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MarCO: CubeSats to Mars in 2016

Andrew Klesh, Joel Krajewski
Jet Propulsion Laboratory
4800 Oak Grove Ave, Pasadena, CA, 91109; 818-354-4104
andrew.t.klesh@jpl.nasa.gov

ABSTRACT

In March of 2016, the InSight lander will launch from Vandenberg Air Force Base to begin a 6.5 month cruise to Mars. Soon after InSight separates from the upper stage of the launch vehicle, the two MarCO CubeSats will deploy and independently fly to Mars to support telecommunications relay for InSight's entry, descent, and landing sequence. These craft will have onboard capability for deep space trajectory correction maneuvers; high-speed direct-to-Earth & DSN-compatible communications; an advanced navigation transponder; a large deployable reflect-array high gain antenna; and a robust software suite. This paper will present preliminary information on the MarCO project, including a concept of operations and details of the CubeSats and subsystem design.

MarCO will open the door for NanoSpacecraft to serve in support roles for much larger primary missions – in this case, providing a real-time relay of for the InSight project. It will also be the first CubeSats to reach deep space, building upon the lessons learned from the INSPIRE project. At only a 6U in size, these craft well illustrate the tremendous capability available in a small package.

And in 2016, CubeSats will reach Mars.

INTRODUCTION

When InSight launches from Vandenburg Air Force Base in March of 2016, two CubeSats will hitch a ride on the aft bulkhead carrier of the Centaur upper stage. These CubeSats, part of the MarCO project, will independently fly to Mars to relay data from InSight to Earth during entry, descent, and landing (EDL).

InSight, like all Mars landers, will travel from interplanetary speeds to landed craft within the well-known "seven minutes of terror". Shortly before this period, the cruise stage will separate from the backshell, revealing the InSight UHF antenna. During EDL, InSight will transmit telemetry data at 8 kbps over UHF. Overhead, the orbiting Mars Reconnaissance Orbiter (MRO) will receive and store this data onboard, but is unable to simultaneously transmit. MRO will immediately pass behind the planet, delaying retransmit of the InSight EDL data for at least an hour.

Simultaneously, the MarCO CubeSats will flyby Mars at an altitude of 3,500 km. Each craft will receive the InSight UHF data, add framing information, and retransmit to Earth, providing a real-time relay for InSight. This technology demonstration will showcase the ability for CubeSats to support larger missions during critical events – a carry-your-own-relay option will be available for future such encounters.

InSight

InSight[1] (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) is a NASA Discovery Program mission that will place a single geophysical lander on Mars to study its deep interior.

But InSight is more than a Mars mission - it is a terrestrial planet explorer that will address one of the most fundamental issues of planetary and solar system science - understanding the processes that shaped the rocky planets of the inner solar system (including Earth) more than four billion years ago.

By using sophisticated geophysical instruments, InSight will delve deep beneath the surface of Mars, detecting the fingerprints of the processes of terrestrial planet formation, as well as measuring the planet's "vital signs": Its "pulse" (seismology), "temperature" (heat flow probe), and "reflexes" (precision tracking).

InSight seeks to answer one of science's most fundamental questions: How did the terrestrial planets form?

Similar to the Phoenix[2] lander, InSight is a fixed lander, traveling via cruise stage from Earth, descending with a backshell and heatshield, and slowing with, first, a

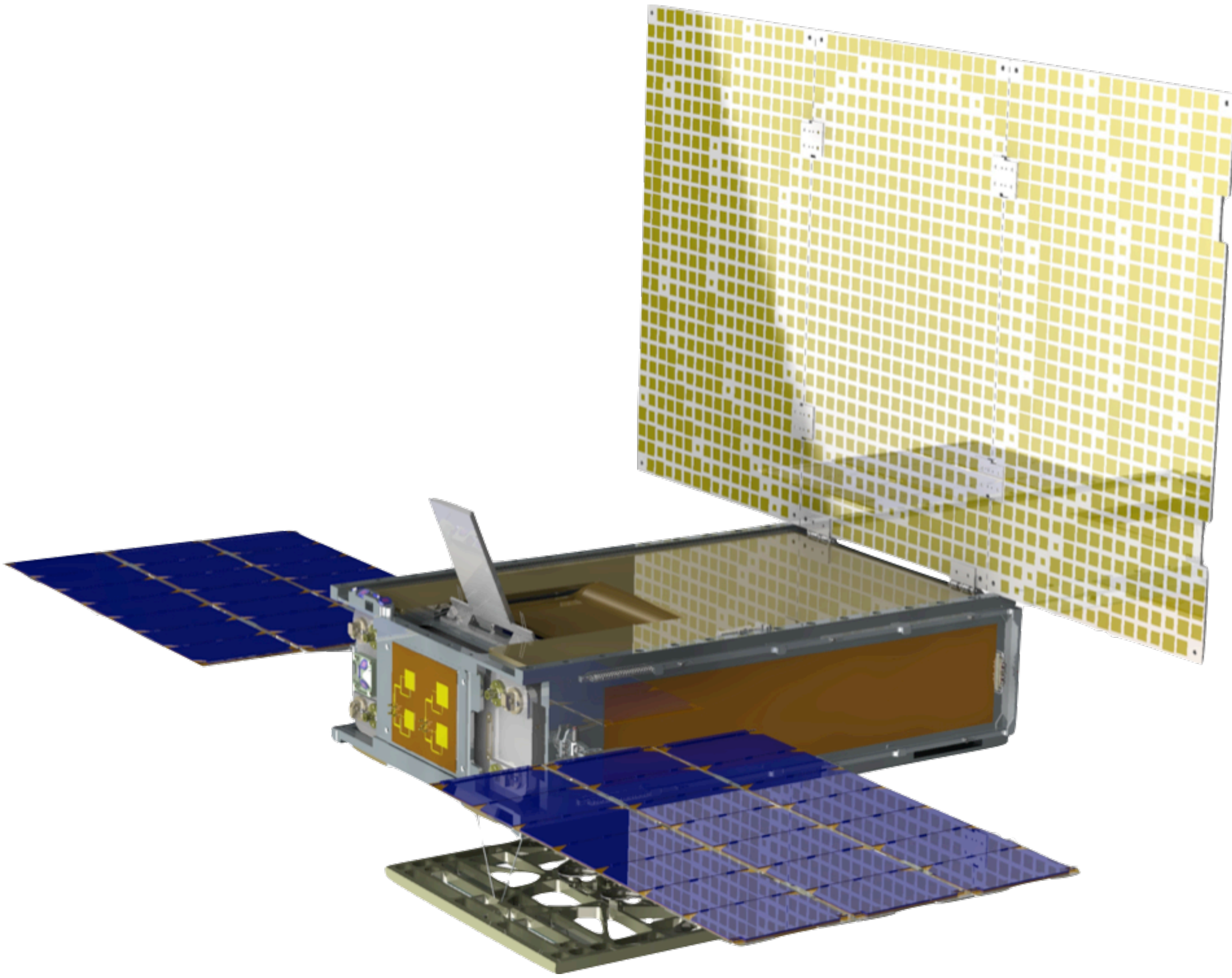

Figure 1 – CAD model rendering of a MarCO CubeSat. The large vertical panel is the high-gain reflectarray, capable of transmitting 8 kbps from Mars to the Deep Space Network's 70m dish in Madrid, Spain.

parachute, and second, rockets, to a soft landing on the surface.

EDL is a critical sequence of events for any landing spacecraft – during this time, the parachute must deploy, backshell separate, landing legs deploy, landing site identified, and rockets fire… all autonomously. Given the hazards of spaceflight (and landing!), data from EDL is prized to continue to improve future EDL opportunities. As well with high-profile and critical events, real-time transmission of EDL data provides both operators and the public a glimpse into the landing.

MarCO will support InSight during EDL, though it is not required for mission success. Each MarCO CubeSat will relay the same data from EDL (identical transmissions for redundancy), but really serve to demonstrate the novel capability of a CubeSat relay.

MISSION CONCEPT

The MarCO CubeSats (illustrated in Figure 1) will launch on the aft bulkhead carrier (ABC) of the Centaur upper stage of an Atlas V-401 in March of 2016. The interplanetary launch window is approximately 30 days long, and for the first time, will occur at Vandenburg Air Force Base, on the west coast. The two CubeSats will be mounted in a Tyvak NLAS Mark II dispensers on the ABC (located well outside the fairing protecting InSight), and will remain completely powered-off during the ascent to orbit.

Approximately 90 minutes after launch, Insight will separate from the upper stage, and soon after, each MarCO CubeSat will deploy via a spring. Several minutes later, the solar arrays will deploy, and the ground control team at JPL will acquire contact via the Deep Space Network (DSN). Each MarCO CubeSat will then stabilize for charging and initial checkout operations.

In the first few days, checkout will include verifying health, onboard systems, power and thermal modeling, and deploying the high-gain and UHF antennas. Approximately a week after launch, each MarCO spacecraft will perform a trajectory correct maneuver (TCM) to align for a Mars flyby some 6.5 months later.

During cruise, navigation and tracking will be performed by the DSN several times per week, and operators will continue to monitor health and prep for the EDL flyby. Additional TCMs will be performed (up to 4 others – see Figure 2) further refining the Mars flyby, and assuring planetary protection requirements are met. With two identical spacecraft, most operations will be performed in series, rather than parallel, as the design allows for a robust schedule up through EDL.

Upon arrival at Mars on September 28, 2016, the MarCO CubeSats will flyby at 3,500 km altitude. Each spacecraft will orient to an inertially fixed position, with the broadbeam UHF antenna pointed toward InSight and the surface and the X-band high-gain antenna (HGA) pointed toward Earth. The EDL sequence will be completed under battery power, as the solar arrays will not be pointed directly at the sun. During EDL, data will be transmitted from InSight at 8kbps. Upon reception, each MarCO CubeSat will retransmit at X-band to the 70m dish in Madrid, Spain.

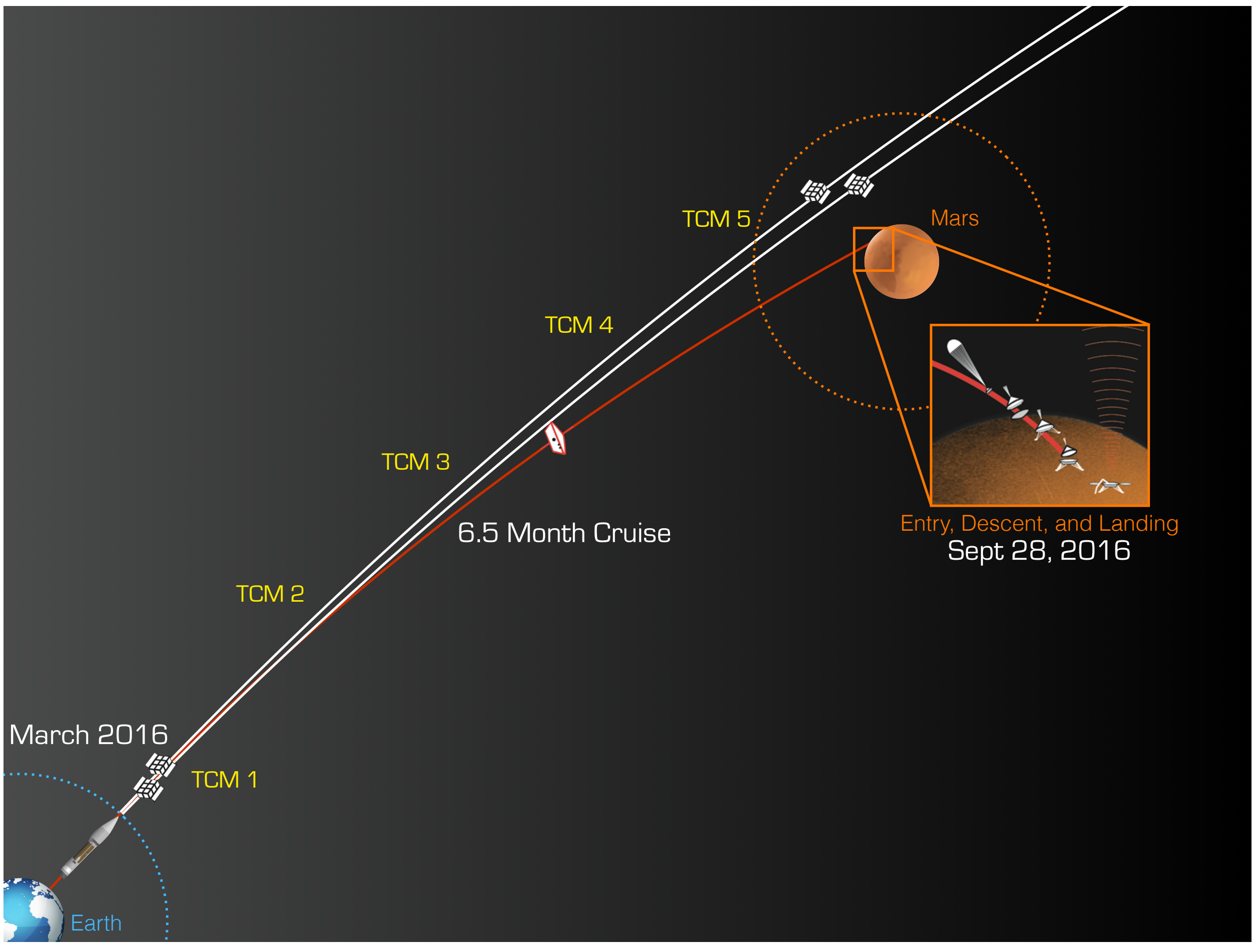

Figure 2 – MarCO concept of operations throughout the 6.5 month cruise.

At Earth, the received data will be routed to the InSight mission operations team. Immediately following the EDL flyby and a period of recharging, the MarCO spacecraft will end its primary mission by retransmiting onboard data, as well as health and performance information. Because the uplink is utilized by the InSight link during EDL, the EDL flyby sequence (see Figure 3) will be performed autonomously.

SPACECRAFT SYSTEMS

Command and Data Handling

AstroDev, LLC is providing an MSP430F2618 based Command and Data Handling board for the MarCO CubeSats. This board is based on modifications to the INSPIRE[3] design, itself heritage from the RAX spacecraft[4]. The CDH has onboard non-volatile storage,

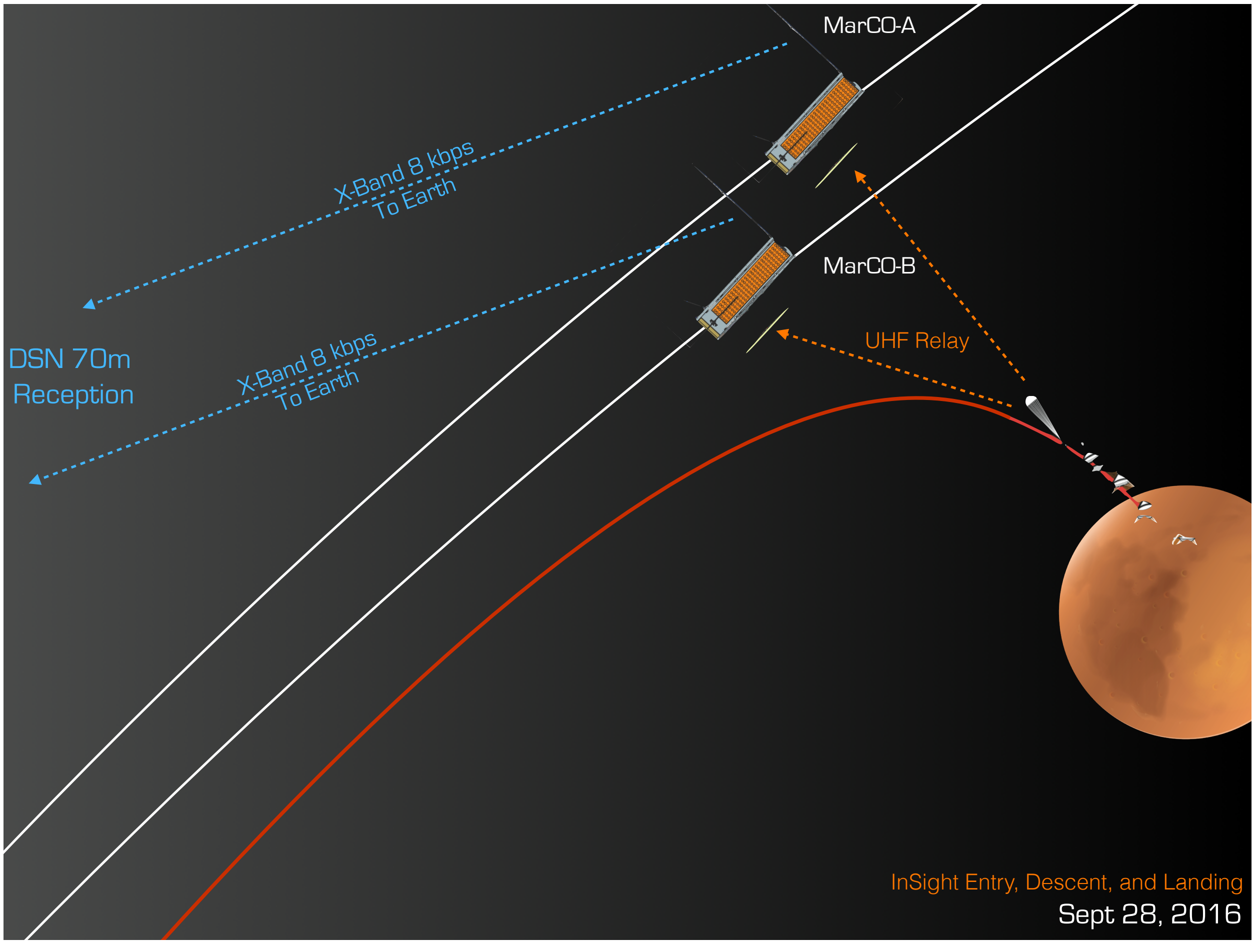

Figure 3 – Concept of operations during InSight's entry, descent and landing on September 28, 2016.

a real-time clock, and cascaded watchdog system, and interfaces (SPI, i^2c, UART, GPIO and RS-422) to all onboard subsystems.

A custom software, *protos*[5], was developed for INSPIRE and adapted for MarCO. This real-time operating system builds upon heritage from many previous JPL missions, yet fits within 128 kB of flash memory, and only 8 kB of RAM. The software allows for uploadable sequences, storage and transmission of real-time and historical telemetry, CCSDS packetizing for communications, and, most importantly, fault monitoring & response.

POWER SYSTEM

The MarCO CubeSats are powered by solar arrays, developed by MMA, LLC. These arrays fold to a single 3U panel for launch, but unfurl to reveal 42 solar cells, providing approximately 35W of power (at 1AU). Each panel rotates upon deployment, but remains in a fixed position for the remainder of the flight.

The University of Michigan, under subcontract to AstroDev, provided the Electrical Power System for the MarCO CubeSats. The single set-point system allows of four channels of solar panel input, while regulating 5V and 3.3V buses (in addition to a battery bus). As MarCO utilizes a 3S4P Lithium Ion battery configuration, the power system was upgraded to an approximately 12V battery bus.

The 18650B Lithium Ion batteries have been tested, screened, and assembled by the power systems section at JPL. A significant effort was made in matching cells and assuring good performance throughout the flight. These cells are protected by custom battery protection circuitry, and monitored by the CDH subsystem.

COMMUNICATIONS

The heart of the MarCO CubeSats is the Iris v2 radio, customized for the MarCO mission to include a UHF receiver. This software-defined radio has up to 4W RF output at X-band frequencies, is fully DSN compatible, and has 4 receive and 4 transmit ports. To better

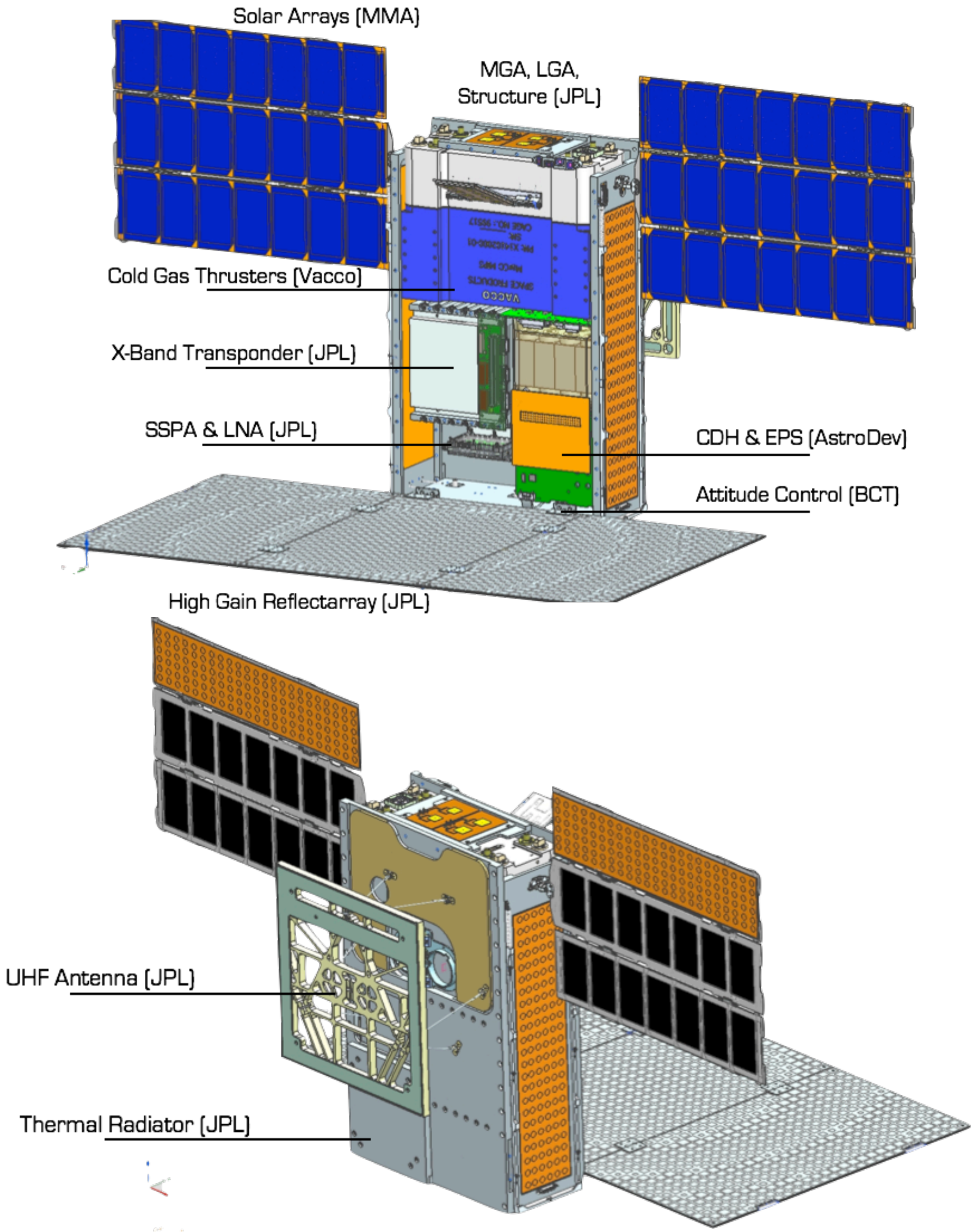

Figure 4 – Front and back of the MarCO CubeSats

accommodate mission communication and thermal requirements, the radio has an external solid-state power amplifier and low noise amplifier. In addition, the radio has been designed to be radiation tolerant.

Each MarCO craft has a low-gain patch antenna for near-Earth communications with wide beamwidth, a medium gain patch array for safe-mode communications far from Earth, and a high-gain reflectarray antenna for high-speed data. The high gain antenna, paired with the Iris radio, can maintain an 8kbps link from 1.05 AU.

In addition, a UHF loop antenna is deployed from the bottom of the spacecraft to receive data from the InSight lander during EDL.

ATTITUDE DETERMINATION, CONTROL, AND PROPULSION

Blue Canyon Technologies is providing the XACT attitude control unit, which includes a star tracker, gyro, coarse sun sensors, and 3-axis reaction wheels. Several modifications have been made to the base unit to include an additional coarse sun sensor and control of the thruster system. In addition, the software has been modified to account for deep space trajectories and related items.

The onboard propulsion system, built by Vacco, contains 8 thrusters – 4 canted for attitude control, and 4 for TCMs. Vacco's single tank design houses all electronics, valves, and propellant. The propellant is R-236FA, a cold-gas propellant often used in fire extinguishers. The XACT system commands the thrusters to fire both for reaction wheel desaturation, as well as for the TCMs. For safety, power control of the propulsion system is maintained by the CDH.

STRUCTURE, THERMAL AND HARNESSING

Both the structure and harnessing (cabling and interface boards) have been designed by engineers at JPL. The structure maintains compatibility with the 6U CubeSat standard.

The MarCO thermal design includes two discrete radiators, thermal blanketing, onboard heaters, and a myriad of temperature sensors throughout the vehicles. As the craft will significantly change their distance from the sun, the project has carefully balanced radiator sizing against subsystem "on" time, power usage, and replacement heater considerations. With the tightest thermal constraints, the batteries have a dedicated radiator to isolate them from larger swings in the overall vehicle temperature.

CONCLUSION

JPL has developed the MarCO CubeSats to demonstrate the novel ability for nanospacecraft to provide a relay link during critical events. When InSight reaches Mars in September of 2016, the MarCO craft will listen to the EDL sequence, and relay that data in real-time to operators and the public on Earth. Nanospacecraft have advanced significantly in the last 15 years, and the technological development to take CubeSats out of low-Earth orbit has now been made. These small vehicles can enable novel science, mission, and support opportunities – now that CubeSats will reach Mars, where will they go next?

Acknowledgments

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