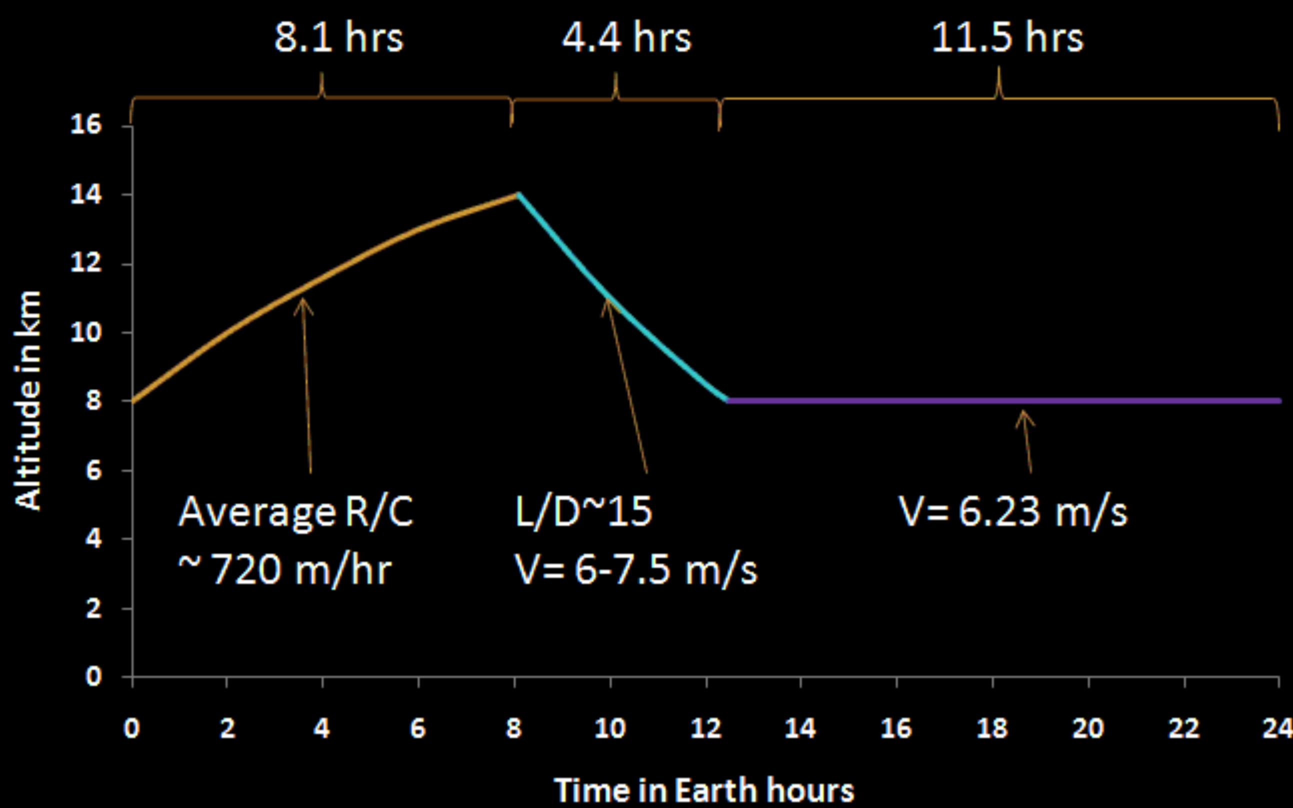
Operations

- On important targets we will execute large image mosaics, not individual frames.
- Mosaics will take most of the mission's bandwidth.
- Mosaics will (in general) have 4 components:

1. Full surface scan just below the horizon
2. Low resolution (4 m) mosaic from 14 km
3. Stereo observations at either 4-m or 1-m res
4. High resolution (1 m) mosaic from 3.5 km

Mosaics

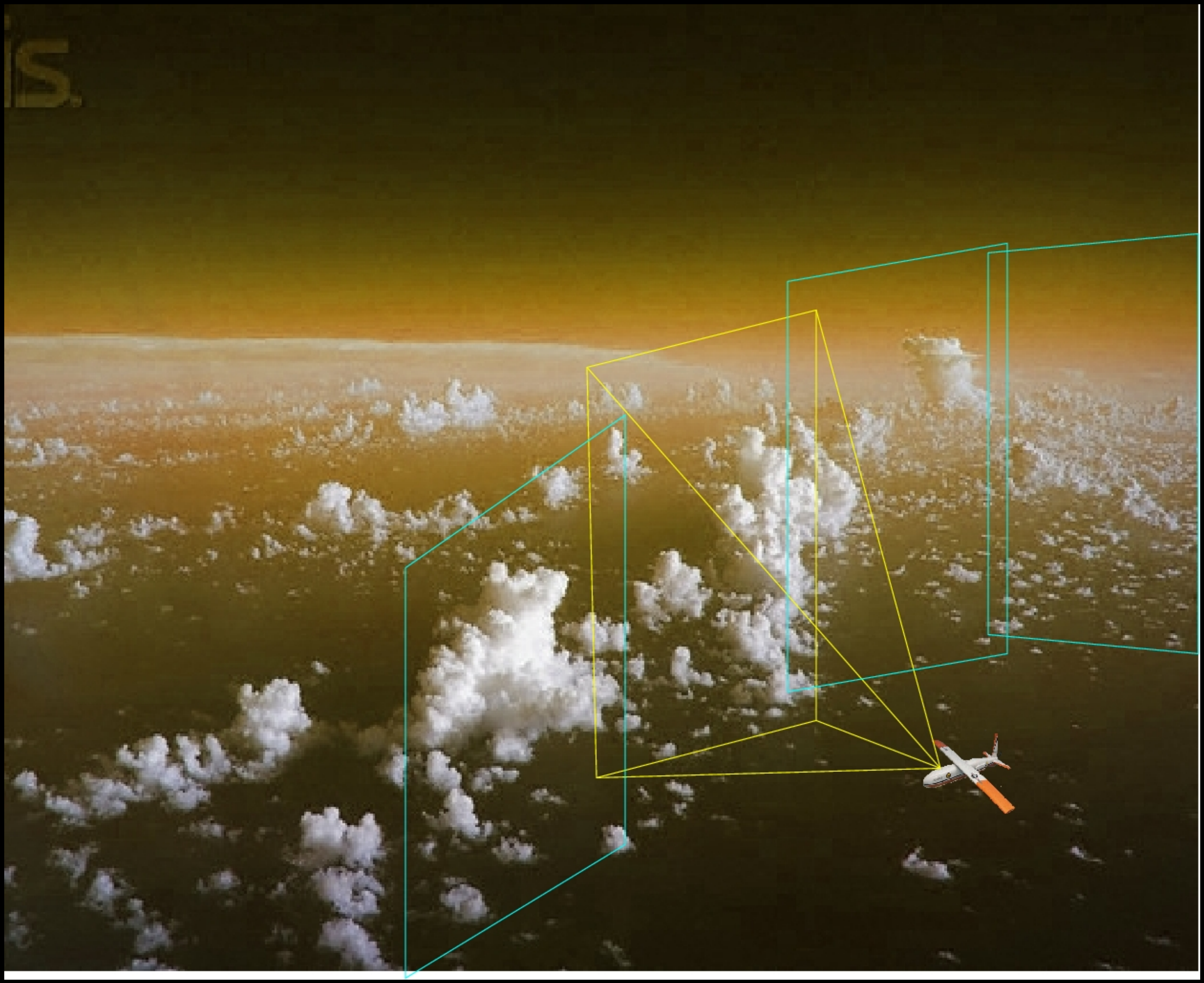
Climb / Glide
Power Management Strategy



	Glide	Climb	Cruise
Transmit (W)	155	0	0
Payload (W)	0	0	40
Avionics (W)	40	40	40
Actuators+Misc. (W)	25	25	25
Propulsion (W)	0	155	115
Total (W)	220	220	220

Figure X. Power Management. The cydical three phase flight profile enables effective flight performance, collection, and communications.

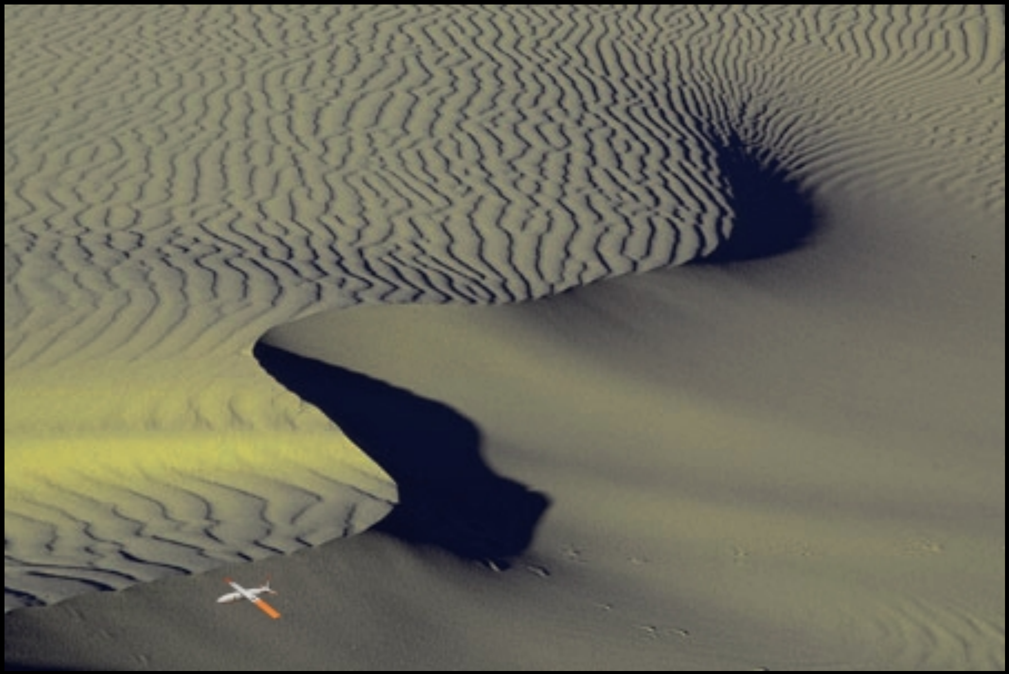
Operations



- Obtain direct images of clouds, and cloud decks using horizon-looking imager.
- Roll left (assuming HLI is on the starboard side) to point HLI toward the sky
- Image while turning thru 360°

Cloud Imaging

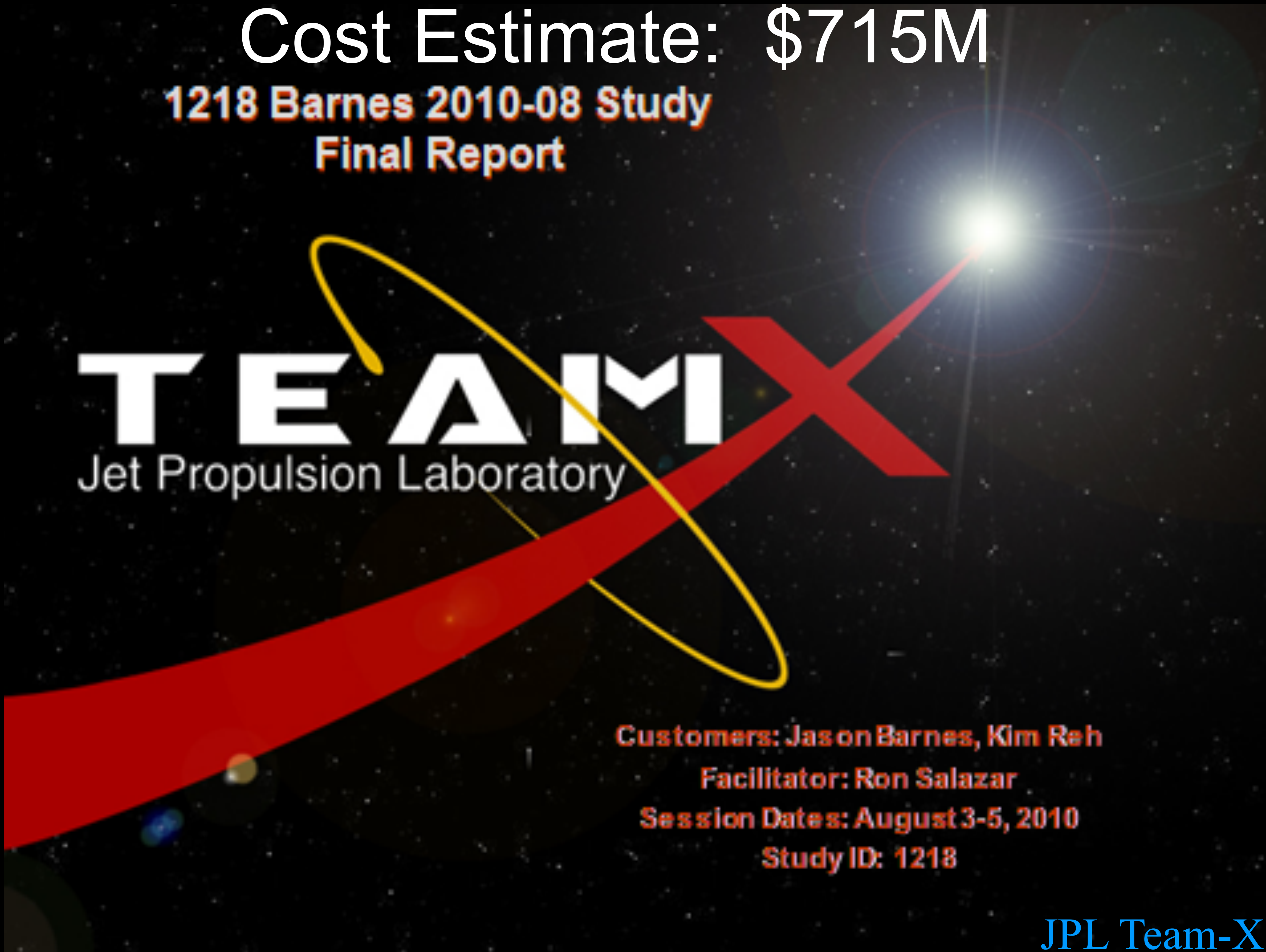
Operations



- Just before end-of-mission, attempt more aggressive fly-throughs of clouds
- At mission termination, enter into deep stall and fall to the surface at ~few meter per second.
- Land on dunes?
- Survival likely quite short on surface due to lack of air coolant flow

End-of-Mission

Cost Estimate: $715M



JPL Team-X

Conclusion:

- Enabled by the ASRG, a single-element Titan airplane mission can achieve majority of TSSM in-situ science
  - Runs on ASRG, not MMRTG
  - Go-to capability
  - Robust airframe
  - Flexible ops
  - Direct comm

- AVIATR would focus on exploring Titan's diversity, both surface and atmospheric
- Team-X Cost estimate: $715M
- Such a mission could be part of a sequence of smaller missions designed to achieve the TSSM Flagship science over time instead of all at once: Titan Exploration Program

Cost Breakdown

WBS Elements	Option 1 1st Unit	Option 2 1st Unit
Project Cost (including Launch Vehicle)	**$714.3 M**	**$684.4 M**
Development Cost (Phases A - D)	**$576.1 M**	**$550.9 M**
Phase A Total	**$3.0 M**	**$3.0 M**
01.0 Project Management	**$30.2 M**	**$30.2 M**
02.0 Project Systems Engineering	**$14.0 M**	**$14.7 M**
03.0 Mission Assurance	**$17.0 M**	**$16.1 M**
04.0 Science	**$9.5 M**	**$9.5 M**
05.0 Payload System	**$10.8 M**	**$10.8 M**
06.0 Flight System	**$269.8 M**	**$258.1 M**
6.01 Flight System Management	$2.0 M	$2.0 M
6.02 Flight System Systems Engineering	$27.3 M	$27.3 M
6.03 Product Assurance (included in 3.0)	$0.0 M	$0.0 M
Space Vehicle	$92.1 M	$83.1 M
Entry Vehicle	$46.4 M	$48.1 M
Airplane	$60.3 M	$60.3 M
Airplane Deltas	$27.1 M	$24.0 M
Aerothermal/Aerostability Analysis	$7.0 M	$7.0 M
6.13 Materials and Processes	$1.1 M	$1.1 M
6.14 Spacecraft Testbeds	$6.5 M	$5.2 M
07.0 Mission Operations Preparation	**$19.7 M**	**$16.3 M**
09.0 Ground Data Systems	**$20.5 M**	**$16.5 M**
10.0 ATLO	**$43.7 M**	**$43.7 M**
11.0 Education and Public Outreach	**$1.6 M**	**$1.6 M**
12.0 Mission and Navigation Design	**$8.7 M**	**$8.7 M**
Development Reserves	**$127.6 M**	**$121.8 M**
Operations Cost (Phases E - F)	**$113.2 M**	**$108.5 M**
01.0 Project Management	**$4.7 M**	**$4.7 M**
02.0 Project Systems Engineering	**$0.0 M**	**$0.0 M**
03.0 Mission Assurance	**$0.8 M**	**$0.8 M**
04.0 Science	**$13.3 M**	**$13.3 M**
07.0 Mission Operations	**$58.6 M**	**$57.4 M**
09.0 Ground Data Systems	**$9.0 M**	**$6.7 M**
11.0 Education and Public Outreach	**$4.1 M**	**$4.0 M**
12.0 Mission and Navigation Design	**$0.0 M**	**$0.0 M**
Operations Reserves	**$22.6 M**	**$21.7 M**
8.0 Launch Vehicle	**$25.0 M**	**$25.0 M**

Cost Breakdown