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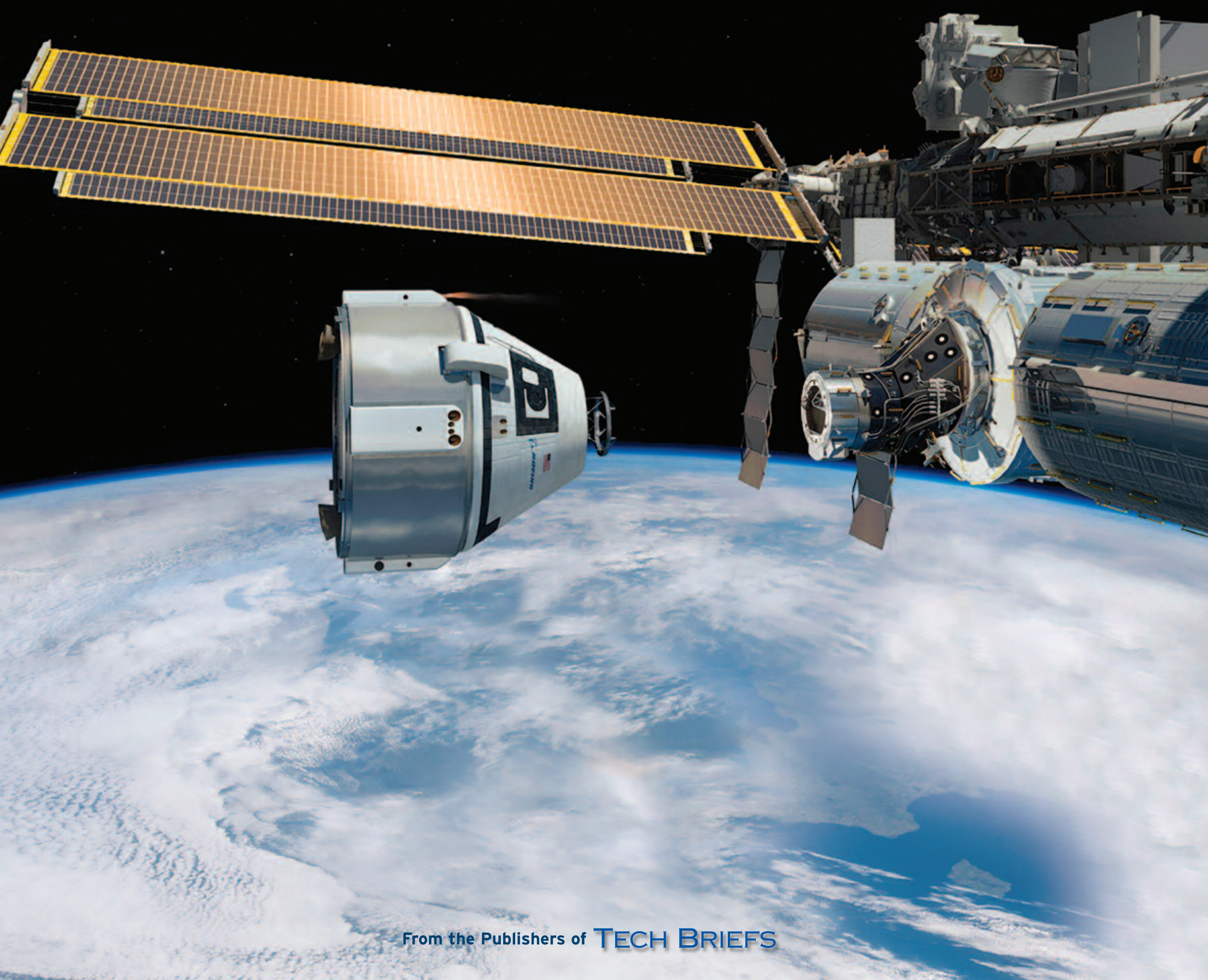
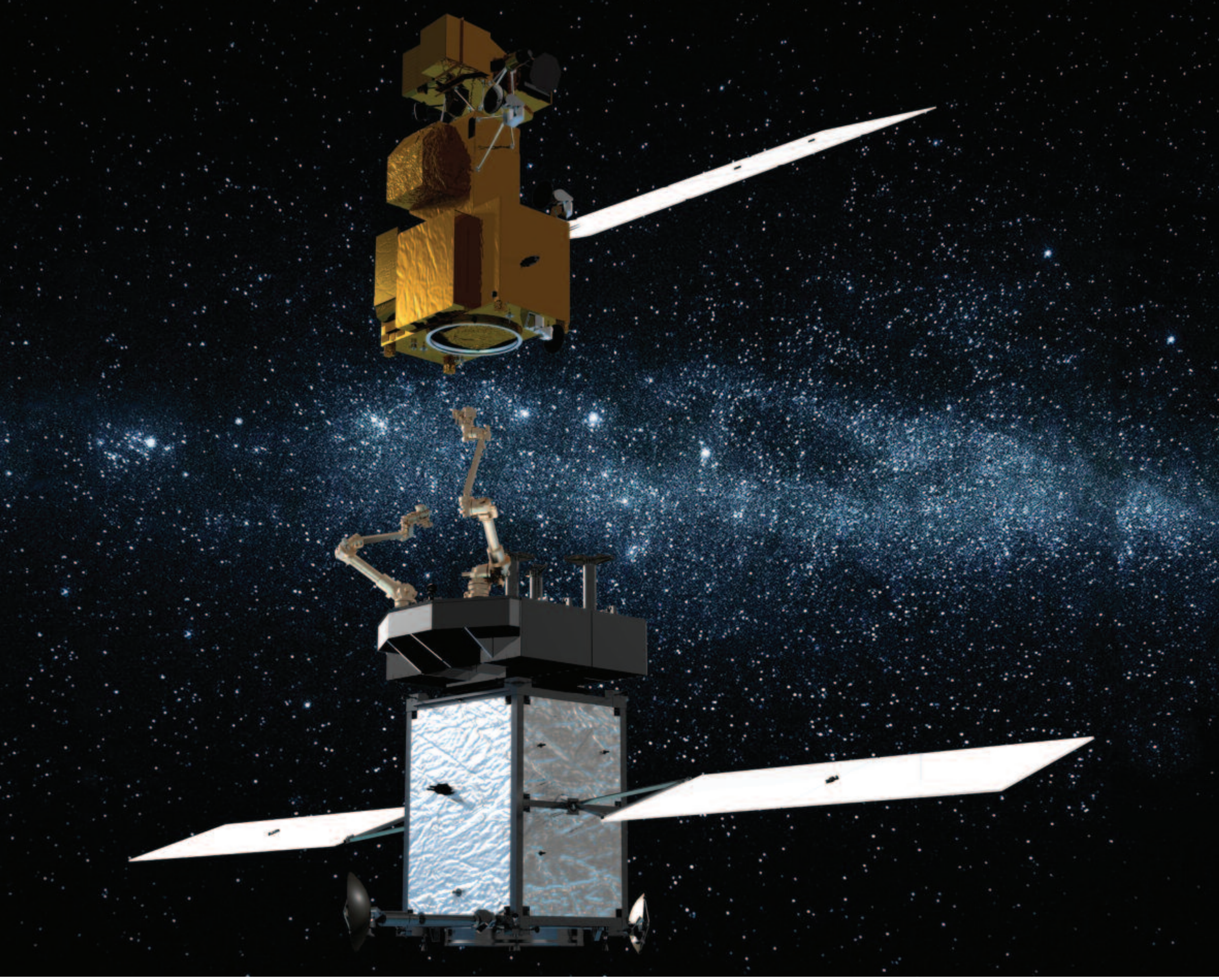
On-Orbit Satellite Refueling Flow Measurement



From the Publishers of TECH BRIEFS

On-Orbit Satellite Refueling Flow Measurement

The Path from Concept to Operational Status



Over 7000 satellites have been placed in Earth-orbit since the beginning of the space age. 3000 are currently in orbit, of which 1000 are active, making our near space neighborhood a pretty crowded place. Now, plans are in motion to launch constellations of globe-girding communication satellites that will number in the thousands to provide worldwide internet connectivity. This is in addition to the ever-expanding constellation of LEO, geo synchronous and geo stationary satellites. Clearly, the number of satellites in orbit is on a trajectory of significant growth and we are approaching a point when the economics will demand longer life from these expensive assets just as the costs to put them in orbit continue to fall. NASA's Restore-L mission, under the direction of the Agency's Satellite Servicing Projects Division (SSPD) headquartered at the Goddard Space Center, is a major step towards realizing key technologies needed to provide in-space satellite servicing in order to increase on-orbit asset life.

Restore-L

In 2020, years of research, development and testing of different technologies by NASA will culminate in the launch of an unmanned vehicle named Restore-L that will rendezvous with the US Geophysical Service's Landsat 7 satellite. Restore-L, once in close proximity, will execute an autonomous capture of the satellite, secure it, perform a complex refueling operation, re-secure the fueling port and then release Landsat-7 back into orbit. With this mission Restore-L will bring servicing technologies to operational status and NASA will make them available to all interested domestic entities through a technology transfer strategy so that licensees may build their own servicers. In this way, NASA is jumpstarting a commercial satellite servicing industry that will be a valued asset for the nation's burgeoning space economy.

The Restore-L vehicle contains five distinct technology packages developed for this task including:

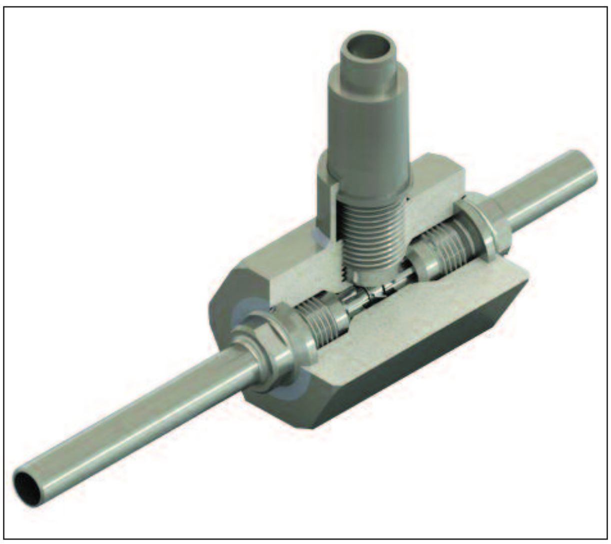
(1) a relative navigation system,
(2) servicing avionics and software,
(3) a purpose-built robotic system,
(4) a tool drive system and special tools and
(5) the fluid transfer system that contains and will deliver the hydrazine replenishment fuel.

The myriad individual tasks that must be precisely performed by the vehicle, including several autonomous ones, are made even more complex by the fact Landsat 7, like every other satellite now in orbit, was never designed to be refueled after launch.

Liquid Turbine Flowmeter

One critical tool on Restore-L to execute and document the mission's performance will be a small custom-designed liquid turbine flowmeter supplied by Hoffer Flow Controls, Inc. For 30+ years Hoffer has supplied NASA with dozens of high-precision turbine flowmeters used in applications ranging from cryogenic fluid flows, fuel flows for full scale rocket engine and engine component testing, and for high-altitude testing payloads launched on sounding rockets. Despite this legacy, the Restore-L mission represents the first time Hoffer will be supplying on-orbit flight-qualified flowmeters to NASA.

The scope of supply includes two turbine flowmeters for qualification, one engineering test unit (ETU), and two for flight. The flight turbine flowmeter will be incorporated into the fluid handling technology system on the vehicle. Other components of this system include the fuel storage tank, the flow and pressure control valves, the delivery umbilical hose assembly and the fueling nozzle assembly that will be attachable to and maneuvered by the vehicle's robot arm. The Kennedy Space Center, working under the direction of Goddard, has responsibility for the design and qualification of the fluid transfer system. A quick connect external fueling valve known as the Cooperative Servicing Valve (CSV) developed by the Goddard Space Flight Center completes the technology suite and will be attached via the same robotic arm to the satellite prior to the start of fueling.



Cutaway rendering of the Restore-L hydrazine refueling flowmeter. (Courtesy of Hoffer Flow Controls, Inc.)

Turbine flowmeter technology was selected by NASA following a rigorous testing and vetting process. The final choice came down to a turbine meter solution or a mass coriolis flowmeter solution. Both technologies showed the ability to make the measurements at the requisite accuracy. Turbine flowmeter technology was selected due to a longer flight legacy as well as a higher degree of confidence in adapting its requisite electronics for space flight within the mission's schedule.

Hoffer's design includes a one-piece radial turbine rotor mounted on miniature precision hybrid ceramic ball bearings. This style bearing has been in use since the 1980's with great success in a wide range of applications including cryogenics and hypergolic fuels. The hybrid ceramic bearings and the basic radial rotor design have previously been shock and vibration qualified in multiple military naval and aircraft applications and used in thousands of such installations. The flowmeter carries a maximum flow rate capacity of 11.3 LPM with a nominal accuracy of +/-0.5%.

The spin of the ferromagnetic rotor caused by the fluid passing through it is detected by a variable reluctance or RF type pickup sensor that is threaded part way through the wall of the central portion of the flow meter body, but does not penetrate into the fluid path. The pickup sensor is equipped with an integral signal conditioning circuit to amplify the RF frequency signal into a higher level square wave frequency pulse output. One pulse is generated for each blade tip of the rotor passing through the sensor's RF field creating a change in both signal frequency and amplitude.

The body consists of a center section and two inserts that thread into either end of the center section. The inserts are each made in a single piece construction with weld-prepared tubes stubs extending out each side to mate with the vehicle's piping. To prevent fuel leaks the two inserts are initially installed into the center section using fine threaded male/female connections. The ends of the inserts that fit into the center section also incorporate tapered ends that form a metal-to-metal seal with counter tapers in each end of the center section. This connection has been successfully pressure tested to 3.5-times the proof pressure specified for the flowmeters. In addition to this primary fluid seal, the inserts will also be welded to the center meter body to provide positive retention and serve as a secondary fluid seal.

The pickup sensor presented some of the most complex design issues. The design concept of an RF sensor combined with an integral amplifier circuit is one Hoffer has successfully used for many years from its sub-supplier, Motion Sensors, Inc. (www.motionsensors.com). The specific demands for electronic circuitry for use in space flight and the delivery schedule led to a decision to use the experience and resources of the Goddard Space Center in flight qualified electronic circuit design and construction to provide critical support to the supply of the circuit in collaboration with Motion Sensors. The boards will be assembled by Goddard using flight qualified components from its extensive inventory. The sensor element assemblies and final integration will be by Motion Sensors.

At the time of writing (July 2017), the mechanical elements of the qualification units were approaching completion, to be followed by a series of pre-assembly fitting, pressure sealing and calibration tests. Design of the pickup sensor was completed and assembly of the qualification and ETU versions was underway. Third-party qualification testing was scheduled for the summer of 2017 to be interspersed with multiple calibration/functionality rechecks of the units at Hoffer. Final delivery of the flight units to Goddard is scheduled for the first calendar quarter of 2018.

The Future

The goals of the Restore-L mission include:

Center section and insert of the Restore-L refueling flowmeter pickup sensor.

(1) a practical demonstration of the five individual technology suites,
(2) successful demonstration of satellite refueling using unmanned vehicles,
(3) generate interest in licensing of the technology suites by private industry with the aim of creating a vigorous, domestic satellite servicing industry and
(4) provide tools to be incorporated into future satellite designs to better facilitate the refueling process such as the docking decals and the CSV, collectively known as the Cooperative Servicing Aids.

These advancements would, in all probability, lead to the development of various standards in the future as the need for in-space satellite servicing increases and the application of these technologies proliferate.

As to the future of flow measurement related to satellite servicing, additional fuel applications will need to be addressed. These would include cryogenic fuels and Xenon. Turbine flowmeters are very capable of measuring all of these fuels and possess the scalability to meet a wide range of flow rates, temperatures and pressures. More satellite specific tasks such as parts replacement are likely to be a part of the future as well. Restore-L, however, is the trailblazer that integrates years of research into one cohesive design to reach the first critical milestone of autonomous satellite refueling.

This article was written by Robert D. Carrell, President, Hoffer Flow Controls, Inc. (Elizabeth City, NC). For more information, visit ***http://info.hotims.com/65855-503***.

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