NASA IV&V Space Flight Design Challenge
Increment 1 – Implementation Plan[1]
10/25/2011

[1] Content in this plan was guided by information contained within 7120.5D "NASA Space Flight Program and Project Management Requirements" – Appendix F Project Plan Template

1.0 Overview

1.1 Introduction

The NASA IV&V Space Flight Design Challenge is an initiative focused on enhancing critical systems education, the tools and methods of IV&V, and systems and software engineering approaches in general. The Space Flight Design Challenge pushes the envelope of education and engages the students of West Virginia in the sciences, technologies, engineering, and mathematics (STEM) needed to successfully build and test complex and critical systems. The Space Flight Design Challenge is a collaborative partnership of the NASA IV&V Program, industry, academia, and other government agencies to foster innovative advancements in the application of IV&V while enhancing the knowledge and capabilities of the public through hands-on spacecraft development. Students across West Virginia will compete in building, testing, launching, and operating flight systems in space. In parallel, transformational innovations for providing mission and safety assurance will be investigated and matured. This integrated approach enables the IV&V Program to be more efficient with its resources, conducting outreach and advancing student capabilities while rapidly maturing innovative capabilities and technologies for infusion into the IV&V Program.

The overarching goals that will be achieved by the NASA IV&V Space Flight Design Challenge are:

1. 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
2. Advance the public's awareness, education, knowledge, and STEM capabilities in space systems software engineering
3. Advance the disciplines of systems engineering and software engineering by exploring game changing technologies for NASA

An incremental approach is being taken to realize these goals in which each increment of the Space Flight Design Challenge identifies the technology innovations to explore and mature through the development of a space-based mission. The innovations in technology to be explored during each increment may come from NASA's integrated technologies roadmap, from IV&V's capability development group, directly from NASA's missions, professional engineering societies, etc.

Each increment of the Space Flight Design Challenge consists of executing NASA's development life cycle, where students will learn firsthand how NASA builds complex systems. Organizing the Space Flight Design Challenge around increments progressively increases participation (second increment involves WV colleges and universities, third increment involves WV colleges/universities and high schools in the state of WV, fourth increment involves all learning institutions in the state of WV, and the fifth increment is nation-wide participation), and builds on growing achievements to reach higher goals for enhancing the educational experience, IV&V benefits, and systems and software engineering disciplines needed to build and deploy state of the art systems. Figure 1 is an overall summary depicting what success looks like for each increment, relative to the overarching goals established for the IV&V Space Flight Design Challenge.

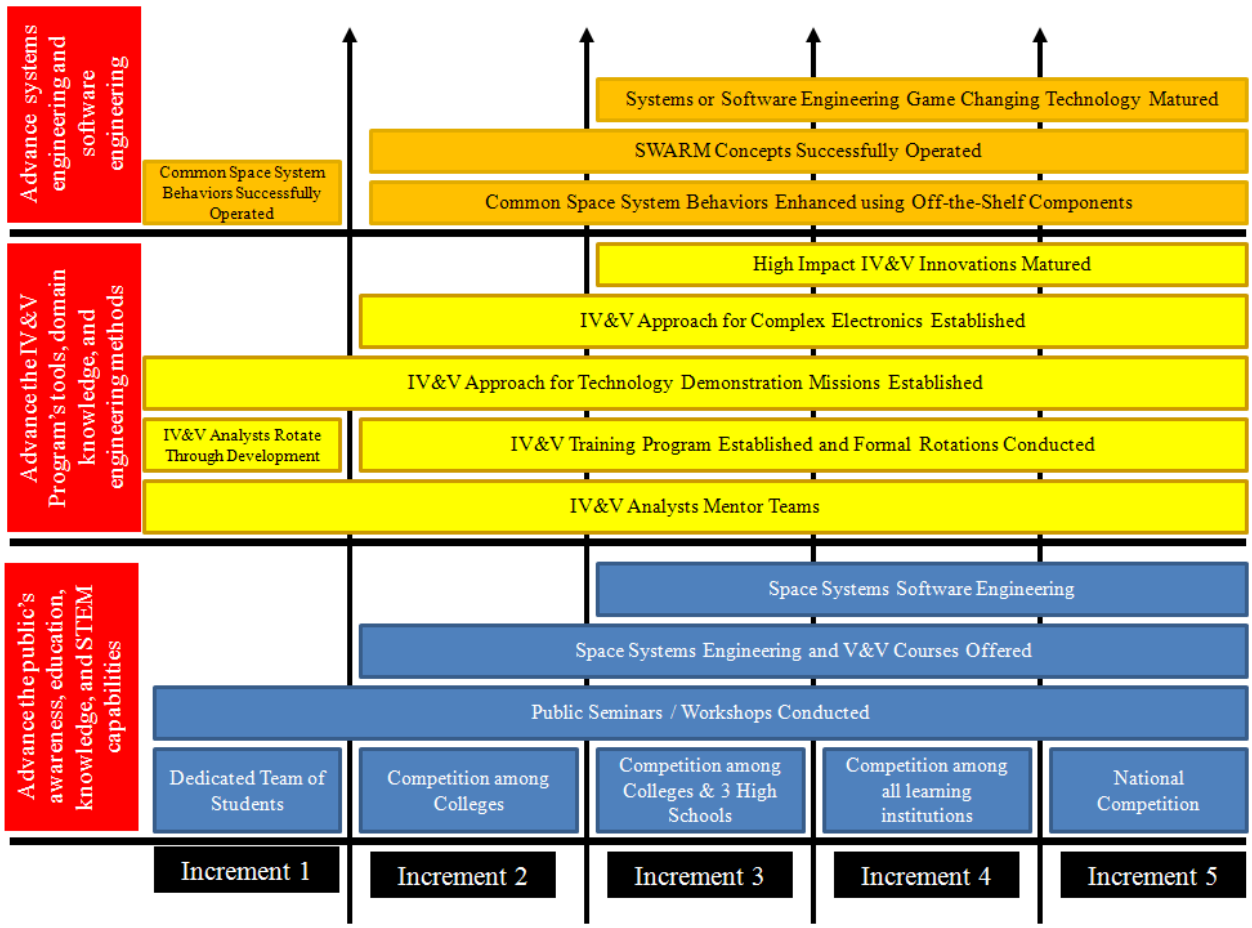

Figure 1: Objectives to be achieved for each increment relative to the overarching goals of the IV&V Space Flight Design Challenge. The overarching goals for the Space Flight Design Challenge are depicted vertically and the increments are represented horizontally. For increment 1 the Space Flight Design Challenge will advance the public's awareness, education, knowledge, and STEM capabilities by utilizing a dedicated team of students to build our first spacecraft and we will conduct public seminars and workshops. To advance the IV&V Program's tools, domain knowledge, and engineering methods increment 1 will focus on incorporating IV&V analysts as mentors and developers, as well as we will apply IV&V on increment 1's development efforts to understand the application of IV&V on university-built technology demonstrating missions. To advance systems engineering and software engineering, increment 1 will focus on developing a reusable architecture for a space-based mission.

Section 1.2 presents the specific objectives for increment 1 along with minimum success criteria.

The risk classification for this project and subsequently the payload(s) that will be flown was assessed using NPR 8705.4 "Risk Classification for NASA Payloads". It is determined that the risk posture for this outreach and technology exploration/demonstration mission is low. Specifically it would be considered a Class D payload based on risk (see appendices).

1.2 Objectives

The first increment of the IV&V Space Flight Design Challenge, strives to advance the overall Space Flight Design Challenge towards its overarching goals by achieving the following objectives:

- Overarching Goal: Advance the public's awareness, education, knowledge, and STEM capabilities in space systems software engineering
    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: 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
    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: Advance the disciplines of systems engineering and software engineering by exploring game changing technologies for NASA
    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

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

Specific science and/or engineering objectives that represent specific technological innovations may be presented in the increment 1 Concept of Operations. The ambiguity created is not ideal however, in order to establish an implementation plan (this document) we know what the minimum success objectives are for increment 1 (see items 1 and 2 above). Other scientific and engineering technology advancements can be included in increment 1 and if they are they will be defined Increment 1 Concept of Operations.

1.3 Mission Description & Technical Approach

OC-Flight-1 is the first space system designed, built, tested, and operated by the NASA IV&V Program and West Virginia Space Grant Consortium. The primary objective is educating university students and enhancing the domain knowledge of the IV&V workforce, ultimately providing opportunities for hands-on learning in the Science, Technology, Engineering, and Math (STEM) disciplines. Additional objectives include enhancing the public's awareness of NASA, establishing IV&V approaches on university-built space missions and establishing a reusable architecture for microsatellite systems.

The first increment of the IV&V Program's Space Flight Design Challenge will utilize the commercial spacecraft kit "TubeSat" offered by Interorbital Systems (http://interorbital.com/). Collaboration with the West Virginia Space Grant Consortium will provide students for a dedicated development team for increment 1. The Increment Development Team will include in addition to the students, employees from the NASA IV&V Program.

The Increment 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 dedicated team is responsible for testing the assembled spacecraft and delivering it to the launch provider 2 weeks prior to launch. The dedicated 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.

More details regarding the spacecraft kit and technologies to be flown is described in the Increment 1 Concept of Operations.

1.4 Management Structure and Implementation Approach

The NASA IV&V Program has teamed with West Virginia's Space Grant Consortium, managed out of West Virginia University (WVU) to implement increment 1. There is an overall group responsible for providing formal authorization to proceed through development, launch and operations. This group is called the NASA IV&V Space Flight Design Challenge Advisory Committee and includes senior leadership from the NASA IV&V Program and the West Virginia Space Grant Consortium. Membership includes:

- NASA IV&V Director and Deputy Director
- NASA IV&V Office Leads –Program Support Office Lead, IV&V Office Lead, Safety and Mission Assurance Support Office Lead, and Strategic Communication Office Lead
- West Virginia Space Grant Consortium Director

This Advisory Committee is responsible for authorizing:

- System Requirements, System Architecture, and Acceptance Level Test strategies using the results from the System Requirements Review (SRR)
- Subsystem requirements, subsystem designs and interfaces, and Integration testing strategies using the results from the Preliminary Design Review (PDR)
- Final Designs and interfaces using the results from the Critical Design Review (CDR)
- Go Forward with integration using the results from the Systems Integration Review (SIR)
- Launch using the results from the Safety and Mission Success Review (SMSR)

The Increment 1 Development Team includes:

- Project Management – NASA IV&V Associate Director

- Project Systems Engineer – NASA IV&V COOP
- Project Engineers – Students from WV Space Grant Consortium
- Project Engineers and Mentors – Employees from the NASA IV&V Program
- NASA IV&V Education Outreach Lead – to guide and advise on approaches and processes to ensure efficient transition towards future increments
- NASA IV&V Capability Development Lead – to guide and advise development in establishing effective IV&V framework for increment 1 as well as subsequent increments

The implementation approach utilizes the development cycle commonly used by NASA missions, slightly modified and adapted to our system development effort. The following is a list of the major phases that the Increment Development Team shall follow:

- (*pre-Phase A*) Concept Exploration
    - The Increment Development Team shall develop the objectives for increment 1, the concept of operations for increment 1, and an increment implementation plan.
        - Product = Increment 1 Concept of Operations describes how the system is to be operated to achieve the objectives for the increment (the objectives are refined to add specificity to the scientific or engineering advancements that the increment is going to mature), describes the measurement set required for a successful mission, data volume for the measurement set, how the system will be integrated, tested, launched, and retired. The Concept of Operations will also describe the major phases of the mission, operational time-lines, operational scenarios, end-to-end communication strategies, and the operational facilities needed.
        - Product = Increment 1 Implementation Plan describes the overall project, the management approach along with products to be developed, organizational structure, technical approach, safety and mission assurance approach, risk management approach, schedule, resource estimate and data management plan.
- (*Phase A*) Concept Development & Technology Studies
    - Increment Development Team shall develop the system requirements and a system architecture that meets the objectives and concept of operations for increment 1.
    - The Increment Development Teams shall model their proposed solution for the mission. The Increment Development Team shall demonstrate their understanding of the concept and requirements to demonstrate the feasibility of their suggested new system.
        - Product = OC-Flight-1 System Requirements specify what the system needs to do in order to realize the objectives presented in the Concept of Operations. Objectives stated in the Concept of Operations will repeat those objectives in the Implementation Plan as well as refine them further to account for the scientific and/or engineering technologies being matured by this increment.
        - Product = OC-Flight-1 System Architecture describes the overarching system components, interactions (i.e. interfaces), performance characteristics and limitations, etc.
        - Product = OC-Flight-1 Acceptance Level Testing describes the verification approach to be followed to assure the system requirements have been implemented. Acceptance level testing includes thermal testing and vibration testing.

    - The Increment Development Team shall conduct a System Requirements Review (SRR) with the NASA IV&V Advisory Committee. The SRR is the logical gate used by the NASA Advisory Committee to ensure engineering artifacts are maturing at a logical rate and that development should proceed.
- (*Phase B*) Preliminary Design
    - The Increment Development Team shall continue to evolve the design of the system in enough detail to establish an initial baseline capable of meeting mission needs.
        - Product = <u>OC-Flight-1 Subsystem Requirements and Designs</u>
        - Product = <u>OC-Flight-1 Subsystem Interface Control Documents</u> (may be part of the Subsystem Designs) describes the interactions of the subsystems within the system-level architecture
        - Product = <u>OC-Flight-1 Integration Testing</u> describes the verification approach that assures subsystem requirements have been implemented, including the interfaces.
    - The Increment Development Team shall conduct a Preliminary Design Review (PDR) with the NASA IV&V Advisory Committee to demonstrate that the preliminary design meets all system requirements with acceptable risk. The PDR will show that the correct design options have been selected, interfaces have been identified, and verification methods have been described.
- (*Phase C*) Design and Manufacturing
    - The Increment Development Team shall finalize their designs to meet requirements and begin fabrication of test and flight article components, assemblies, and subsystems.
        - Product = Final Designs and Interfaces
    - Critical Design Review (CDR) is conducted about halfway through this phase and the Increment Development Team demonstrates that the maturity of their design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.
    - The Increment Development Team finishes building and unit testing of flight and ground subsystems.
    - Systems Integration Review (SIR) is conducted and ensures that the system is ready to be integrated. Segments, components, and subsystems are shown to be available and ready to be integrated into the system. Teams demonstrate that integration facilities, support personnel, and integration plans and procedures are ready for integration.
- (*Phase D*) Systems Integration and Test
    - The Increment Development Team shall integrate their subsystems (including operations systems) to create the system, while developing confidence that it will be able to meet the systems requirements and objectives for increment 1.
    - The Increment Development Team conducts integration testing and acceptance-level testing
        - Product = All Test Results
    - Safety and Mission Success Review (SMSR) – The NASA IV&V Committee invites representatives from the Office of Safety and Mission Assurance (OSMA) to participate in an overarching technical review to determine if the Increment Development Team is ready for launch. The review examines tests, demonstrations, analyses, and audits that determine the system's readiness for a safe and successful flight or launch and for subsequent flight operations. It also ensures that all flight and ground hardware, software, personnel, and procedures are operationally ready.
- Launch

- (*Phase E*) Operations
    - The Increment Development Team operates the mission as defined in the concept of operations that was developed in earlier phases, commissioning their flight systems and collecting and archiving mission and science data.
- (*Phase F*) Decommissioning
    - The Increment Development Team disposes of the system in a responsible manner as defined in the concept of operations.

In parallel to the development efforts:

- Employees from the IV&V Program shall join the development efforts to enhance their domain knowledge
- Employees from the IV&V Program shall mentor the Increment Development Team in developing the system
- The Increment Development Team shall conduct several public seminars and workshops to engage the public in NASA's efforts in general as well as in specific topics associated with Increment 1 development efforts

2.0 Project Baseline

2.1 Schedule Baseline

See Project schedule entitled "Increment 1 Schedule"

2.2 Resource Baseline

Item	Cost
TubeSat Kit including launch	$8,100
PCB Fabrication	~$1,500
Students	~$30,000
Additional Spacecraft Components	~$2,000
Payload(s) - concept is we team with those that bring in kind contributions to fly their instruments and advance their position in the scientific community	~$5,000
Test Facilities - concept is we team with those willing to donate time in vibration and thermal chambers	$0
Shipping with insurance	~$1,000
Publications and Literature	~$2,400
Total	~$50,000

As you can see from the resource estimate, over 60% of the costs are for labor (students). Future increments will plan to integrate the development of the spacecraft into the classroom resulting in the labor costs for students disappearing. This will effectively give the NASA IV&V Program the capability to perform advancements in STEM, IV&V, and systems engineering for around $20,000 per mission.

3.0 Project Control Plans

3.1 Technical and Schedule Control Plan

As described in the Implementation Approach of section 1.4, several reviews are held to help ensure engineering artifacts are maturing appropriately and risks are being properly managed. Additionally, monthly reporting shall be conducted to maintain awareness of progress being made.

3.2 Safety & Mission Assurance Plan

Given that this mission is an outreach and technology exploration/development effort and the accompanying payload(s) are characterized as Class D payloads (see accompanying appendices), increment one will focus on two major areas for Safety and Mission Assurance:

1) Safety and mission assurance

The Safety and Mission Assurance Support Office (SSO) within the NASA IV&V Program shall determine the assurance-related activities applicable to this mission. Specifically, it would be ideal if Fault Tree Analysis (FTA) would be conducted along with training sessions for the Increment Development Team and the public.

2) Independent Verification and Validation of system software
    a. Probability Based Risk Assessment
        - The IV&V effort shall evaluate the mission scenarios used to develop the system requirements to identify those scenarios that are of highest concern.
    b. Requirements Validation
        - The IV&V effort shall determine whether or not the Increment Development Team has specified the right requirements using an advanced approach for validating requirements
    c. Test Validation
        - The IV&V effort, using the results from the risk assessment, shall determine if the Increment Development Team is adequately testing the system
    d. Architecture/Design Verification
        - The IV&V effort shall determine whether or not the proposed architecture can satisfy the system requirements.
    e. System Implementation verification
        - The IV&V effort, using the results of Test Validation, shall complement the development testing and provide advanced strategies for executing the system.

A closed loop problem reporting and resolution system will be used that is maintained by the NASA IV&V Program, ORBIT.

3.3 Risk management Plan

The risk management approach used for Increment 1 is to follow the risk management approach employed by the NASA IV&V Program.

4.0 Waivers

There are no waivers being sought.

5.0 Change Log

Date	Version	Description of Changes
10/25/2011	1.0	Initial plan
11/16/2011	1.1	Identified the products to be developed during each phase of implementation

6.0 Appendices

6.1 Acronyms

IV&V	Independent Verification and Validation
SFDC	Space Flight Design Challenge
SMA	Safety and Mission Assurance
SSO	Safety and Mission Assurance Support Office
WVU	West Virginia University

6.2 Payload Risk Classification and Safety and Mission Assurance Requirements

See NASA NPR 8705.4 “Risk Classification for NASA Payloads”

6.3 Technical Reviews

See NASA NPR 7123.1