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NASA Dragonfly Mission MMRTG

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Changing the World's Energy Future

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Idaho National Laboratory

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What is Dragonfly

Dragonfly is a NASA New Frontiers mission, led by the Johns Hopkins Applied Physics Laboratory (APL), to explore Titan a moon of Saturn. Dragonfly, a dual-quadcopter the size of a compact car (concept shown in Figure 1), will leverage Titan's thick nitrogen atmosphere that is 60% more dense as the Earth's and 1/7th of Earth's gravity to fly to dozens of sites on Titan's diverse surface over its three-year mission.

INL is responsible to deliver the MMRTG to Kennedy Space Center and assist APL in integrating the MMRTG to the lander for a 2027 launch. Dragonfly will arrive at Titan in the mid-2030s, descend through the atmosphere, drop away from the parachuting backshell, and fly to a safe landing zone. Unlike descent to Mars which takes 7 minutes, the descent phase to Titan will take 90 minutes due to the thick atmosphere.

The MMRTG will provide electric power to recharge the large battery pack during Titan's 192-hr night (8 Earth-days). Each exploration flight will traverse 14 km and return to a pre-determined safe landing site approximately 7 km from the takeoff site. In this way, Dragonfly will leapfrog along the surface surveying perspective landing sites before returning to a known safe landing site.

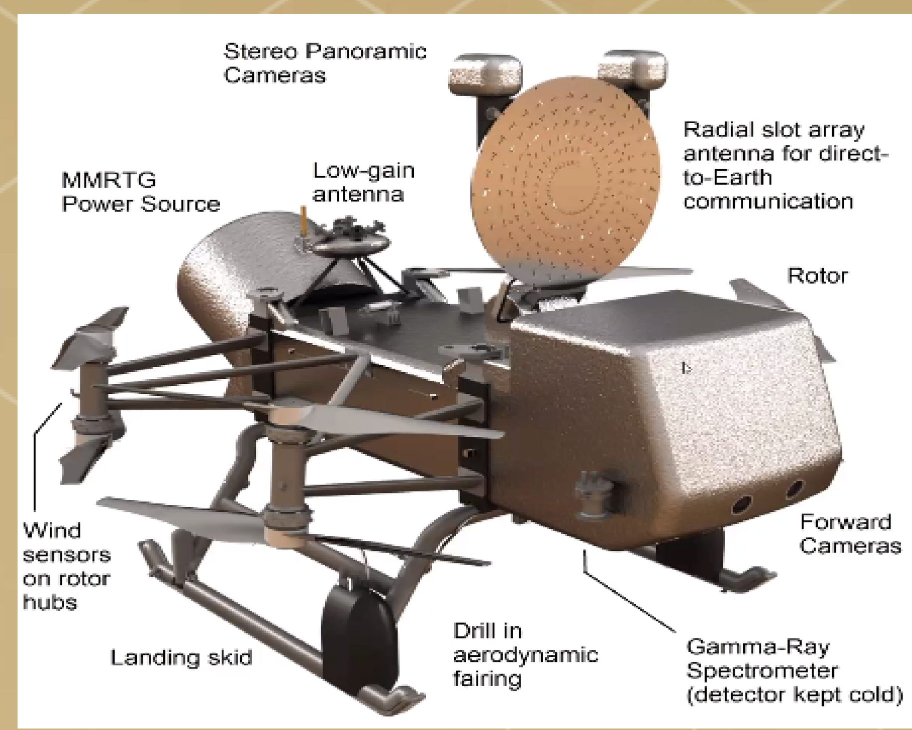

Figure 1. Dragonfly Lander concept

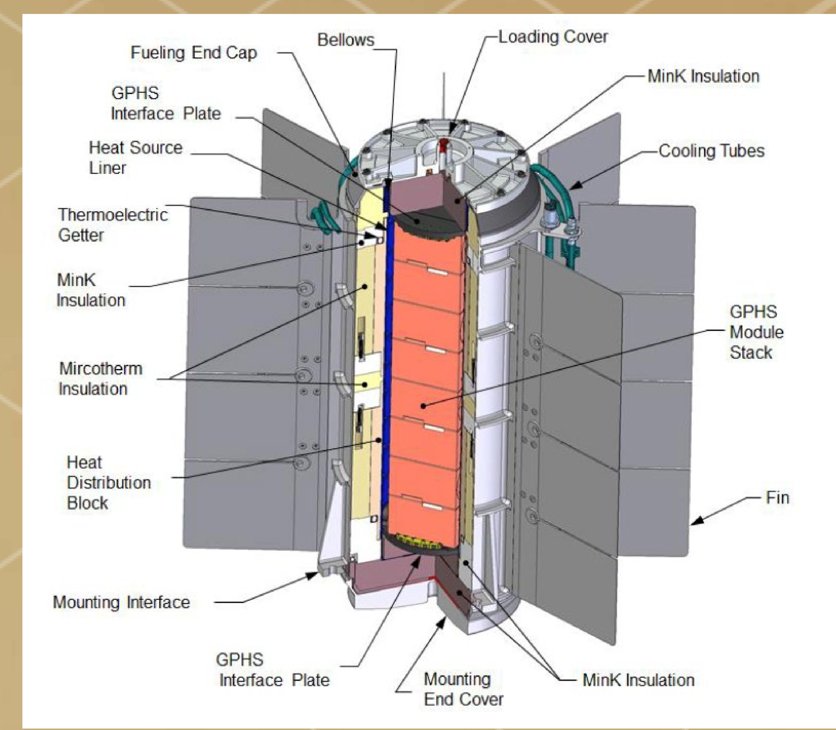

Figure 3. MMRTG components

Why Titan

Titan had been previously observed by the Voyager spacecraft in 1979 and 1980; but due to the thickness of its atmosphere most of the moon could not be viewed. Cassini mapped much of the moon and studied the atmosphere using infrared imaging. It even delivered the Huygens probe which landed in 2005 but only lasted about 2.5 hours before depleting its battery. The Hubble Space telescope has also imaged Titan. All observations to date point to a liquid water ocean core over a thick water-ice crust (see Figure 2). Due to the extreme temperatures (-290°F or -180°C), the surface has liquid methane, rain, rivers and lakes like Earth's water cycle. The rich hydrocarbon environment combined with liquid water may harbor prebiotic organic compounds.

Dragonfly will use the following on-board science package to perform key scientific observations:

- Mass spectrometry of surface material
- Neutron activated gamma spectrometry
- Meteorology
- Visual imaging
- Seismic detection

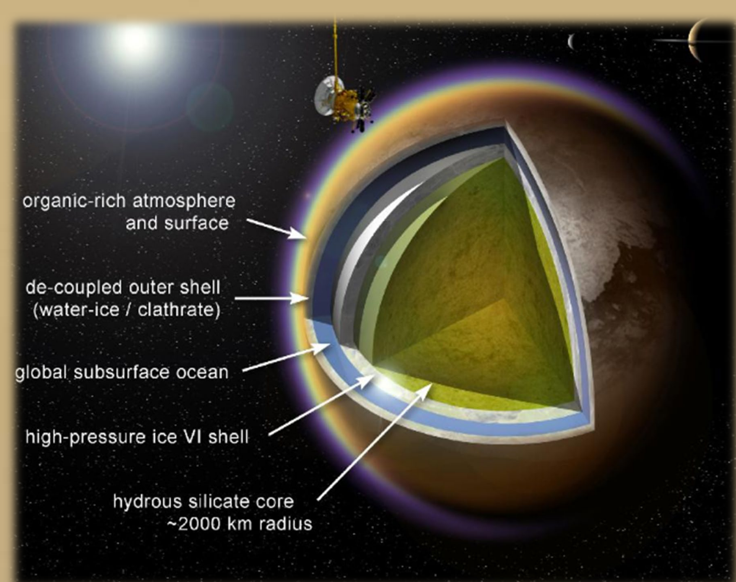

Figure 2. Titan Surface Layers

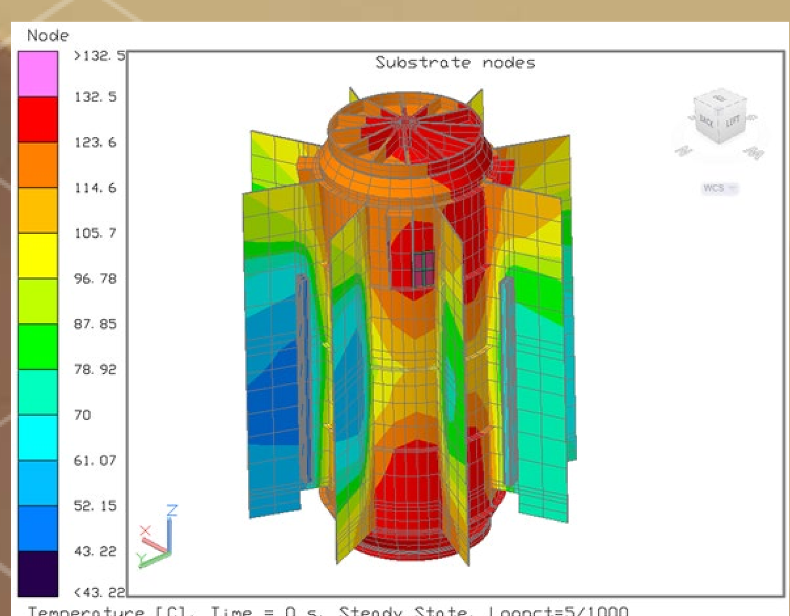

Figure 5. CFD modeling of shorter fins

MMRTG Overview

The MMRTG is the current state of the art RPS designed to provide a robust power system capable of operating in remote, harsh environments (e.g., deep space or extreme cold) where more conventional electrical power sources such as chemical batteries or photovoltaic panels cannot provide sufficient power without significant engineering trade-offs. The basic characteristics of an MMRTG, including the basic performance, weight, and dimension specifications, are listed in Table 1. Beginning of Mission is defined as the launch date of the spacecraft from Earth.

The MMRTG (Figure 3) converts thermal energy from the radioisotope heat source ($^{238}PuO_2$) to usable electricity and provides waste heat for spacecraft use. Electricity is generated within the MMRTG from a series/parallel combination thermoelectric elements that produce a micro voltage when exposed to a temperature difference. Simply stated, the larger the temperature difference, the more power produced.

The main interfaces with a spacecraft/lander are thermal, electrical, and structural as shown in Figure 4.

Table 1. MMRTG characteristics

Parameter	Nominal MMRTG
Output Voltage	22 to 36 Vdc
Electrical Power	110 W_e BOM
Waste Heat	2000 W_{th} BOM
Mass (w/o cooling tubes)	45 kg
Length	69 cm
Width (fin to fin w/ std fins)	65 cm

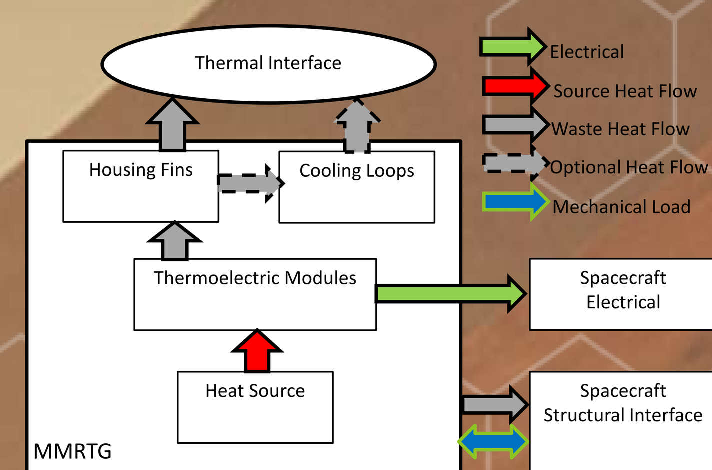

Figure 4. MMRTG interfaces

MMRTG Modifications for Dragonfly

Several possible MMRTG modifications were studied and traded. The higher-pressure atmosphere of Titan (1.5 Bar) may cause more atmospheric gases to enter the heat source cavity through the helium permeation gasket which could damage the high temperature components inside. The heat source cavity internal getters were increased to address any uncertainty and retire the risk of any atmospheric intrusion. The additional mass of these getters was about 33 g.

Dragonfly is encased in a foam insulation to retain heat generated from the MMRTG. A trade study of the MMRTG fin length using SINDA Fluent CFD modeling is shown in Figure 5. A fin length of 50% of the original heritage MMRTG design was chosen which provided the optimum length for use on the lander while retaining passive cooling for capabilities for ground testing and handling. The resulting fin length reduction reduces the system mass by 1.2 kg and width (fin to fin) to 49 cm.

The cooling tubes on the external surface of the housing comprise of a primary and secondary loop. The primary loop is used by the spacecraft during cruise. The secondary loop is used during spacecraft integration and could be used during lander operations. The cooling tubes were evaluated to increase the diameter to improve the pressure drop through the system while minimizing weight resulting in a side-by-side cooling system design vs the heritage over-under design. In addition, the fittings were also changed to a Beam Seal style as a lessons learned improvement. The mass increase for the cooling tube changes is approximately 1.6 kg.

Figure 6 shows the differences between the Dragonfly MMRTG and the heritage MMRTG. There were no design changes to the housing or thermoelectric modules. The cumulative mass change for the Dragonfly MMRTG is 0.4 kg.

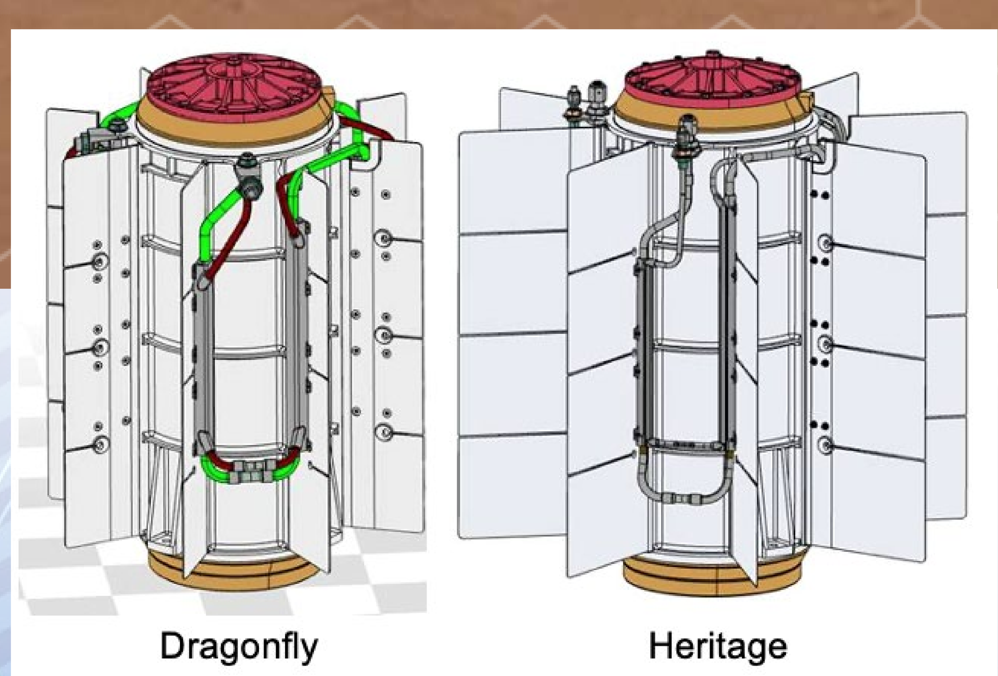

Figure 6. Comparison of MMRTGs

MMRTG Fabrication Status

The Dragonfly MMRTG fabrication began, under an INL managed contract, at Aerojet Rocketdyne and their supplier Teledyne Energy System in FY21. Table 2 shows the key deliverable dates for the Dragon mission MMRTG. The focus of FY21 and FY22 was to produce the sixteen 48-couple thermoelectric modules (Figure 7) needed for the flight unit and to review and update procedures and specifications as it had been nearly 10 years since fabrication of the last MMRTG.

Machining of the housing and fins for two MMRTG simulators (TSIM and DSIM) as well as the flight unit were completed in FY23 after the trade studies were completed to identify Dragonfly specific changes. At the end of FY23 the fins were welded onto the TSIM and the flight unit (Figure 8). The DSIM will finish fin welding in FY24.

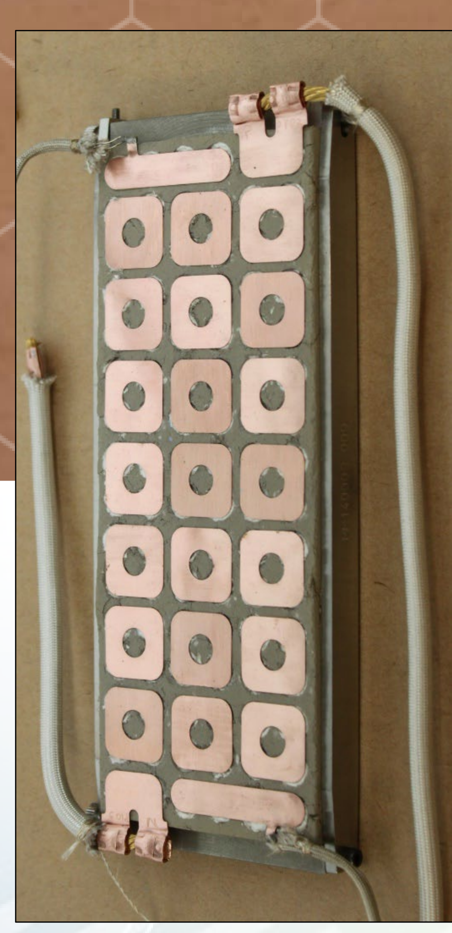

Figure 7. Completed 48-couple thermoelectric module

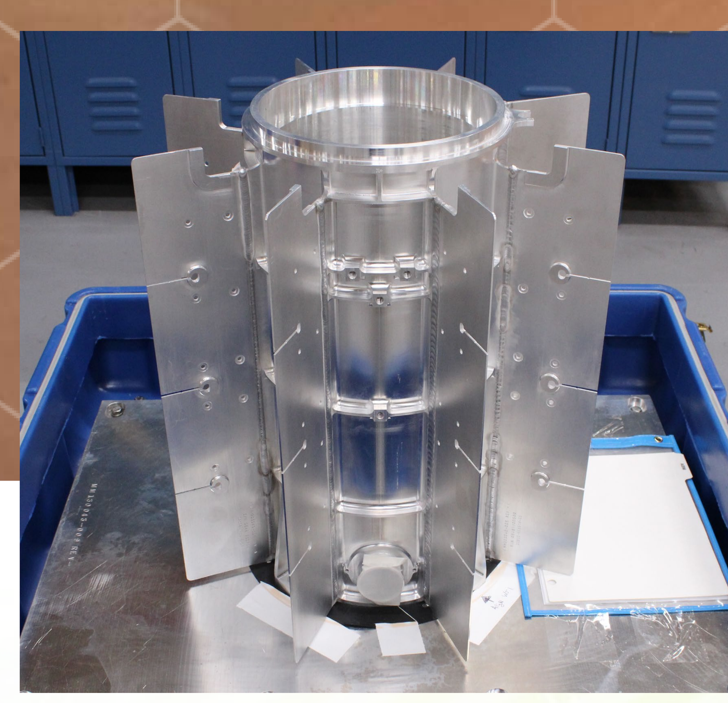

Figure 8. MMRTG Housing after fin welding

Table 2. Key MMRTG Deliverables for Dragonfly

Key Deliverable	Date
Thermal Simulator (TSIM)	9/2024
Dynamic Simulator (DSIM)	9/2024
F4 (ETG delivered to INL)	9/2025
Go, No-Go fueling mission pole	6/2026
Fueling and acceptance testing	6/2026 – 12/2026
Launch	6/2027

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy
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