Titan Sample Return

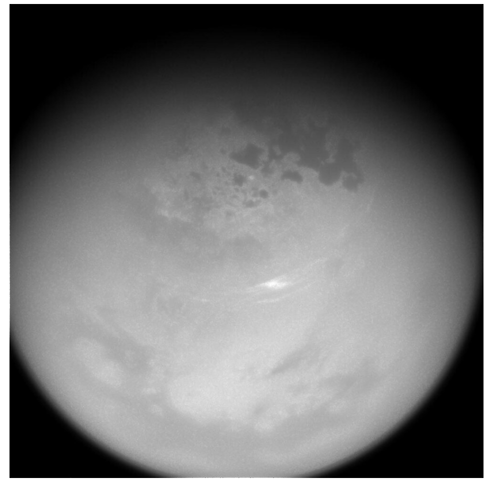
Caltech Space Challenge 2022

1. Background[1]

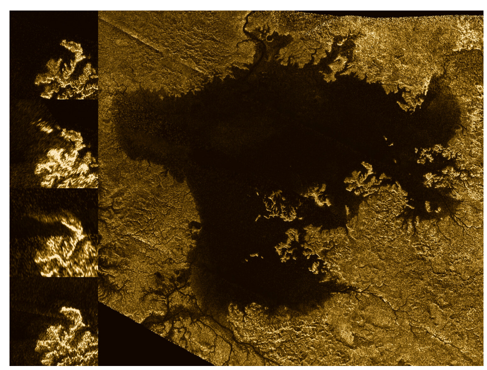
The search for life is one of the main drivers behind planetary exploration, motivating our continued interest in Mars as well as bodies such as Europa, Enceladus, and Titan. Presently, most efforts are focused on the presence of liquid water underneath the surface of satellite bodies in the solar system. For the Caltech Space Challenge 2022, our approach will be different - we will analyze liquid lakes on the surface of Titan using state- of-the-art scientific equipment.

Titan has several qualities that make it a unique candidate worthy of exploration in our search for life within the solar system. Besides Earth, Titan is the only other planetary body where there is clear evidence of stable bodies of surface liquid as well as subsurface oceans. The only difference is that these lakes contain methane and ethane. This means that Titan has an active methane-based hydrologic cycle. Titan's methane-based hydrologic cycle is analogue to Earth's water cycle, which suggests that a different type of life form, based on methane instead of carbon, may exist. These life forms would inhale hydrogen instead of oxygen and exhale methane instead of carbon dioxide.

In addition to this, it is the only moon in the solar system with an atmosphere that consists of more than just trace gases. It is made up of nitrogen, methane, and small amounts of carbon-rich compounds. This is similar to the early history of Earth, where instead of oxygen, the atmosphere consists of methane. Furthermore, in the upper layers of Titan's atmosphere, methane and nitrogen molecules are decomposed by the sun's UV rays and recombined into several organic chemicals, including oxygen and nitrogen. These elements are essential to life as we know it.



Clouds above the hydrocarbon lakes in the north polar region of Titan are visible in this image captured by the Cassini spacecraft. Image credit: NASA / JPL / Space Science Institute



These images from the radar instrument aboard NASA's Cassini spacecraft show the evolution of a transient feature in the large hydrocarbon sea named Ligeia Mare on Saturn's moon Titan. Image credit: NASA/JPL-Caltech/ASI/Cornell

[1] This section is copied from Caltech Space Challenge 2022 Website. Refer to the website for more information.

The complex chemistry and similarity to an early Earth make Titan a prime candidate for exploration on our quest in search of life in the solar system.

2. Objective[2]

The Caltech Space Challenge 2022 mission will include a sample return of the surface liquid in addition to in-situ measurements to enable a detailed analysis of the samples. The students will have to decide how to collect the sample and how to safely contain it for their ascent from Titan and the return journey back to Earth. To design the optimal mission concept, the students will have to be creative and work on questions such as orbital trajectory, power management, communication, sample integrity, and economic feasibility.

3. Science Requirements

As part of this activity, you are responsible for deriving the science requirements for the mission based on what is published in this RFP, NASA Strategic Roadmap, Planetary Decadal Survey, and published scientific journals with high citations related to the importance of science at Icy Moons of Solar System including Titan. You must develop a Science Traceability Matrix for this RFP. The details and format of STM will be shared in the class.

The proposal must submit detailed payload instruments, mission design, and spacecraft configuration that comply with the science objectives and the Design Requirements stated in the next section.

4. Design Requirements

The proposed design must comply with the following requirements and constraints:

i. The spacecraft *shall* provide the capabilities for responding to the science objectives developed in section 3.

ii. The project *shall* return the sample and all science data to Earth no later than December 2045.

iii. The mission design *shall* address all required maneuvers and corrections to the orbit.

iv. The mission *should* provide a schedule for all major science experiments, with necessary power profile, and data communication requirements. The vehicle *shall* meet these requirements.

v. The project cost including mission operations *should not* exceed **$5B** (in FY21).

5. Deliverables

The design team must specify the payload and spacecraft configuration(s) and mission design(s).

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The spacecraft may be launched in any suitable window prescribed by the properties of available launch vehicles from the world's spacefaring nations (including NASA's SLS) and the requirements of the spacecraft mass and orbit.

The design team will specify the extreme operating conditions (e.g., temperature, radiation exposure) of the vehicle in the environments it will pass through and operate within. Systems for command, control, communication, and data storage and transmission will be specified. The requirements on and characteristics of the power system, thermal protection systems, tracking and positioning systems, any unique systems, etc., required for operations shall be specified. Indicate any needs for planetary protection protocols and their influence on designs.

The design team will prepare and provide a 3-view layout of the proposed vehicle(s). Provide the configuration of all systems and their placement on the structure, including both engineering and science subsystems. Masses for structure, piping, and cabling should be noted, as well as tank capacity and total dry and wet masses as appropriate. Power requirements for all engineering and science subsystems should be compiled.

A cost analysis must be provided for the project from initial design, fabrication, and testing, through launch, flight, and data return. It should contain both hardware (including launch vehicle and adapter) and flight and ground system software, planetary protection protocols, and data archiving in the Planetary Data System.

Estimate costs for interplanetary cruise operations and then science operations. Flight operations costs should also include add-on estimates of science acquisition costs during any gravitational assist flybys or targets of opportunity during the cruise phase including potential asteroid flybys or unexpected targets of opportunity including, for example, the flyby of an asteroid or the appearance of another comet or a supernova.

The following is a list of information to be included in the final report. Students are free, however, to rearrange the information in a clear and logical way.

1. **Motivation and Objective** - should include the goals and objectives of the mission.
2. **Requirements Definition** - should consist of the science requirements, mission requirements, and design requirements at the mission, system, and subsystem level.
3. **Trade Studies** - should consist of trade studies for the mission architecture and mission operations.
4. **Concept of Operations** - a detailed concept of operations should be added to describe all phases of the mission and to demonstrate the realization of the science requirements set in section 3.
5. **Design Integration and Operation** - should discuss how the trades are integrated into a complete package. This section should discuss the design of all subsystems: structures, mechanisms, thermal, attitude control, telemetry, tracking, and command,

electric power, propulsion, scientific payload, and sensors, interface with the launch vehicle, and mission concept of operations. A mass and power budget should be included, broken down by subsystem, with appropriate margins. The ground system proposed for operation shall also be included. A summary table should be prepared showing all mass, power, and other resource requirements for all flight elements/subsystems with appropriate PDR-level margins.

6. **Cost Estimate** - a top-level cost estimate covering the life cycle for all cost elements should be included. A Work Breakdown Structure (WBS) should be prepared to capture each cost element, including all flight hardware, ground systems, test facilities, and other costs. Estimates should cover design, development, manufacture, assembly, integration and test, launch operations and checkout, in-space operations, and disposal/decommissioning. Use of existing/commercial off-the-shelf hardware is strongly encouraged. A summary table should be prepared, showing costs for all WBS elements distributed across the various project life cycle phases.
7. **Schedule** - a mission development and operation schedule should be included. Schedule margin should be applied to appropriate areas with funded schedule reserve detailed in the cost estimate.

6. Basis for Judging

1. **Technical Content (35 points)**
   This concerns the correctness of theory, validity of reasoning used, apparent understanding and grasp of the subject, etc. Are all major factors considered and a reasonably accurate evaluation of these factors presented?
2. **Organization and Presentation (20 points)**
   The description of the design as an instrument of communication is a strong factor on judging. Organization of written design, clarity, and inclusion of pertinent information are major factors.
3. **Originality (20 points)**
   The design proposal should avoid standard textbook information, and should show the independence of thinking or a fresh approach to the project. Does the method and treatment of the problem show imagination? Does the method show an adaptation or creation of automated design tools?
4. **Practical Application and Feasibility (25 points)**
   The proposal should present conclusions or recommendations that are feasible and practical, and not merely lead the evaluators into further difficult or insolvable problems.