BSS1 Propulsion Experiment CONOPS,

And Thrust Effects on the Satellite Orbit

Introduction

The BSS1 mission will launch on the Firefly Alpha rocket from Vandenburg AFB, around June 30, 2020, to a circular orbit of 300 km and inclination of 137°. It is predicated to de orbit about 4 months later. This mission will demonstrate the capability of Benchmark Space System's DFAST propulsion system. The DFAST product line was developed to provide reliable, high-precision positioning, and control capability. Use of an inert, non-toxic, powdered propellant known as azodicarbonamide (ADA) allows the system to be safely fueled, transported, or stored for long durations, without the concern of pressurized vessels, fluid leakage, or chemical breakdown.

DFAST contains approximately 30 grams of powdered propellant in non-pressurized vessels throughout ground operations and launch. In orbit, the BSS1 satellite requires a signal from ground to command the fuel heating operation, which will heat the fuel until it exothermically converts into gas. The gas is stored within the propulsion system pressure vessels. A ground signal is then required to open a valve, which will let the gas flow from the storage tanks, through a regulator, through the valve and then exit out through the nozzle on the satellite Z face. The ground signal will include a duration for the valve to be opened, eliminating the chance of a missed ground signal to close the valve. The longest duration planned is 30 seconds.

The DFAST module is approximately 90mm x 90mm x 50mm, and nominal thrust level of 50mN from the single nozzle centered on the anti-RAM face. Total impulse available to the satellite is 25Ns, resulting in a total delta V capability of about 4.2 m/s for the BSS1 satellite.

Concept of Thruster Operations

High level description of satellite CONOPS modes:

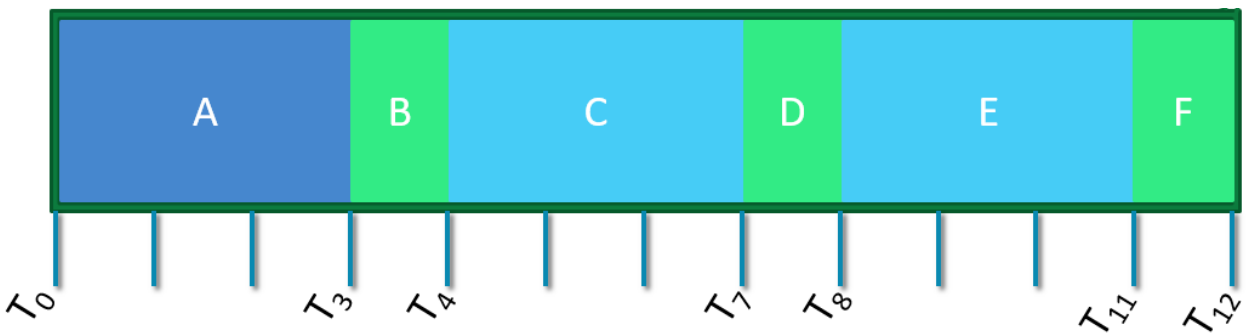
- Mode 0 – Satellite has been released from the deployer. The deployer switches have been tripped, which begins the TX inhibit timer to prevent RF transmissions during the first 30min of flight.
- Mode 1 – The 30 min TX inhibit concludes, and the BSS1 begins attempting to establish radio communication with mission operations, by transmission from the Simplex radio to the Globalstar constellation
- Mode 2 – First contact with mission operations is confirmed by communications from mission operations into the satellite via the GlobalStar duplex, then telemetry downloads via Simplex will be initiated.
- Mode 3 – At the conclusion of Mode 2, BSS1 enters normal operation. Normal operation is broken down into the primary mission, which includes all thruster operations described

below, and secondary mission operations which include telemetry monitoring and check out of ADCS systems and GPS systems. Health and safety and GPS position data will be downloaded via Simplex radio, every 30 minutes.

- Mode 4 – If the satellite BSS1 detects a drop in BUSS+ voltage to less than 6.5V it will extend the time between telemetry downloads to 2 hours.
- Mode 5 – If the satellite BSS1 detects a drop in BUSS+ voltage to less than 6.0V it will extend the time between telemetry downloads to 4 hours, and set all EPS switchable power rails to OFF.

Discussion of MODE 3 – Thruster Operations

Primary mission duration is expected to be around 12 days broken out as follows:



- A: Day 0 – 3 Includes de-tumbling the spacecraft, communications checkout and beacon, and DFAST startup and health check.
- B: Day 3 – 4 Sequence: GPS acquisition, pressurization, GPS acquisition, 30 second thruster fire, GPS acquisition, 30s (total valve open time) of pulse firing, GPS acquisition. The GPS, long fire, GPS, pulse fire, GPS operation is repeated two more times. Occasional GPS acquisitions may be conducted as needed for the remainder of the day.
- C: Day 4 – 7 Includes idle time for the stored gas to cool and data from previous operations to be analyzed. Occasional GPS acquisitions may be conducted as needed.
- D: Day 7 – 8 Repeats B, with the exclusion of the pressurization event. Due to the cooling of the stored gas, the Isp and thrust levels will be less than that during operation B.
- E: Day 8 – 11 Repeats C
- F: Day 11 – 12 Includes a final firing to safe the propulsion system. GPS acquisitions will proceed and follow the firing.
- Throughout the 12 day primary mission period, continuous health and telemetry checks are expected to be performed on the spacecraft and the DFAST system.

Ephemeris Updates

Mission Operations will provide predictions of ephemeris resulting from planned thruster operation, to the 18th SpCS by using the procedures described in the Spaceflight Safety Handbook for Operators (https://www.spacetrack.org/documents/Spaceflight_Safety_Handbook_for_Operators.pdf).

We will communicate prior to any thruster activity, and assure they are aware of the pre burn ephemeris as established by data from the two on board GPS units, and aware and able to incorporate the predictive ephemeris into conjunction assessment. Following thruster operation, further GPS data will verify the resulting ephemeris, which will also be communicated to the 18th SpCS.

Delta-V and Orbit Lifetime Calculations

The orbit lifetime due to natural decay is estimated to be about 94 days, see the ODAR for details. Per the following calculations, thruster operation can add at most 30 days to the orbit lifetime.

1. The thruster has a window of about 2 weeks of operation, over which a maximum of 200 pulses total may be tested. In one day, no more than 93 pulses will be fired, with a maximum of 200 pulses per week. The initial planned testing is less than 200 pulses per week.

2. To maximize the calculated effect on the orbit, it is assumed that all thrust will be in the negative RAM direction.

Summary of Calculated Values:

1. The maximum possible delta-V from the thruster, if all gas was released when hot, is 5.0 m/s. This will not be achieved because the gas will be released over a two week period, so the majority of the gas is released cold.

2. The maximum possible delta-V from one day of operation is 1.8 m/s.
   a. This could occur in a single orbit, for which the drag contribution is ~0.00162 m/s
   b. The drag contribution in a single day is ~0.02581 m/s, which is ~0.00161 m/s per orbit.

3. The upper end of planned operations delta-V over 2 weeks is 4.2 m/s.

4. The delta-V from drag over the 2 weeks is approximately -0.36 m/s.

5. A conservative estimate of drag was used considering low solar activity to give an estimate on the drag force of 9.95E-6 Newtons over this time, the total delta-V over 2 weeks including the drag force is given below for each situation.

Notes on calculation:
Circular Orbit at 300 km:
v = 7.7258352 km/s
Force drag = 9.95 μN (low estimate)
Period: 5431.2 seconds -> 90.52 min ~>1.5 hours
24 hr / 1.5hr ~= 16 orbits/day
16 orbits/day * 7 days/week = 112 Orbits/Week

<u>Mode 3, Thruster Operation B (All firings occur in a single orbit)</u>

Firing One Burst for 30s

v_Final (No Drag) = 7.7261352 km/s	dv = 0.300 m/s (pos.) dv = 0.300 m/s (cum.)	**1 Pulses**

Firing 30, 1sec Bursts

v_Final (No Drag) = 7.7264352 km/s	dv = 0.300 m/s (pos.) dv = 0.600 m/s (cum.)	**30 Pulses**

Firing One Burst for 30s

v_Final (No Drag) = 7.7267352 km/s	dv = 0.300 m/s (pos.) dv = 0.900 m/s (cum.)	**1 Pulses**

Firing 30, 1sec Bursts

v_Final (No Drag) = 7.7270352 km/s	dv = 0.300 m/s (pos.) dv = 1.200 m/s (cum.)	**30 Pulses**

Firing One Burst for 30s

v_Final (No Drag) = 7.7273352 km/s	dv = 0.300 m/s (pos.) dv = 1.500 m/s (cum.)	**1 Pulses**

Firing 30, 1sec Bursts

v_Final (No Drag) = 7.7276352 km/s	dv = 0.300 m/s (pos.) dv = 1.800 m/s (cum.)	**30 Pulses**
v_Final (W/Drag) = 7.7276336 km/s	dv = 1.7984 m/s (pos.)	

<u>Mode 3, 3 Days of Non-Thruster Operation</u>

v_Final (W/Drag) = 7.7275562 km/s	dv = -0.07743 m/s (pos.)

<u>Mode 3, Thruster Operation D (All firings occur in a single orbit)</u>

Firing One Burst for 30s

v_Final (No Drag) = 7.7278562 km/s	dv = 0.300 m/s (pos.) dv = 0.300 m/s (cum.)	**1 Pulses**

Firing 30, 1sec Bursts

v_Final (No Drag) = 7.7281562 km/s	dv = 0.300 m/s (pos.) dv = 0.600 m/s (cum.)	**30 Pulses**

Firing One Burst for 30s

v_Final (No Drag) = 7.7284562 km/s	dv = 0.300 m/s (pos.) dv = 0.900 m/s (cum.)	**1 Pulses**

Firing 30, 1sec Bursts

v_Final (No Drag) = 7.7287562 km/s	dv = 0.300 m/s (pos.) dv = 1.200 m/s (cum.)	**30 Pulses**

Firing One Burst for 30s

v_Final (No Drag) = 7.7290562 km/s	dv = 0.300 m/s (pos.) dv = 1.500 m/s (cum.)	**1 Pulses**

Firing 30, 1sec Bursts

v_Final (No Drag) = 7.7293562 km/s	dv = 0.300 m/s (pos.) dv = 1.800 m/s (cum.)	**30 Pulses**
v_Final (W/Drag) = 7.7293546 km/s	dv = 1.7984 m/s (pos.)	

Mode 3, 3 Days of Non-Thruster Operation

v_Final (W/Drag) = 7.7292772 km/s — dv = -0.07743 m/s (pos.)

Mode 3, Thruster Operation F (All firings occur in a single orbit)

Firing Initial Burst for 60s [Gas may not be present to support full firing period]

v_Final (No Drag) = 7.7298772 km/s	dv = 0.600 m/s (pos.)	**1 Pulses**
v_Final (w/Drag) = 7.72987560 km/s	dv = 0.5984 m/s (pos.)	