A relocatable lander to explore Titan's prebiotic chemistry and habitability

Flights of Exploration on an Alien Moon: Dragonfly Mission Reliability

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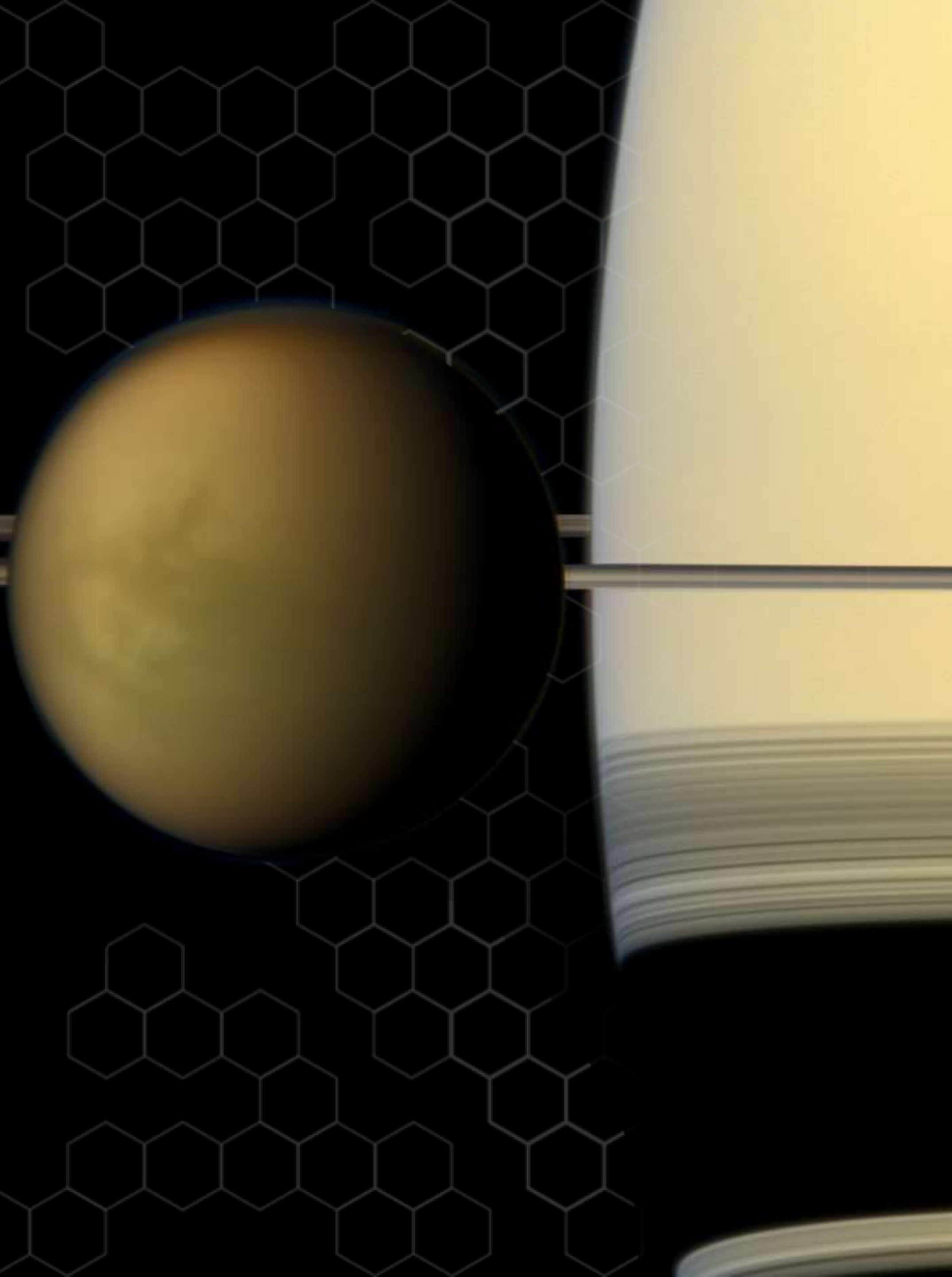


Background

- Working at Johns Hopkins University Applied Physics Laboratory since 1991
- Reliability lead for APL's Space Exploration Sector
- Reliability engineering for many missions
- Probabilistic Risk methods to various sponsor problems and studies
  - Interstellar Probe Study (50 year mission)
  - Missile production issues
- Research interests
  - Optimized risk bases testing
  - Long duration missions (multiple decade missions)
  - Interplay between Qualification testing and Reliability

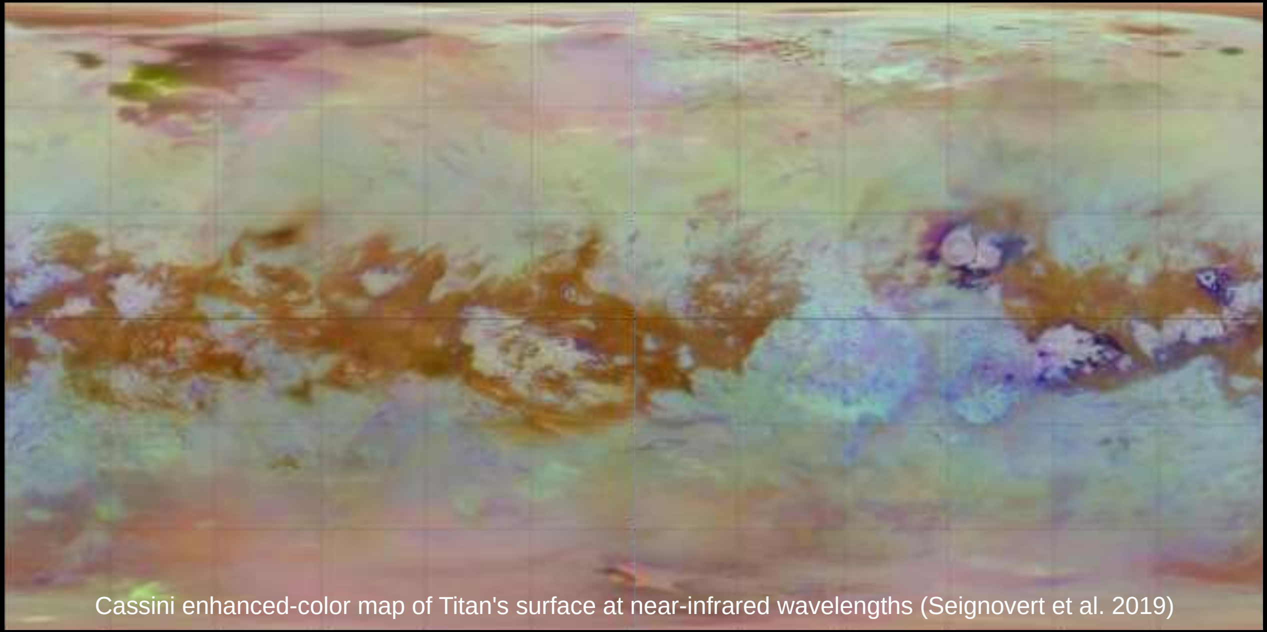
Johns Hopkins University Applied Physics Laboratory

- Research division of Johns Hopkins University
- Nation's largest University Affiliated Research Center
  - ~8,000 staff
- Sponsors include:
  - Department of Defense
  - NASA
  - Department of Homeland Security
  - Intelligence Community
- Our purpose is make ***critical contributions to critical challenges***

Titan's unique environment

Voyager 2, 23 August 1981

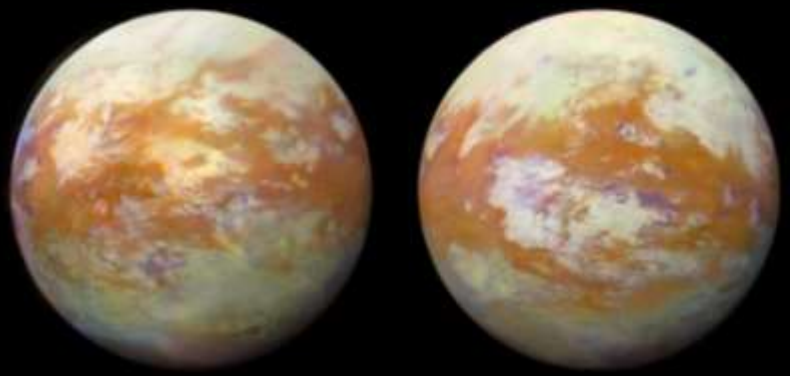
- Largest of Saturn’s 62 moons
- Diameter: 5,150 km (3,193 miles)
- Surface gravity: 1.35 m/s^2 (0.14 g)
  - 14% of gravity at Earth’s surface
  - 83% of gravity at Moon’s surface
- Surface temperature: 94 K (–179°C, –290°F)
  - Bedrock composition: water ice
  - Atmospheric composition: nitrogen, few % methane
- Surface pressure: 1.5 bar
  - 1.5× pressure at Earth's surface
- Deep interior ocean of liquid water



Cassini enhanced-color map of Titan's surface at near-infrared wavelengths (Seignovert et al. 2019)

Lander with aerial mobility enables wide-ranging in situ exploration – key for science measurements

Cassini revealed where to look for answers



- Diverse surface materials and environments
- Earth-like variety of geologic processes
- Science challenge is to get instruments to multiple sites to sample materials and measure composition

Heavier-than-air mobility highly efficient at Titan

- Atmospheric density 4x higher than Earth's reduces wing/rotor area required for lift
- Gravity 1/7th of Earth's → reduces power required

Science goals and payload focus on chemical inventory and opportunities for materials to interact

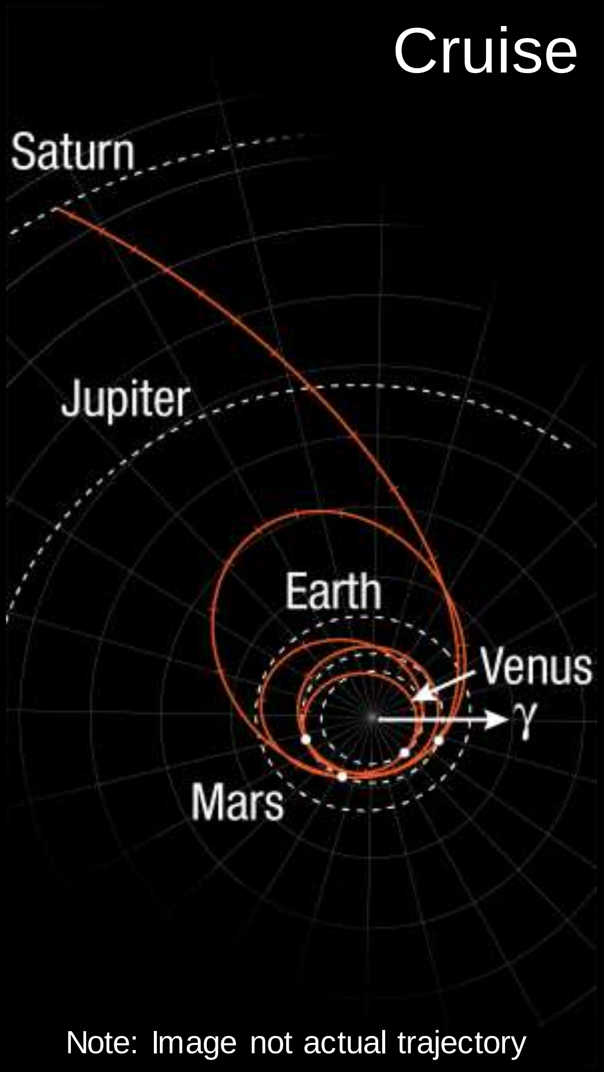
- DragonCam: Camera Suite (MSSS, APL)
- DraGMet: Geophysics & Meteorology Package (APL, JAXA Lunar-A seismometer)
  - Needed continuously on the surface including hybernation
- DraGNS: Gamma-ray Neutron Spectrometer (APL, LLNL, GSFC, Schlumberger PNG)
- DrACO: Drill for Acquisition of Complex Organics (Honeybee Robotics)
- DraMS: Mass Spectrometer (GSFC, CNES)
- DrEAM (on aeroshell): Entry Science Investigation (NASA/Ames, DLR, AMA Inc.)
  - Operates only during EDL

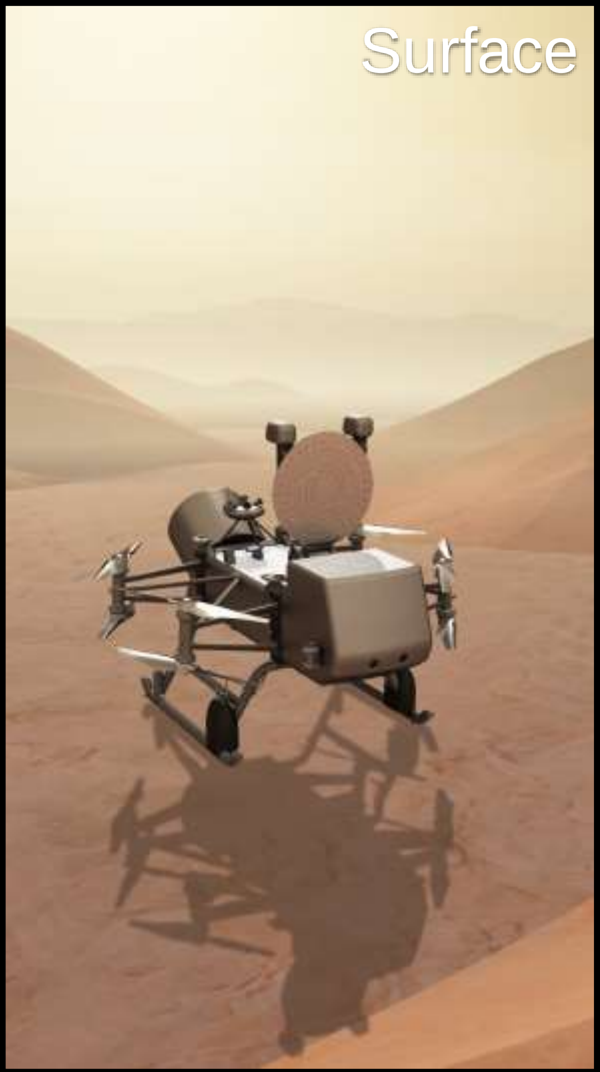
Minimum Mission Success Criteria

- For mission success, the following minimum criteria must be met:
  - Land on Titan and establish a communication link
  - Characterize the terrain near the lander with multi-scale imaging to identify local geological features
  - Monitor meteorological conditions over a full diurnal cycle (1 Tsol) and measure surface properties at the landing site
  - Perform compositional measurements of Titan's surface materials

- Launch is scheduled in 2027 with arrival by 2034 (6+ years transit time)
- Nominal mission duration on the surface is 3.3 years, with a concept of operations to travel ~100 km and explore a few dozen landing sites

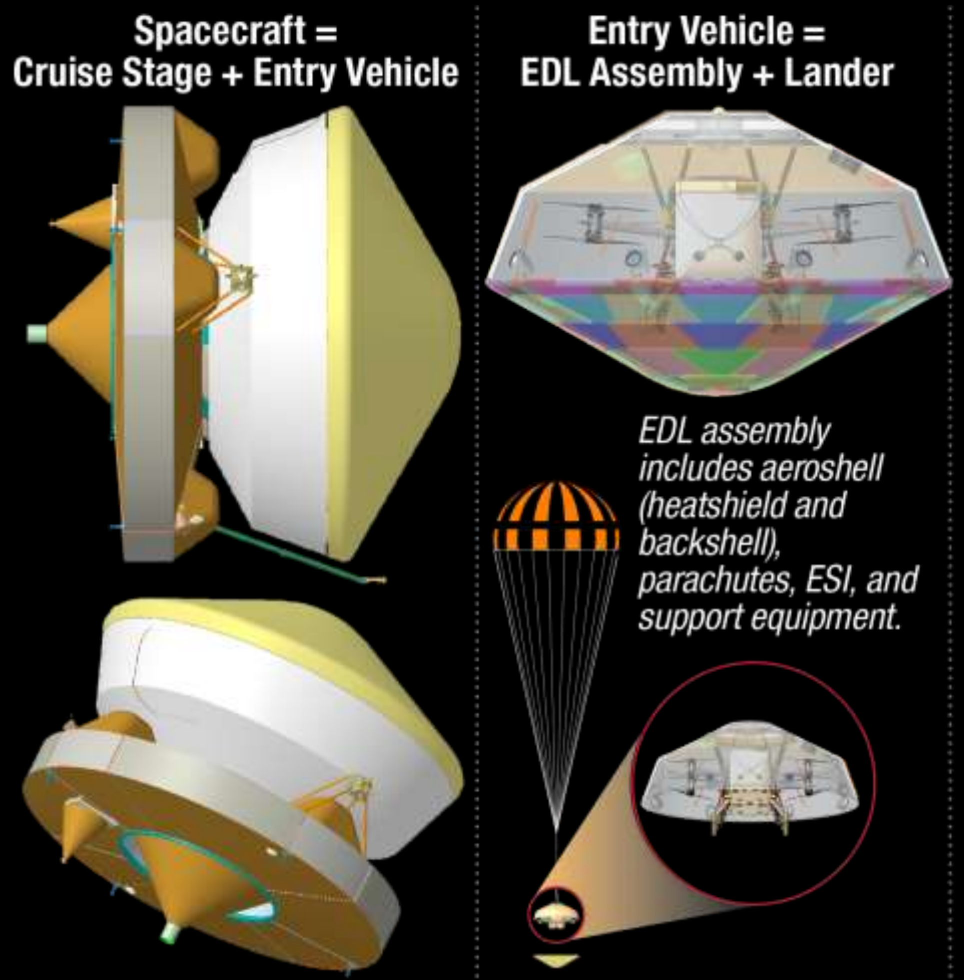
Dragonfly's Efficient Implementation Consists of Four Distinct Mission Phases





DRAGONFLY

Flight System Elements

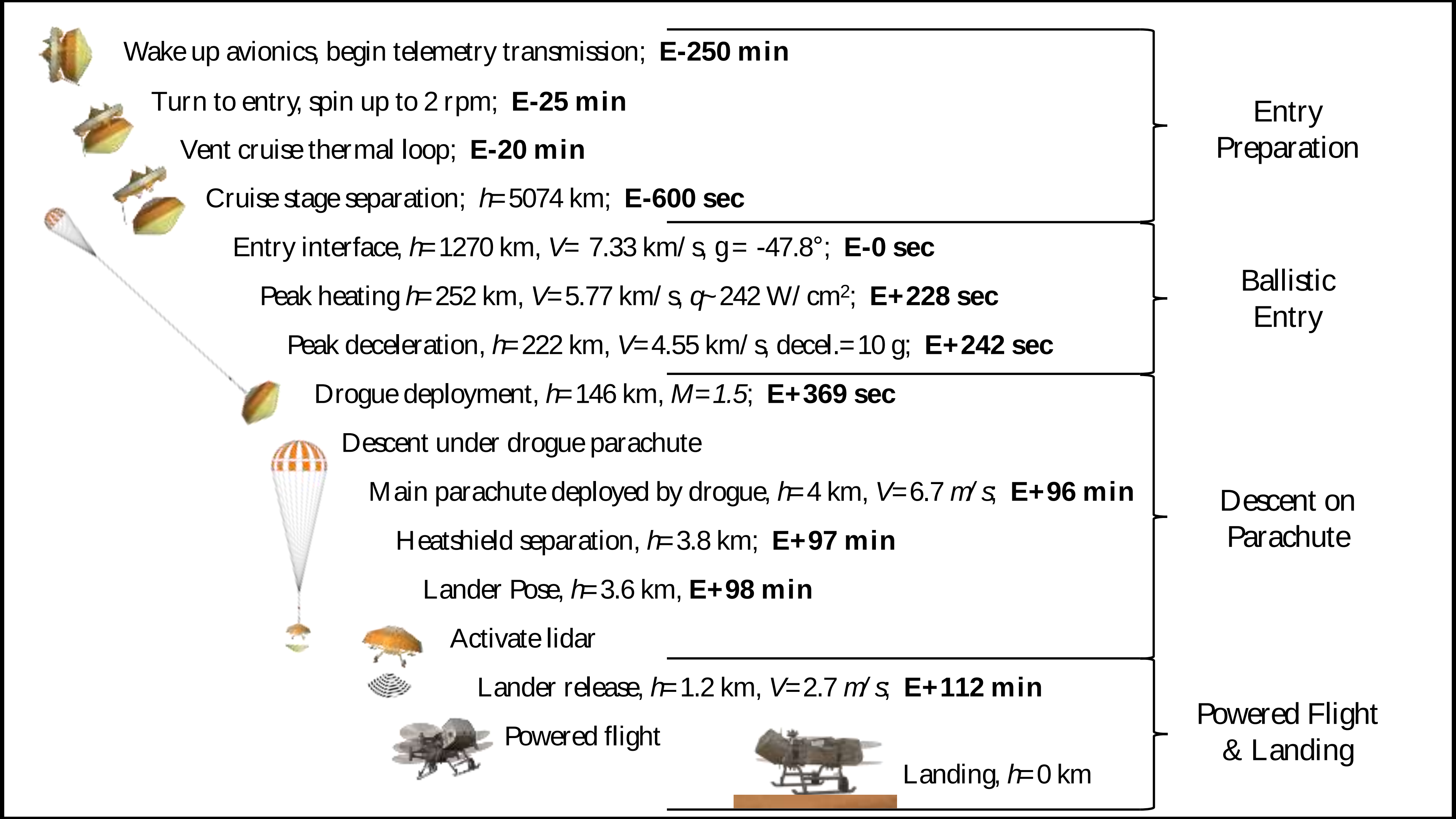


Rotorcraft Lander
Flight configuration with HGA stowed

Note: Images above are used to delineate elements and do not reflect current configuration

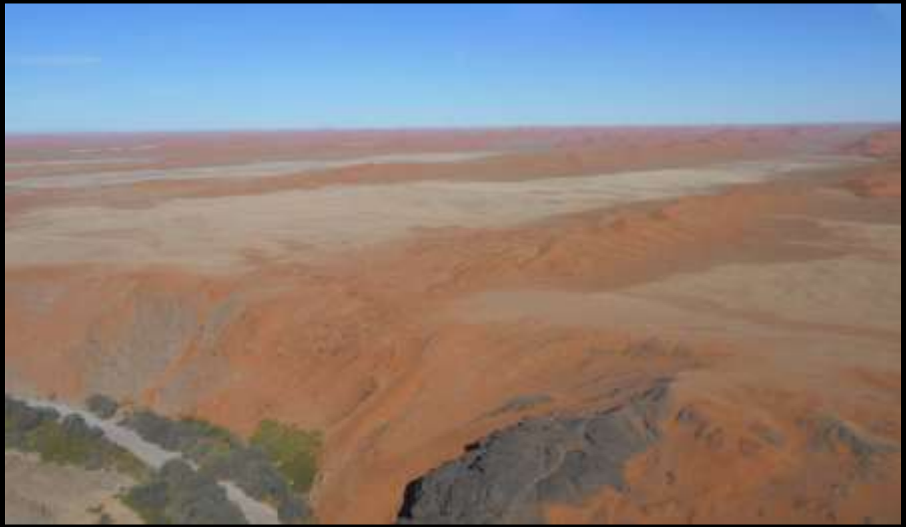
- NOT a typical Mars stack-up
  - Cruise Stage is not independent, as there is a common fluid loop for thermal, power comes from Lander, and "brains" of the entire vehicle lives in Lander
- Cruise stage provides functions needed for travel between Earth and Titan
  - Propulsion, guidance & control, (attitude control) and telecommunications
- EDL Assembly provides functions needed for safe descent through Titan's atmosphere
  - Heatshield, backshell, parachute system, separation systems, and LGA
- (Rotorcraft) Lander provides functions needed for surface exploration at Titan
  - Octocopter for mobility (flight) at Titan
  - Science instruments for studying Titan's surface and atmosphere

Entry, Descent, and Landing (EDL) at Titan



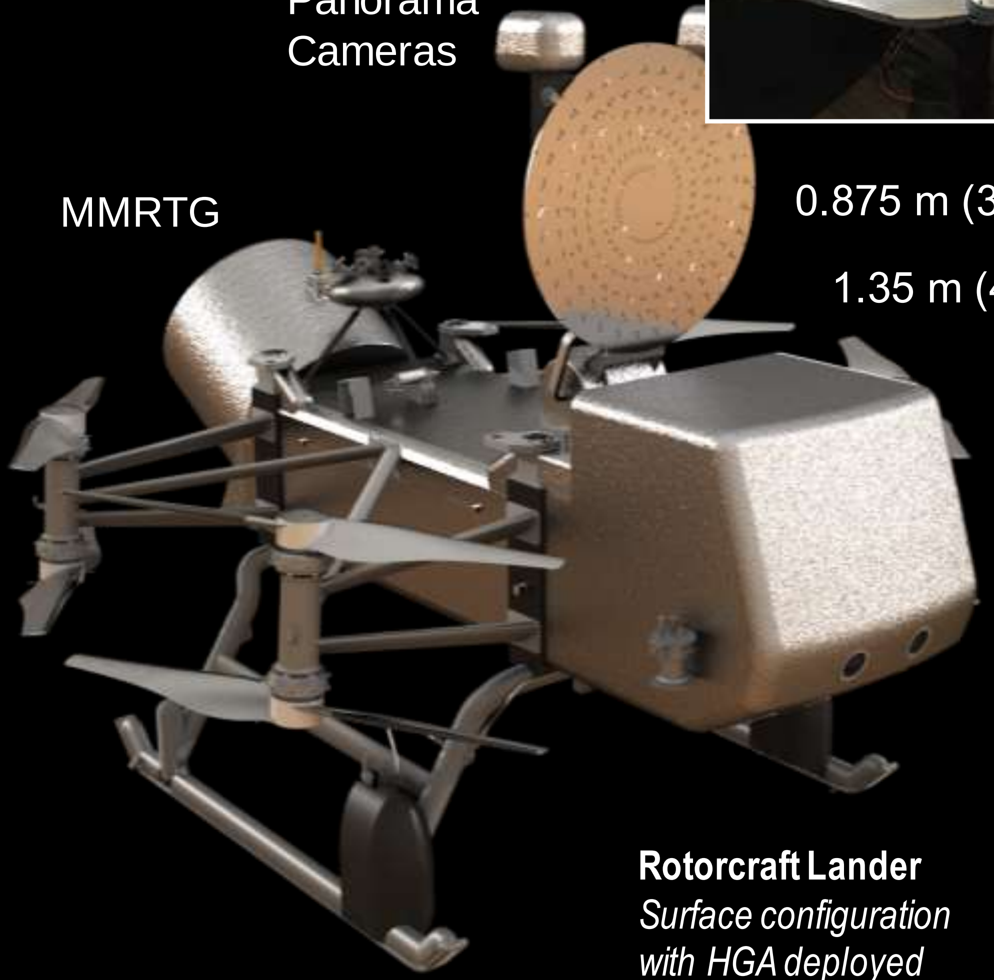
Initial Landing Site Provides Access To Multiple Geologic Settings

- Dunes
- Interdunes
- Impact crater deposits
- Access to sample organic sediments and materials with a water-ice component



Landed Configuration and Payload Accommodation

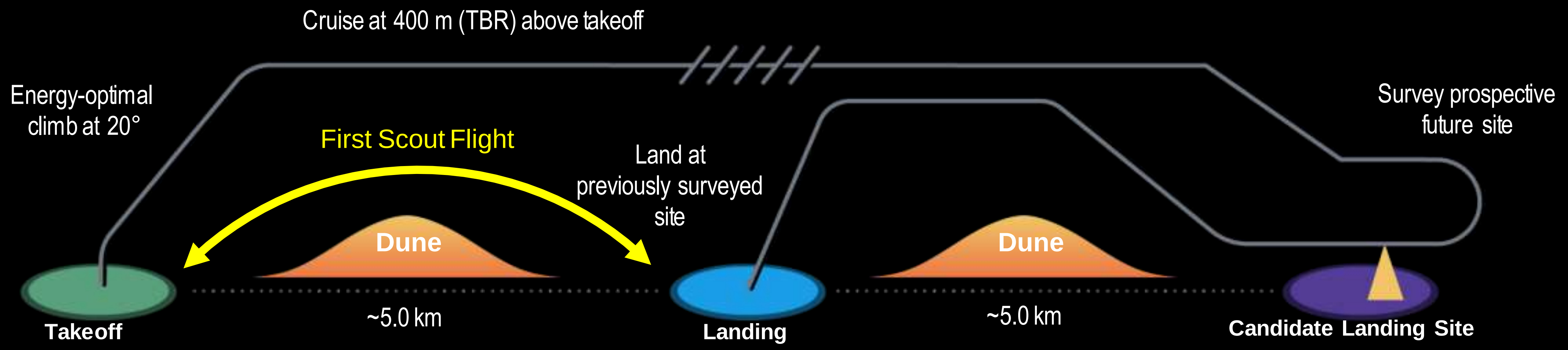
- Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) power
  - Charge battery used for flight and science activities
  - Waste heat maintains nominal thermal environment in lander
- Direct-to-Earth (DTE) communication
  - High-gain Antenna (HGA) articulation used to target cameras to build up panoramas of surrounding terrain
- Science measurements on surface and in flight
  - Aerial imaging
  - Atmospheric profiles



Rotorcraft Lander
Surface configuration with HGA deployed

Mission Timeline and Exploration Strategy

- “Leapfrog” exploration strategy to scout future landing sites
- 16-day Titan Tsols → relaxed operations schedule
  - Most of time is spent on the surface making science measurements



Reliability Engineering

- At JHU/APL, Reliability Engineering (RE) is a system engineering function
  - Reliability is the probability that an item performs its intended function for a specified time interval under stated conditions
  - System reliability is achieved through the creation of a robust design and the discovery, elimination, and avoidance of defects through a rigorous assurance process consisting of a set of well-defined closed-loop activities performed over the life of a flight project
- “Do reliability engineering”
  - There is no reliability number requirement, NASA focuses on reliability practices and assessments
  - Dragonfly Reliability Requirements are defined in the project level documentation and those requirements are referenced in the Reliability Plan

Reliability Engineering

- Dragonfly is a Class B mission
  - NPR 8705.4A "Risk Classification for NASA Payloads"
- FMEA/CIL: At black box (or circuit block diagram) level as a minimum; Scope further refined by Project needs
  - Functional FMEAs, Interface FMEAs, GSE FMEAs
  - Produced to support Fault Management design team
- Tailored PRA: "Limited Scope" focusing on mission-related end-states of specific design decisions and trade studies
  - Fault Tree Analysis (FTAs) developed as part of PRA

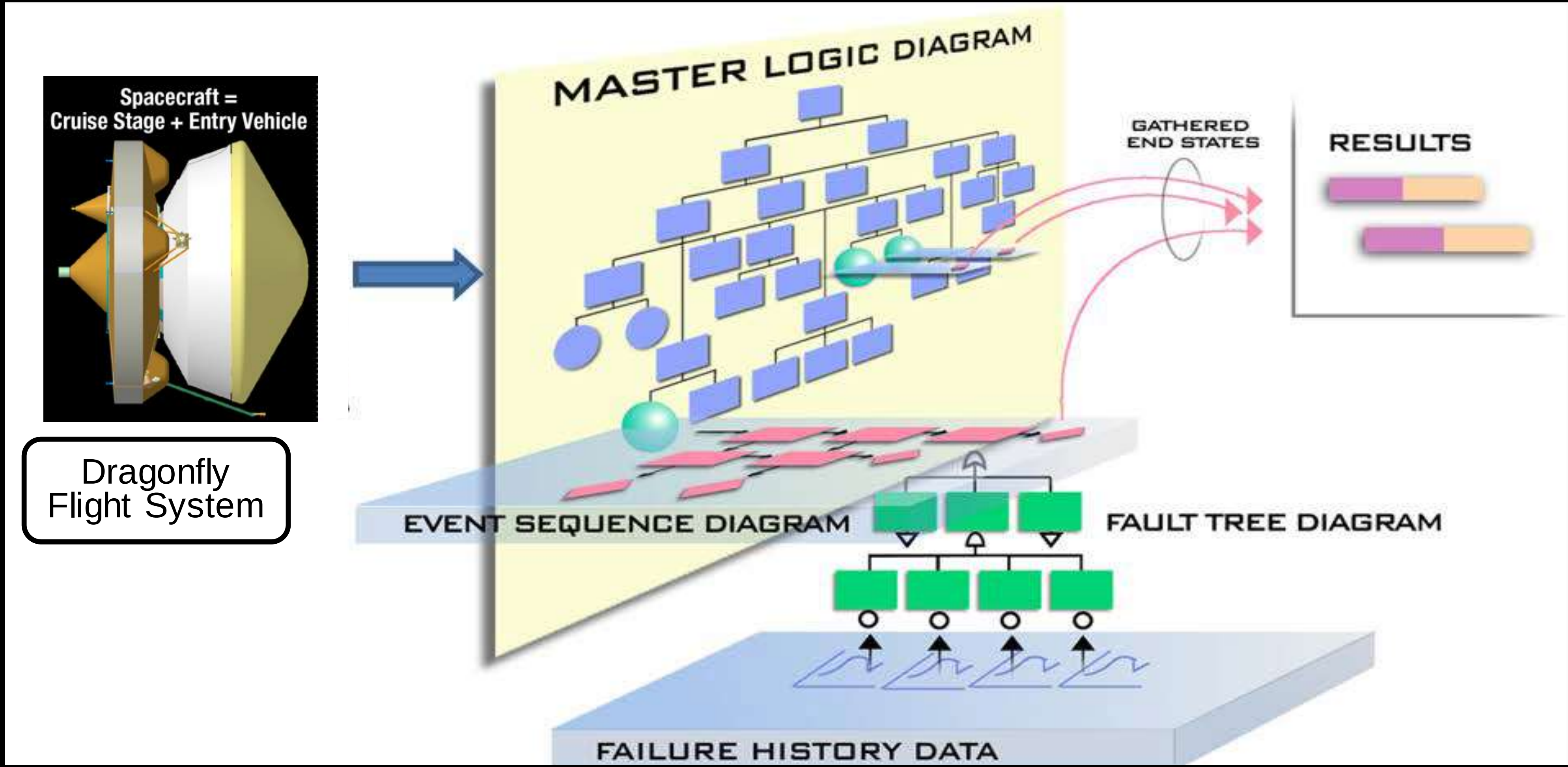
Reliability Engineering

- EEE Parts Selection process – Further defined by SMEs and Project level decision makers
  - Per the Dragonfly Parts Control Plan (PCP), Dragonfly is a Level 2 parts program
- Worst Case Analysis (WCA)
  - Developed by the design teams for all parts and circuits that have a severity category of 1 or 2
  - A two-step process will be implemented: First, there will be a screening process consistent with an Extreme Value Analysis, and then a Monte-Carlo approach where the EVA shows no margin
  - WCA does not apply to COTS hardware

Reliability Engineering

- Additional reliability analyses
  - Parts Stress Analysis
  - Reliability Analysis of Test Data
  - Identify Limited Life Items and Limited Shelf Life Material
- Expertise for a given assessment rests across multiple groups
  - Design Lead, Components Engineer, Reliability Engineer, Radiation Engineer, System Mission Assurance Manager

Probabilistic Risk Assessment (PRA)



Watch Items

- Single point failures items (including Common Cause Failures)
  - Many normal items (structure, tanks, etc..)
  - Instruments needed for ground operations
  - Trades between mass and redundancy
- Long cruise duration
- Entry, decent, and landing
  - Many events need to occur in succession
- Environmental uncertainty
  - Cruise is very well understood
  - Atmospheric uncertainty affects on EDL
  - Surface environmental affects of instruments, flight and communications


DRAGONFLY
http://dragonfly.jhuapl.edu