NASA IV&V Space Flight Design Challenge
Increment 1 – Concept of Operations
12/29/2011

1.0 Introduction

The NASA IV&V Space Flight Design Challenge (SFDC) consists of a series of increments. This is the first increment of SFDC and the first increment consists of one mission called OC-Flight-1.

The purpose of this document is to describe conceptually the phases of the mission (OC-Flight-1) and what is expected from the mission system (mission operations system and spacecraft system) in order to achieve the objectives of the mission. This document describes the major phases of the mission, operational scenarios related to the phases of the mission, the communication strategies, and the operational facilities needed. The structure of information has been borrowed from NASA Procedural Requirements (NPR) 7120 document's description for an Operations Concept "The Operations Concept should describe how the flight system and ground system work together across mission phases for launch, cruise, critical activities, science observations, and end of mission to achieve the mission."

2.0 Increment 1 Mission Objectives (OC-Flight-1)

The first increment of the IV&V Space Flight Design Challenge (SFDC) entails one mission and is called OC-Flight-1 (in honor of Bryan O'Connor and his service to NASA and specifically to the IV&V Program). OC-Flight-1strives to advance the overall Space Flight Design Challenge towards its overarching goals by achieving the following objectives:

- Overarching Goal of SFDC: Advance the public's awareness, education, knowledge, and STEM capabilities in space systems software engineering. The derived objectives for OC-Flight-1 include:
    a. Educate a dedicated team of students in NASA's approach to engineering space-based vehicles.
    b. Enhance the public's understanding and general knowledge about NASA and the engineering of space-based missions through public seminars and workshops.
- Overarching Goal of SFDC: Advance the IV&V Program's tools, domain knowledge, and engineering methods to ensure mission and safety critical software is reliable and safe to operate. The derived objectives for OC-Flight-1 include:
    a. Enhance mentoring skills, leadership skills and domain expertise of IV&V workforce
    b. Establish an approach to conduct IV&V on university-built technology demonstration missions where it is perceived that these types of missions will lack formal engineering artifacts and maturity traditionally produced on NASA missions.
- Overarching Goal of SFDC: Advance the disciplines of systems engineering and software engineering by exploring game changing technologies for NASA. The derived objectives for OC-Flight-1 include:
    a. Develop a reusable space system (ground system, space-based vehicle, and science payload) using off the shelf components that can be utilized on future increments
    b. Measure the magnetic field of the Earth using off the shelf components
    c. Take stereoscopic images of the Earth using off the shelf components
    d. Explore the use of artificial intelligence for fault protection
    e. Explore the use of off the shelf wireless technologies for spacecraft to spacecraft communications

Minimum success is achieved if the following two objectives are met:

1. Students demonstrate working knowledge of NASA's engineering approaches in building and operating a flight system for space
2. Employees of the NASA IV&V Program demonstrate enhanced mentoring, leadership, and/or domain expertise in space-based missions

3.0 Mission Overview

3.1 Scope

OC-Flight-1 consists of multiple spacecraft, science payloads, and a mission operations center (which also includes testing and evaluation facilities). The scope of OC-Flight-1 does not include the launch vehicle nor does it include the ejection cylinder the spacecraft is housed within during launch and is separated from once in space.

To stay within the theme of the Space Flight Design Challenge, OC-Flight-1 is built using the lowest possible costs and utilizes any and all off the shelf capabilities. OC-Flight-1 spacecraft is a spacecraft kit offered by Interorbital Systems called TubeSat (reference TubeSat PS Kit Assembly Guide Release 1.2). Interorbital Systems is also the launch provider.

To achieve the derived objectives for OC-Flight-1, the development team for the overall system (mission operations and spacecraft) will consist of West Virginia University (WVU) students (through our NASA WVU Space Grant agreement) and employees from the IV&V workforce. Figure 1 is a depiction of the organizational structure to support the achievement of the derived objectives.

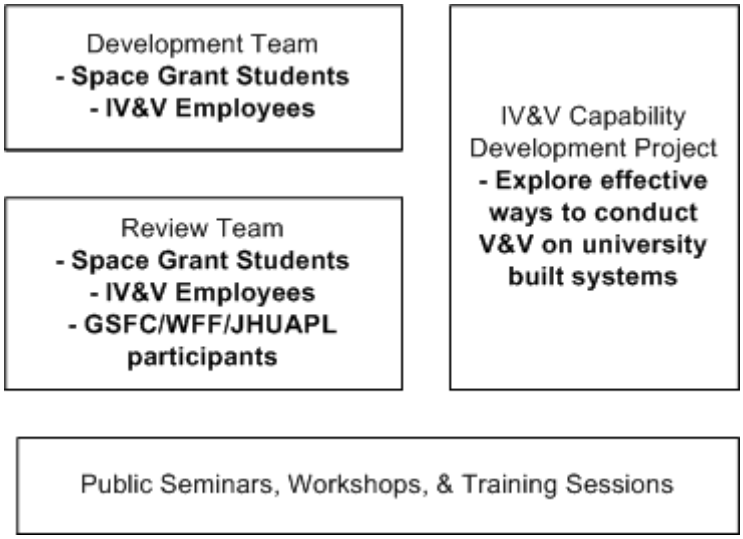


Figure 1: Organizational approach to help in accomplishing the derived objectives for OC-Flight-1

Even the though the derived objectives for OC-Flight-1 relative to exploring game changing technologies in systems and software engineering are not really "game changing" for the disciplines, they serve as our first step in realizing a successful mission and will be used in future increments that truly emphasize the "game changing" concept.

The development team will have the responsibility of developing system and subsystem requirements, establishing designs, fabricating designs, integrating the spacecraft components that come in the spacecraft kit (power distribution unit, solar arrays, batteries, transceiver, microcomputer, and the overall spacecraft structure). The team will be responsible for building or acquiring a payload (approximately 2x3.5 inches and less than ½ pound) that satisfies the system-level requirements. The development team is responsible for testing the assembled spacecraft and delivering it to the launch provider. The development team is responsible for operating the spacecraft on orbit; the spacecraft will transmit on amateur radio bands allowing communication between ground and spacecraft using amateur radio equipment. The launch is expected to put the spacecraft in a polar orbit at an altitude of approximately 310 km for an operational life of about 3 months.

3.2 Launch Characteristics

The launch vehicle being utilized is the IOS NEPTUNE launch vehicles built by Interorbital Systems. The rockets are three-stage, modular, ultra low-cost orbital launch vehicles designed to place 30 or 45 kilograms into polar low-Earth orbit. This payload capacity allows formations of

32 to 48 TubeSats, or a combination of CubeSats and TubeSats, to be launched per orbital mission with each TubeSat or CubeSat housed in its own dedicated ejection cylinder.

OC-Flight-1 spacecraft, a TubeSat, will be housed in its own dedicated ejection cylinder which is depicted below in Figure 2:

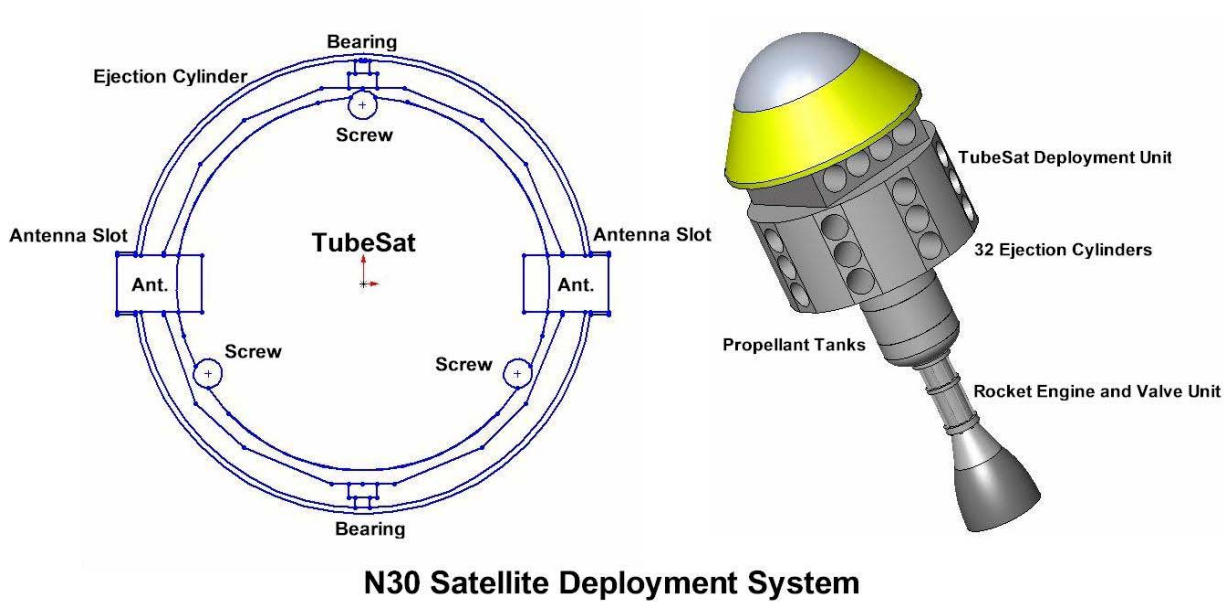


Figure 2: N30 Deployment System that OC-Flight-1 will be contained in.

3.3 Operational Facilities

The mission operations facilities is responsible for integration and testing of systems, communications and planning for the spacecraft, software updates during operations phase, processing of telemetry and trouble shooting.

The system will be integrated, tested and evaluated within the Mission Operations Center dedicated for OC-Flight-1. The spacecraft will undergo:

- Vibration testing (need launch vehicle characteristics)
- Thermal vacuum testing
- Integration testing
- Acceptance testing (test scenarios that exercise the system (mission operations and spacecraft)) that shows the operational scenarios and system requirements have been met.
- Unit testing will also be conducted but will not have test procedures formally documented and unit testing will occur before the subsystems are integrated together.

Communications with the spacecraft will utilize the amateur radio band of 433-434Mhz. The system will need to decode Morse Code as well as understand AX.25 protocol (Health and Status telemetry is sent as Morse Code signals and science data uses AX.25 protocol).

During operations phase operators receive orbital data about the spacecraft from the NORAD web-site. Operators will then model the spacecraft's orbit to determine downlink and uplink schedules between mission operations and the spacecraft. Operational priority is to communicate directly with the spacecraft, however secondary measures are to post the uplink packets to the

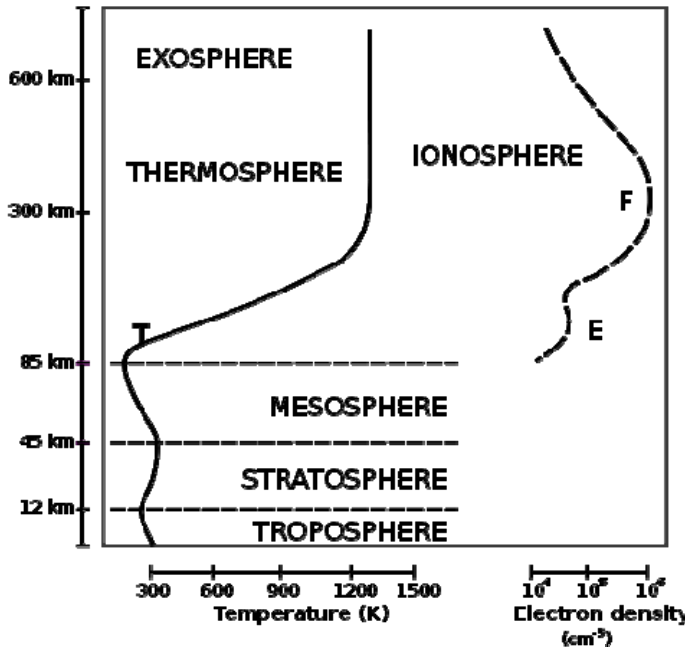
OC-Flight-1 web-site and ask for assistance from the ham radio operators across the globe to transmit the uplink packets. The web-site is also a place that ham radio operators can submit any data they have received from the spacecraft.

Mission operations will also have a spacecraft simulator to test out health and status telemetry in order to understand performance of the spacecraft or troubleshoot.

3.4 Space Environment

The launch vehicle is expected to put the spacecraft in a polar orbit at 310 kilometers (km) of altitude for approximately 3 months of operational time before succumbing to atmospheric drag and descending/burning up in the Earth's atmosphere. OC-Flight-1 spacecraft will need to operate at approximately 310 km of altitude which places it in the Thermosphere for the majority of its life. The spacecraft will need to cope with near vacuum, variable accelerations, ionized gases, and sometimes intense particle and electromagnetic radiation.

At about 85 km to 690 km is the Earth's Thermosphere (one of the 5 main layers of the Earth's atmosphere (Troposphere, Stratosphere, Mesosphere, Thermosphere, and Exosphere)) in which OC-Flight-1 spacecraft will operate. The temperature within the thermosphere increases in height and varies between 300 Kelvin to 1400 Kelvin (~26 degrees Celsius to ~1100 degrees Celsius (~80 degrees Fahrenheit to ~2000 degrees Fahrenheit)). There are other layers of the atmosphere that are determined by properties other than temperature, the ionosphere being one of them and applicable to OC-Flight-1 spacecraft since the spacecraft will operate within the ionosphere (part of the thermosphere) and is ionized by solar radiation (see photo below taken from Wikipedia).



<u>The Plasma Environment</u>

Gas in the thermosphere is ionized by ultraviolet and X-radiation from the Sun. The partially ionized gas, the plasma, is termed the ionosphere. Plasma density is said to peak at 300 km, and its properties are described by specifying particle density and particle energy. OC-Flight-1 can

develop an electrical potential while the positively charged ions and negative electrons can cause significant physical effects.

As OC-Flight-1 travels through this ionized portion of the atmosphere, it may be subjected to an unequal flux of ions and electrons and may develop an induced charge. Plasma flux to the surface of OC-Flight-1 can charge its surface and disrupt the operation of electrically biased instruments, and induce arcing and sputtering at significantly high negative potentials relative to the plasma.

The development team will conduct a plasma study for two purposes: (a) the choice of spacecraft ground since it is an important consideration in determining where the spacecraft will float electrically relative to the surrounding plasma and (b) to understand the electrical potential differences between the space vehicle structure and the ambient plasma.

<u>The Vacuum Environment</u>
At ~400 km altitude, the pressure is ~10^{-6} Pa, 11 orders of magnitude less than at the surface of the Earth. Under such conditions, lubricants between moving metal surfaces may not work well. Gas particles stuck on satellite surfaces outgas and may then stick on sensitive surfaces like the lens of a camera. The Sun's radiation is bright and degrades mechanical or thermal properties of some surface materials. The solar constant of 1.368 kW m^{-1} and the terrestrial infrared radiation, heat the spacecraft. In the absence of gas to carry away heat by convection, excess heat can only be conducted through the satellite to a radiator.

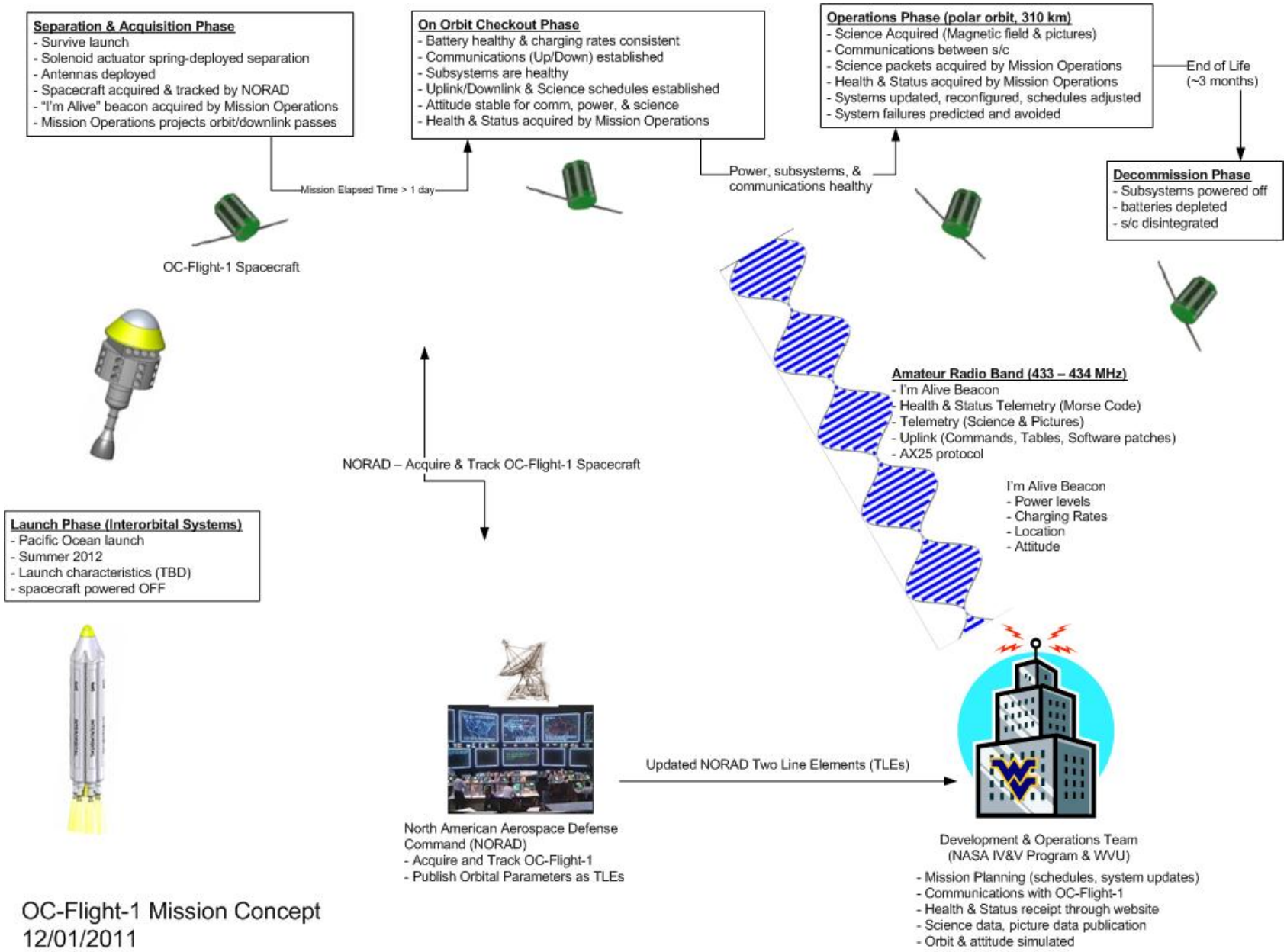
The development team will conduct a thermal analysis to study heat absorption, radiation, and the heat flow within the body of the spacecraft. The main purpose of this analysis is for predicting and controlling the temperature of the electrical and mechanical parts in order to avoid overheating or cooling.

<u>The Radiation Environment</u>
Charged particles with energy much greater than the thermal energy of the plasma (less than 1 eV, equivalent to 11,600 K) constitute the radiation environment of space. Ions with an energy ~0.1 keV impinging upon the surface of a satellite eject atoms from the surface. Called sputtering, this process, over time, can remove a thin coating applied to part of a satellite's surface. Much higher energy charged particles can penetrate solar cells and microelectronic chips inside a satellite, causing them to change their state or even destroying them completely.

The development team will conduct a radiation analysis to study understand the expected exposure amounts to radiation and the effects that it can have on OC-Flight-1. The purpose is such that designs can utilize this information in order to avoid adverse effects to radiation.

4.0 OC-Flight-1 Mission Phases

A conceptual image for the multiple phases of the mission is below and the phases are described further in subsequent sections.



OC-Flight-1 Mission Concept
12/01/2011