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AMSAT Fox-Plus Satellite
Concept of Operations

1. Introduction

The AMSAT Fox-1 satellites, Fox-1A through Fox-1E, were the first CubeSat projects undertaken by AMSAT. Within a 1U satellite form factor, they provide an FM repeater function, except for Fox-1E which provides a Linear Transponder. The Fox-1 satellite family orbits were intended to provide wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a walkie-talkie) and a small handheld antenna. This type of satellite operation is often referred to as the EasySat mode due to its simplicity. It is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations, and at amateur radio publicity events. In addition, the Fox-1 series CubeSats hosted several experiment payloads provided by educational institutions such as Vanderbilt University ISDE, Penn State Erie, Virginia Tech, and the University of Iowa.

The fifth and final Fox-1 satellite, RadFxSat-2, was built by AMSAT and launched in January 2021 by Virgin Orbit. The RadFxSat-2 spacecraft bus was built on the Fox-1 series but featured a linear transponder to replace the standard FM transponder in Fox-1A through D. In addition, the uplink and downlink bands were reversed from the previous Fox satellites in a Mode V/u (J) configuration using a 2 meter uplink and 70 cm downlink.

The Fox-Plus program seeks to build on the Fox-1 platform. Fox-Plus will refresh the Fox-1 series, to enhance the capabilities and address any issues identified while extending the Fox-1 series.

This Concept of Operations documents the overall vision for the Fox-Plus program and provides the foundation for the design and implementation of the Fox-Plus satellite.

The launch of Fox-Plus satellites will likely be accomplished via a variety of options, to include NASA ELaNa launchesas well as commercial launches.

1.1 Document History

DATE	VERSION	AUTHOR	SUMMARY OF REVISION CHANGES
9 FEB 2022	V0.0	M. Moore	Initial draft
10 FEB 2022	V0.1	M. Moore	Inclusion of specifics from Jonathan Brandenburg
15 FEB 2022	V0.2	M. Moore	Incorporating comments and more specifics

17 FEB 2022	**V0.3**	**M. Moore**	**Clean-up + comments**
22 FEB 2022	**V1.0**	**M. Moore**	**Clean up + formatting only**
16 AUGUST 2022	**V1.1**	**J. Brandenburg**	**Clean up + formatting**

1.2 Program Goals and Objectives

The AMSAT Fox-Plus satellite is intended to:

- Continue to build relationships with universities, including student development of satellite components and subsystems
- Provide a platform to test and demonstrate low cost radiation event fault tolerant IHU and satellite command radios
- Improve upon the Fox 1U CubeSat platform and to develop a solar panel design that can serve a variety of missions
- Provide an on-orbit amateur radio transponder to allow communications between amateur radio operators, the vision is for multiple FM channels
- Provide a platform to test and demonstrate technology for amateur radio communications using AMSAT Ground Terminal design-based ground stations
- Provide a platform to test and demonstrate software defined radio (SDR) transponder technology for amateur radio communications.

1.3 Mission Overview

The mission of the Fox-Plus satellite is to provide one or more amateur radio transponders demonstrating communications capability that can be accessed using AMSAT Ground Terminal design-based ground stations or relatively simple ground station equipment such as low power portable transceivers paired with a small, handheld beam antennas. The satellite communications transponders will employ SDR based radios.

The Fox-Plus satellite will provide the hardware and software systems necessary to demonstrate and build upon knowledge gained in the Fox program of a 1U satellite. It is a refresh of the Fox-1. The Fox-Plus satellite program will start with a 1U satellite with a vision to increase the satellite size to accommodate experiments and technology demonstrations.

The radio communications capabilities of the satellite will be used to uplink control commands for operation of the satellite, as well as operation of the radios and experiment(s) as needed. Communications capabilities will also downlink data necessary for data collected from the experiment(s) to ground stations.

1.4 Scope

The scope of this Concept of Operations (CONOPS) document describes the Fox-Plus satellite system and how it will be used. This is not a requirements document but provides operational context that should be helpful in developing and understanding system requirements and interface specifications.

2.System Description

2.1 Spacecraft

This project, to be executed under the Fox program, will be called Fox-Plus, where the "Plus" indicates an augmentation of the Fox satellites with new features based upon the latest technologies. The satellite is expected to exhibit the following features and characteristics:

- Initially a 1U CubeSat form factor
- 500 km or greater orbit
- Initially gixed solar panels
- Experimental payloads as determined by future partners
- UHF transponder for command / telemetry
- VHF/UHF FM transponder
- 300 mW minimum RF output power to FM transponder
- Deployable antennas
- Rechargeable battery to support operation during eclipse periods
- Proprietary scheme for command control uplink
- Separate dedicated channel for downlinking telemetry and experiment data

This list is preliminary and subject to change.
NOTE: This CONOPS is <u>not</u> the controlling document for satellite technical specifications.

2.2 Telemetry and Experiment Data

Telemetry data consists of internally monitored satellite subsystem points that provide a measure of the satellite's attitude, status, and health. The satellite will autonomously and regularly measure these points and transmit the data provided on the telemetry downlink. Experiment data will be collected as per the requirements of the experiment and will be stored and/or transmitted on the downlink as needed.

Additionally, Whole Orbit Data (WOD) will be collected for the above measurements and transmitted to ground.

Telemetry and experiment data will be transmitted in the clear allowing any ground station to receive it. The information needed to demodulate and decode the downlink signal will be placed in the public domain. An open-source, software package for decoding the telemetry and experiment data will be made available by AMSAT.

2.3 Satellite Commands

The satellite will accept commands from AMSAT vetted control stations. These are used to

control the modes and operation of the satellite. Commands are intended to be limited to use by authorized stations only. Private codes and/or unpublished information will be used to command the satellite.

2.4 Ground Control Stations

Commands will be executed by way of the VHF or UHF amateur radio satellite band. It is expected that control stations will not require any specialized radio equipment/hardware, but may need to be able to generate higher radiated power levels than typical for users in order to gain control of the satellite. In order to command the satellite, specialized software will be required. This software will be developed and provided by AMSAT as part of the satellite development effort.

2.5 Amateur Radio User Stations

This satellite will employ radio standards commonly used on the amateur radio VHF and UHF bands for the FM transponder and will not require any specialized equipment for normal operation on that transponder. A low power transmitter/receiver pair for duplex operation, with a small hand-held Yagi antenna, should be considered a typical user station for the VHF/UHF FM transponder. Operation with fixed, omni-directional antennas should also be possible with typical amateur radio base and mobile transceivers.

3.Satellite Operational Modes

3.1 Quiescent Mode

This mode will be used when the satellite is flight ready but has not yet been integrated into the deployer (P-POD.) A "Remove Before Flight" pin, inserted into its receptacle on the satellite, will disconnect the battery and prevent any operation of the avionics.

3.2 Deployer (P-POD) Mode

After the satellite is integrated with the deployer, the "Remove Before Flight" pin will be pulled but deployment switches on the satellite will prevent power-up of the avionics. In this mode, a test umbilical cable can be connected to a port on the satellite which will allow limited avionics to be powered, the battery to be charged, and diagnostic tests to be run. Once a CubeSat has been integrated with its deployer and the launch acceptance tests have been run, the only way to know if a satellite is still functional is via these diagnostic tests. Therefore, the diagnostics should be as thorough as possible within the limitations of the deployer environment.

3.3 Startup Mode

When the satellite is released in orbit, the deployment switches on the satellite will be activated allowing the satellite to power up. At this point, the satellite will enter Startup Mode. The satellite will time a 50-minute interval and then deploy the antennas. This delay is required by the CubeSat Design Specification. After deploying the antennas, the satellite will enter Beacon Mode.

3.4 Beacon Mode

Beacon Mode allows transmission of a limited set of telemetry only, to provide command

stations to assess the health and status of the satellite after deployment. On orbit testing is performed prior to making the satellite transponders available for general use.

NOTE: After completing the Startup Mode timer, the satellite will always monitor the command uplink frequencies for a command from a Ground Control Station. A Ground Control Station can command the operation of the various satellite systems at any time, regardless of the operational mode in effect.

3.5 Transponder Mode

In Transponder Mode, signals appearing on the uplink will be repeated on the downlink for the selected transponder(s) as activated by AMSAT Ground Control Stations. Amateur radio user stations can use the satellite for general communications with each other. The satellite will simultaneously send telemetry data on a separate telemetry downlink so as not to interfere with transponder communications.

3.6 Telemetry Mode

Telemetry Mode is intended to support transmission of the full set of satellite telemetry while inhibiting the transponder(s). This mode is to be used when it is necessary to monitor the health and status of the satellite, similar to Beacon Mode, but with all of the telemetry being downlinked and available for analysis. In Telemetry Mode, user signals appearing on the transponders' uplink(s) will not be repeated on the downlink(s). The satellite will use the telemetry downlink exclusively to send telemetry and experiment data.

3.7 Safe Mode

Safe Mode is a protective mode of operation that is initiated by Ground Station Command or automatically by the satellite operating system itself when certain parameters are met that imply a possibly harmful state of satellite operation or systems functions. Safe Mode will inhibit the transponder(s) and send a subset of telemetry containing key elements for troubleshooting and problem determination. The telemetry transmission may be at a reduced power output and/or duty cycle.

3.8 Transmitter Inhibit

In order to meet FCC requirements, the satellite will accept a control station command to inhibit the transmitters regardless of the operating mode. Once inhibited, the transmitters will not be activated under any autonomous conditions, but the satellite will continue to monitor the uplink for commands. A Ground Control Station must send a proper command to remove the inhibit and re-enable the transmitters. Transmitter Inhibit must be executed via a hardware action on each transmitter and not executed via a software action.

3.9 Loss of Command

If the Fox-Plus satellite has not received a command in a configurable amount of time, it will cease to beacon and will enter the Transmitter Inhibit mode as described in 3.8 above.

3.10 Partial Failure Operation

Partial failure tolerance is intended to extend the usable life of the primary mission of the satellite. An experiment may or may not be operable under a partial failure scenario. This type of operation is desirable if possible without impacting the attainment of any other operations in this document due to the limited time for development.

3.11 Battery Failure

If the battery deteriorates or fails completely, including a short circuit, the satellite will continue to operate on its solar panels while in the sun. In eclipse, the satellite may power down. When back in sunlight, the satellite will automatically enter Transponder Mode.

3.12 IHU Processor Failure

The satellite will operate in Transponder Mode by default and will not require intervention from a ground control station. If the Internal Housekeeping Unit's (IHU) processor fails, there may be limited control of the satellite and attitude and limited or no telemetry data available, but the transponder will continue to operate.

4.Mission Operations Overview

The AMSAT Operations and Engineering Teams will work together to commission the satellite after launch. Commissioning is required to ensure the satellite is operating nominally or to determine the capabilities of the satellite if nominal operation is diminished. Commissioning will include all specified qualification tests of the IHU required to fulfill the goals of the mission. After commissioning, the satellite will be turned over to the AMSAT Operations Team. It is expected the AMSAT Operations Team would then open the satellite for general communications use by any licensed amateur radio station, and perform communications scheduling and required attitude control to maintain desired performance.

The AMSAT Operations Team will collect and archive all telemetry and experiment data and make it freely available on the Internet.

5.Reference Documents

1. CubeSat Design Specification Rev. 13. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/s/cds_rev13_final2.pdf
2. ITU Radio Regulations, Edition of 2016. available from http://www.itu.int/pub/R-REG-RR-2016
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision B (from NASA)
4. Fox-1 Concept of Operations DRAFT F , July 19, 2011 AMSAT