DUPLEX Satellite Technical Description

The overall goal of the Dual Propulsion Experiment (DUPLEX) mission is to test and establish flight heritage for two polymer fiber propulsion systems in low Earth orbit on a 6U cubesat, and a new sensor system. Specifically, these systems are the Fiber-fed Pulsed Plasma Thruster (FPPT), the Monofilament Vaporization Propulsion (MVP), and the Distributed Inertial Sensor Integration (DISI) Kit.

The experiment will be carried to the ISS as cargo aboard the SpaceX 28 resupply vehicle launching from Cape Canaveral FL, no earlier than June 1, 2023. DUPLEX will deploy from the ISS no earlier than June 3, 2023, into Low Earth Orbit (LEO), at approximately a 420 km circular orbit, on an inclination from the equator of 51.6° degrees. Per the mission plan it will deorbit about 1.5 years after launch. See the Orbital Debris Assessment Report for details.

The spacecraft is a single unit with the dimensions of 116.5 mm x 237.7 mm x 366 mm stowed, and a total mass of approximately 10.5 kg. The exterior structure is comprised of anodized aluminum and there are double-deployable solar arrays, which are stowed flush with the spacecraft bus during launch.

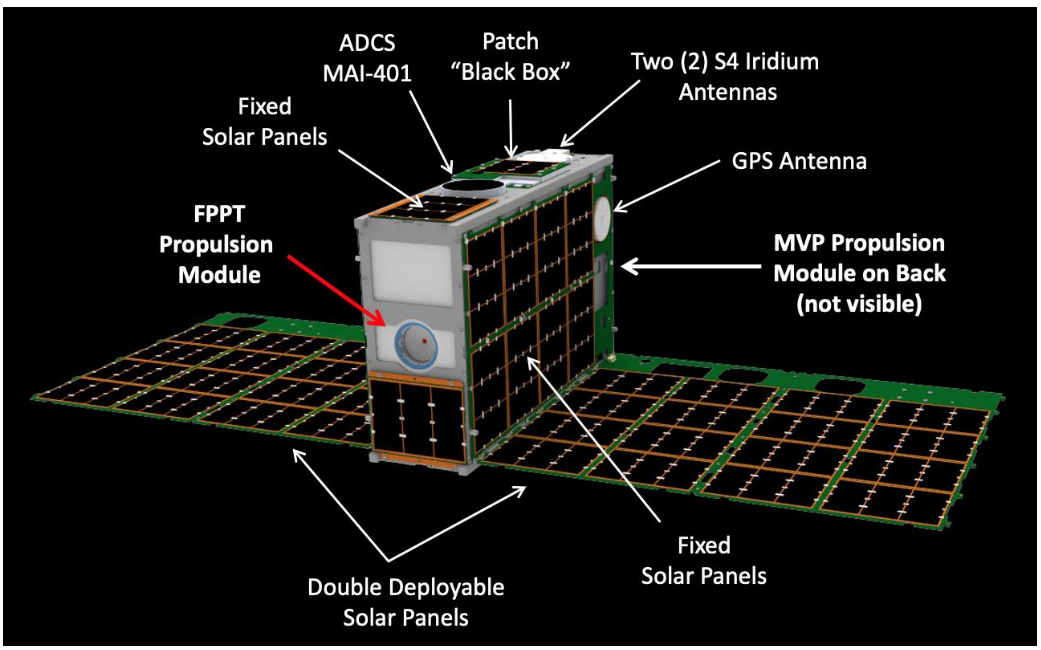

Figure 1. DUPLEX Overview

The satellite contains the following systems:

<u>Guidance, Navigation and Control (GNC) Subsystem:</u> The Adcole Space MAI-401 is a complete 3-axis Attitude Determination and Control System (ADCS). It is suitable for up to about 10 kg nanosatellite applications requiring precise 3-axis pointing such as is required for the DUPLEX mission. The MAI-401 combines 3-axis modular reaction wheels, 3 magnetic torque coils, a 3-axis magnetometer, a 3-axis MEMS accelerometer/gyroscope, 1 star tracker, and a fully programmed ADCS computer. The MAI-401 can provide commanded and automated control of the DUPLEX orientation during all operations including thruster maneuvers.

Command and Data Handling (CDH) Subsystem: The two critical printed circuit boards in the CDH subsystem are the Level Zero (L0) and the Flight Computer (FC) boards. The L0 board is the most critical spacecraft control hardware and operates regardless of flight computer operating state. The L0 includes all communications interfaces to the transceiver and the FC and performs basic spacecraft state of health maintenance. The FC includes all communications to the payloads, comm systems, and EPS, and controls the OEM719 GPS receiver. FC will relay commands received by either EyeStar-S4, to appropriate subsystems. FC will also relay data sent from each subsystem to the appropriate comm for downlink.

Communications Subsystem (COMMS): Comms includes the following radios: 2 EyeStar-S4 Iridium Transceivers; OEM-719 GPS Receiver; and as components in the NSL Black Box Patch system, a Globalstar EyeStar-S3 Simplex Transmitter and an NSL GPS receiver. All use patch antennas. All radios use satellite to satellite transmission and therefore may operate from any location on the orbit of the satellite.

The EyeStar-S4 units will downlink of payload data, as well as SMS message uplink commanding. Either will be able to receive a kill command for all satellite transmissions, should that be required. The OEM719 will receive GPS data and relay solutions to the FC, which will in turn pass the info to relevant subsystems.

The Black Box Patch comms will operate independent of the rest of the satellite. GPS and sensor data will be downlinked from the Black Box EyeStar-S3.

Electrical Power Subsystem (EPS): The EPS is a direct energy transfer system using a solar array producing approximately 24W of orbit average power to charge the 6.4 A-hr battery system. The solar arrays utilize standard photovoltaic cells; the batteries are lithium polymer cells. The L0 board sends signals to the Power Switch Boards to control charging and load switching. High current switches are included to meet power requirements of certain payloads. The EPS includes: a mechanical RBF switch, a deployment switch, and a solar detection circuit which inhibit power from the battery. The charging circuit supplies solar power to the battery and a regulator transfers battery power to the rest of the system. E-fuses limit current supplied to the payload to 100 mA per line.

Thermal Control Subsystem (TCS): The TCS controls hardware temperature through cold biasing of the thermal design, utilizing heaters to stabilize temperatures. Sensors are wired to the L0 board, which hosts thermal control algorithms to control the heaters. DUPLEX has an Al 7061 frame which thermally shorts internal and external surfaces. Copper ground planes in external PCBs, including solar arrays, provides good radiation surfaces. Thermally radiative substance will also be applied where possible to aid in heat dissipation.

Structure Subsystem: The structure is fabricated of anodized 6061-T6 aluminum. Large single panel plates are used to aid in rigidity, precision, and thermal transfer. Surfaces are finished with a hard anodize to meet CubeSat interface and outgassing requirements.

Propulsion Subsystem #1: The Monofilament Vaporization Propulsion (MVP) thruster system uses the high density, nontoxic, solid propellant Delrin. This propellant is stored as fiber on a spool and fed to the thruster with technology proven in 3D printing applications. This approach enables very long-term storage, a temperature envelope beyond that of a typical satellite's onboard electronics, and a competitive ΔV performance with no significant spacecraft hazards. MVP is an electrothermal wall-heated resistojet. The propellant feed system uses technology based upon 3D printers to both feed and pre-melt the Delrin filament propellant into the heater tube, where it is de-polymerized, vaporized, and superheated upstream of a supersonic nozzle. The 1U MVP system has a specific impulse of 66 s and a total impulse of 280 N-s.

Propulsion Subsystem #2: The Fiber-fed Pulsed Plasma Thruster (FPPT) takes advantage of technology advances from the past 20 years that enable the FPPT system to be miniaturized into a 1.7U package with high total impulse of 28,000 N-s. The ability to control both power per pulse and feed rate allows the system to vary both the specific impulse in a range between 1000 – 3500 s and the thrust from 0 – 100% in this innovative PPT system. The FPPT system utilizes the completely non-toxic solid propellant Teflon with a benign exhaust, no corrosive / leaking / propellant plugging issues, and has on-demand throttleable thrust with no warmup time requirement. The propellant is stored as a fiber spooled inside the FPPT housing.

Payload Subsystem: The Distributed Inertial Sensor Integration Kit (DISI Kit) is composed of a hardware and software package. The hardware consists of a mother printed circuit board (PCB) and multiple daughter PCBs. All boards are composed of COTS MEMS accelerometers and gyroscopes. The mother board distributes power to and receives signals from the daughter boards that are "distributed" throughout the DUPLEX satellite (including placement on each of the deployed solar panels). The mother board also has a microcontroller which processes signals to interpret the data and reduce data download requirements. The primary flight objectives for the DISI Kit are to provide: (i) system self-alignment, (ii) inertial navigation validation and attitude determination, (iii) jitter source identification, and (iv) in-the-loop control of the MAI-401 ADCS unit.