Deep Dive: A Saturn Probe with In-Situ Power

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Abstract

Probes into the atmosphere of the gas giant planets, Jupiter and Saturn, and the ice giants, Uranus and Neptune, are identified as high-priority science missions by the NASA planetary science decadal survey. Jupiter and Saturn have complex and interesting atmospheres, with structures exhibiting wind motion on all scales, as well as a complicated structure of colored clouds. To date only a single probe has entered the atmosphere of a gas giant, the Galileo atmospheric probe. Temperature and pressure are the major considerations for the depth into the atmosphere which can be achieved. The Galileo probe penetrated to a depth of 134 km below the 1-bar level of Jupiter; failing at a pressure of 22.7 atmospheres, when the probe reached a temperature of 152°C.

Due to Jupiter's deep gravity well, the Galileo probe achieved the highest velocity of any atmospheric entry, 47 km/second. Saturn's gravity well is only slightly less deep, with a V_∞ of 35.5 km/sec.

The mission science objectives include magnetic fields, atmospheric isotopic composition and particulates), temperature, and atmospheric motion. A top-level reason for choosing Saturn as the baseline target for the conceptual design is that it is less well probed and less well understood than Jupiter, and was listed as one of the five top priorities for a medium-sized planetary mission in the most recent NASA Planetary Science Decadal survey

At atmospheric probe will require power. For many probes, this power is provided by solar arrays or by batteries. However, at Saturn the solar intensity is about 1/100th that of that available at Earth, and the probe will descend through clouds, which will limit sunlight even further. For battery power, the battery mass will increase proportional to the desired probe lifetime. Alternately, a probe descending through an atmosphere releases gravitational potential energy, E = mgh (where E is the gravitational potential energy, m the mass of the probe, g the gravitational constant, and h the height above or below a reference altitude). In this case, we will harvest the energy released as it descends to power the probe.

The power available at a descent velocity V is:

$$P_{descent} = dE/dt = mgV$$

For Saturn's gravity, g=10.44 m/s^2 (about 6% higher than Earth's), and hence the power per unit mass available is 10.4 V W/kg. For an example probe of 100 kg mass descending at 10 m/s, the available descent power is a kilowatt.