CubeSat Launch Initiative
Reference Number: NNH11SOMD002L

To inspire, engage and educate the next generation...

AMSAT *Fox-1*

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AMSAT *Fox-1* CubeSat Project

The front cover photo shows 5th grade students participating in a *hands-on* STEM learning experience offered through their school's gifted and talented program. These elementary school students learned about space communications *first hand*, as they accessed the AMSAT AO-51 satellite. Though AO-51 is now experiencing battery problems, Fox-*1* will ensure continued availability of these learning opportunities.

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Abstract

AMSAT is a non-profit, research and education organization. Since its founding in 1969, it has been a pioneer in the development and applications of small and micro satellites. AMSAT projects are funded through donations and passionate volunteers do all of the technical work. While most of our volunteers are highly experienced industry veterans or retirees, AMSAT welcomes contributors of all ages and technical abilities and provides training as needed. With over 3,000 members, AMSAT is well represented throughout the ranks of industry, NASA and the university satellite community. Many AMSAT members have been technical advisors on university CubeSat projects.

AMSAT *Fox-1* is a 1-Unit CubeSat and the primary focus of the project is education. The satellite will host a two-way FM communications transponder and an experiment payload. The communications package is specifically designed to be *easy-to-use* requiring only a simple *walkie-talkie* style radio combined with a small hand-held antenna. Using amateur radio frequencies, it will be open and available to the general public. This simple, low-cost on-orbit capability facilitates a wide spectrum of STEM educational opportunities from inspiring young minds and engaging secondary school students to educating teachers and university students.

In the classroom, having an accessible on-orbit asset will allow schools, teachers and students to participate in space technology with a *hands-on* experiential learning approach. This approach can help make difficult STEM concepts far more interesting and easier to grasp. AMSAT aims to make STEM education *fun*.

On the informal side, *Fox-1* will provide a technology *stepping stone* that is easily accessible to the average citizen, requiring only an amateur radio license to participate. This can generate interest in STEM topics through a hobby activity and may even lead to active participation in satellite technical advancement. *Fox-1* will also enable informal groups with educational goals, such as youth scouting organizations, to help inspire their members to embrace STEM through participatory activities using the satellite. This promotes technology and space literacy among the general public.

In addition to the communications package, *Fox-1* will host an experiment payload developed by university students. AMSAT is sponsoring this development as a *capstone* project at Penn State University for the 2011-2012 academic year. Senior engineering students are developing an attitude determination experiment for graduation credit with mentoring and guidance provided by AMSAT. In addition to the hands-on, real-world experience provided to the students, the experiment data will be valuable in planning future satellite projects. All of the experiment and satellite telemetry data will be collected and stored on our Internet server. This data will be made publicly available for use in the classroom by educators and shared with the general CubeSat community.

The Fox-1 project has an educational focus and we conducted a non-competitive merit review. Our review panel members included academic and industry experts who were not on the Fox-1 development team. The merit review panel concluded that the project "meets NASA needs and

goes beyond." The merit review team also offered suggestions for improving our education message and these have been incorporated in the *Fox-1* project.

We conducted a non-competitive feasibility review. Our review panel members included academic and industry experts who were not on the Fox-1 development team. The feasibility review committee concluded that there was "a very high probability of success" and noted that the AMSAT team "well exceeded typical other CubeSat teams in depth and breadth of skill and experience." The feasibility review team offered suggestions for improving our development process and these have been incorporated in the *Fox-1* project.

Compliance Checklist	Section
☑ Respondent is a NASA center, a U.S. not-for-profit organization, or an accredited U.S. educational organization	**1**
☑ Proposal includes demonstration of the benefits to NASA	**9**
☑ Proposal identifies a project focus area	**1**
☑ Proposal includes a description of the merit review process and outcome	**10**
☑ Proposal includes a description of the feasibility review process and outcome	**11**
☑ Proposal must fully comply with the P-POD integration requirements	**2**
☑ Proposal includes a completed Mission Parameters Table.	**8**
☑ Proposal includes a schedule for remaining CubeSat development that supports a launch in 2012, 2013, or 2014	**6**
☑ Proposal includes funding commitment letters demonstrating sufficient financial support for remaining CubeSat development	**Appendix 2**

Proposal Detail

1 Introduction

1.1 Eligibility

AMSAT, The Radio Amateur Satellite Corporation, was incorporated in 1969 in Washington D.C. It is a non-profit 501(c)(3) research and education organization listed in IRS Publication 78. AMSAT has over 3,000 members.

1.2 Mission Overview

AMSAT volunteers and undergraduate university students are developing the *Fox-1* CubeSat. The primary focus of this project is to support STEM education. *Fox-1* will host a two-way FM communications transponder and an experiment payload. The communications package will be specifically designed to be easy-to-use requiring only a simple *walkie-talkie* style radio combined with a small hand-held antenna. Using amateur radio frequencies, it will be open for use by the general public. This capability will facilitate a wide spectrum of STEM educational opportunities from inspiring young minds and engaging K-12 pupils to educating teachers and university students. Collaboration with ARRL, The National Association for Amateur Radio will result in educator training seminars that will include using *Fox-1* in classroom activities.

In addition to the communications package, *Fox-1* will host an experiment payload. AMSAT is sponsoring a *capstone* project at Penn State University for the 2011-2012 academic year. Senior engineering students will be participating for graduation credit with mentoring and guidance provided by AMSAT volunteers. The project will involve designing and constructing an attitude experiment based on a 3-axis, micro-electro-mechanical gyroscope. The experiment data will measure the performance of the satellite's magnetic stabilization system. While the primary focus of the experiment payload is to provide a hands-on, real-world educational experience for the students, the experiment data will be valuable in planning future CubeSat projects.

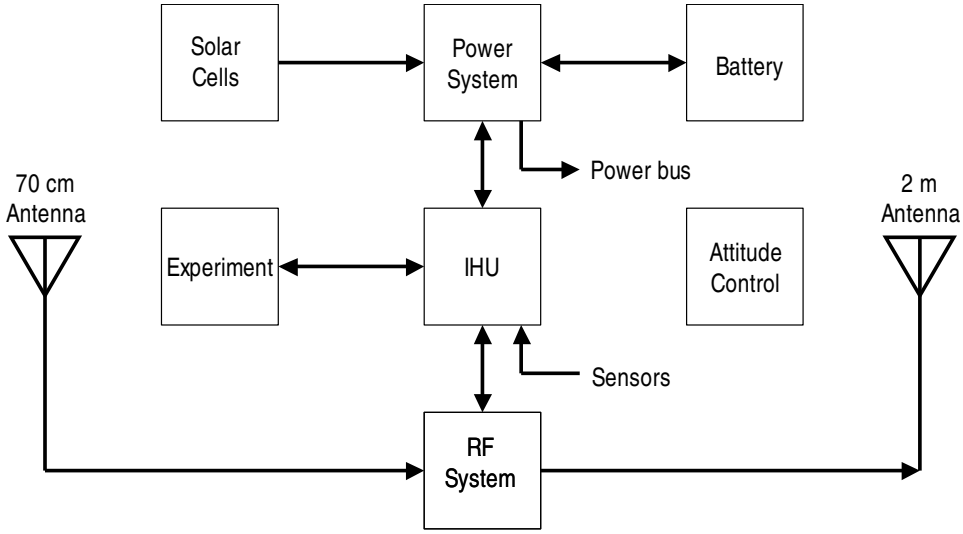
1.3 CubeSat Project Details Table

CubeSat Project Details						
Focus Area	Student Involvement	NASA Funding		Sponsor	Proposal Collaboration	
		Yes or No	Organization		Yes or No	International- Yes of No
Education	Yes	No		AMSAT	Yes	No

AMSAT is collaborating with ARRL, The National Association for Amateur Radio. ARRL will be incorporating *Fox-1* into their professional development seminars for educators. A letter of support from ARRL and a copy of the Teacher Institute program brochure are included in APPENDIX 2.

2 *Fox-1* Spacecraft Description

Fox-1 is a 1U CubeSat. It will be designed and tested to be fully compliant with the Launch Services requirements as described in “Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (P-POD) and CubeSat Requirements Document (LSP-Req-317.01).”



The major subsystems of the Fox-1 satellite include the attitude control system, the power system, an internal housekeeping unit (IHU,) the radio (RF) system and the experiment payload as shown in the figure above. There are six solar panels with one on each face of the CubeSat. The power system uses the power generated by the solar panels to drive the power bus and charge the battery. In eclipse, the power needed to run the satellite comes from the stored energy in the battery. The internal housekeeping unit (IHU) is the brains of the satellite and is based on an ultra-low-power microcontroller. The RF system includes a FM receiver, a FM transmitter and the necessary logic to operate either under control of the IHU or as an automatic FM repeater. The satellite uses passive magnetic stabilization and a photon motor to spin the satellite for thermal considerations. The antennas are monopoles aligned with the satellite's magnetic axis to minimize spin-modulation. The experiment payload, being developed by students at Penn State, will include a 3-axis micro-electro-mechanical gyroscope and a microcontroller to calculate the satellite spin rate, direction and off-axis "wobble." This will measure the performance of the attitude stabilization system. Project technical documents are included in APPENDIX 3.

3 Project Organization and People

AMSAT engineering is staffed completely by passionate volunteers and is organized as project teams. Each project has a project leader who is responsible for the overall success of the project including the planning, execution, monitoring, control, completion and budget.

The project work and activities are structured by function or subsystem. A self-directed individual or team is responsible for each of these functional parts of the project. There is no official hierarchy or management within a functional team. AMSAT relies on outstanding

informal leaders who have demonstrated superior technical and influence skills to provide guidance to their functional team as well as the entire project. This structure has been used on previous satellite projects and works very well for our distributed volunteer teams.

AMSAT has a university program manager who is responsible for representing AMSAT on the experiment team. The experiment team is staffed with six undergraduate students and a faculty member from Penn State. There is also an AMSAT technical mentor on the team to provide technical assistance.

In addition to the Penn State students, two undergraduate students are working on Fox-1 as AMSAT volunteers. AMSAT recognizes that school is their top priority and welcomes their participation.

The current list of AMSAT and Penn State team members is provided in the Project Plan in APPENDIX 3. Resumes for key AMSAT team members are provided in APPENDIX 1.

4 Engineering Process

Fox-1 follows the AMSAT engineering process. This documented process describes a project *lifecycle* model and includes Concept, Design, Implementation & Test, and Operations & Maintenance phases. Both formal and informal reviews are used within the phases to maintain system consistency, detect errors as early as possible and to facilitate a clear understanding of the project status. A copy of the AMSAT engineering process is included in APPENDIX 3.

5 Risks and Mitigation

The following areas have been identified as the major project risks and the means of mitigation.

5.1 Volunteer Staff - High Risk

AMSAT's engineering team is all volunteers. Unforeseen family and day-job related events can and have caused loss of volunteer time availability. AMSAT has no capacity to hire replacements. This is the major schedule risk. To mitigate this risk, AMSAT:

- Makes an upfront attempt to staff each functional area with more than one volunteer
- Constantly recruits new volunteers
- Looks to our "bench" of past volunteers for short term assignments if needed
- Includes 3 months of contingency time in the development schedule

5.2 Space Radiation - Medium Risk

The *Fox-1* satellite has a target mission lifetime of 5 years in orbit. The target orbit is sun-synchronous at 650 km altitude, which will cause substantially higher radiation exposure than an ISS orbit. AMSAT cannot afford to use Rad-Hard components and COTS components are generally sensitive to radiation. To mitigate this major technical risk, AMSAT will:

- Include a team member who assigned to research radiation
- Model the radiation exposure
- Test key components for radiation sensitivity
- Design the electronics systems for fault tolerance
- Use additional radiation shielding to protect key components.

5.3 New, High Performance Components - Low Risk

Several new high-performance components are recently available that have considerable benefits for use in the *Fox-1* satellite. Since they are new, team members have no experience using these components and are unfamiliar with their limitations, especially undocumented or unspecified behaviors. These include components such as a high-efficiency RF power amplifier, an ultra low power microcontroller and a solar panel maximum power point tracker. Since these risks can be reasonably controlled, they pose a low risk level after mitigation but remain as the second source of technical risk. To mitigate these risks, AMSAT plans to:

- Prototype specific circuits and test them in laboratory settings
- Test using manufacturers evaluation cards where possible
- Prove-in new components before design-in to the satellite

5.4 Penn State Student Developers - Low Risk

The experiment card for the *Fox-1* satellite is being designed by undergraduate engineering students. These students have limited technical experience. They are also expected to graduate in May 2012 and cannot be counted on after that to work on the project. Since the key NASA benefit from student involvement is training, that benefit is not at risk if the students don't finish the experiment card by graduation. In addition, the primary mission of the satellite will operate without the experiment card. However, AMSAT would not be able to obtain our desired experiment data. To mitigate this low technical risk, AMSAT has :

- An AMSAT program advisor to track progress of the student team
- Provided a technical mentor to the students
- A contingency to have AMSAT volunteers complete the experiment

6 Project Status and Timeline

The initial technical and operational investigations of the AMSAT *Fox* satellite program were kicked off in October 2010. A Concept Review was held in April 2011 to review the results of these investigations. After further investigations, the program strategy was refined and endorsed by the AMSAT board of directors in July 2011. *Fox-1* represents the first project planned within a new series of AMSAT CubeSats. The project progress so far includes:

- *Fox-1* project defined - July 2011
- Concept of Operations (ConOps) - Sept 2011
- System Requirements Spec (SRS) - Oct 2011
- Experiment Payload Specification - Nov 2011
- Project Plan draft - completion expected Dec 2011

A second Concept Review was held in October 2011 to review the proposed Fox-*1* satellite bus architecture and design. As of November 2011, two subsystems had been prototyped and tested to address technical risk areas. These include the RF power amplifier and the IHU microcontroller.

Key milestone dates for the remaining development work are as follows:

- Preliminary Design Review (PDR) - March 2012
- First complete engineering prototype - July 2012
- Critical Design Review (CDR) - August 2012

- Flight model ready for test - November 2012
- Launch Readiness Review - January 2013
- Launch Target - 2nd half of 2013

Note that the launch target date includes a 3-month contingency interval to mitigate schedule risk.

7 Project Funding

7.1.1 Indirect Costs

AMSAT engineering resources are expected to be needed for the project. These do not represent direct project costs but are already included in the overall AMSAT engineering budget.

7.1.2 Direct Costs

Total component and non-recurring engineering (NRE) costs are estimated at $38,500. Other direct expenses for the project such as travel, meetings, shipping and supplies are estimated at $25,000. The total of the direct project costs is estimated at $63,500. In 2011, approximately $1,500 will be spent on the project leaving $62,000 needed for 2012.

AMSAT has committed to funding the complete cost of the project including the flight satellite and a complete flight spare unit. In addition, the AMSAT budget includes a launch contingency reserve in the event of a requirement to reimburse NASA. Please see the AMSAT funding commitment letter in APPENDIX 2.

8 CubeSat Mission Parameters Table

CubeSat Mission Parameters								
Mission Name	Mass (kg)	Cube Size	Desired Orbit		Acceptable Orbit Range (minimum)	325 km @ 51.6 degree incl. Acceptable- Yes or No	Readiness Date	Desired Mission Life
Fox-1	1.33	1U	Altitude	650 km	600 km apogee	No	April 2013	10 years
			Inclination	98.2°	40°			

While AMSAT has indicated a 650 km, sun synchronous orbit as our target, the satellite design will accommodate a wide range of orbit altitudes and inclinations. The major consideration is the desire for at least 10 years in orbit.

9 Benefits to NASA

The AMSAT *Fox-1* project addresses a broad spectrum of involvement identified in the NASA Education Strategic Coordination Framework. This includes inspiring youth and the general public via outreach activities to formal education of university students and professional educators.

9.1 Education Goal: Engaging Americans in NASA's mission

NASA will engage students, educators, families, the general public, and all Agency stakeholders to increase Americans' science and technology literacy.

Photo courtesy of Make Magazine.

Fox-1 will be a publicly available on-orbit asset designed to be *easy-to-use*, requiring only an amateur radio license to participate. This technology *stepping-stone* will help generate interest in STEM topics through hobby activities and will lead to active participation in technical advancement.

Fox-1 will enable groups, such as youth scouting organizations and amateur radio clubs, to promote informal STEM education through activities using the satellite. It offers opportunities for self-learning and improved technology literacy to interested Americans.

Shown in the photo is Diana Eng, a well-known fashion designer, demonstrating a collapsible fabric antenna that she created to communicate through the AMSAT AO-51 satellite. Her article about this project appeared in Make Magazine, which targets a wide audience and promotes technology literacy. Though AO-51 is now experiencing battery problems, *Fox-1* will ensure continued availability of these opportunities for public engagement.

9.3 Education Goal: Attracting and retaining students in STEM disciplines

NASA will focus on engaging and retaining students in STEM education programs to encourage their pursuit of educational disciplines critical to NASA's future engineering, scientific, and technical missions.

In the classroom, *Fox-1* will allow schools, teachers and students to actively participate in space technology with a unique *hands-on* experiential learning approach that includes communicating through a satellite in orbit. And, while AMSAT encourages everyone to obtain an amateur radio license, the students do not have to have one to be involved. All that is needed is for a licensed teacher or classroom volunteer to be present.

The smiles on these 7th grade students in the photo on the left belie the fact that they are actively engaged in a STEM activity at their school and learning about satellites. The recent AMSAT ARISSat-1 satellite enabled this activity and shows how the *hands-on* approach can help make difficult STEM concepts far more interesting and actually *fun*! ARISSat-1 will de-orbit next year but all of the satellite telemetry data is being collected and stored on an AMSAT Internet server and is openly available for use in the

classroom. The *Fox-1* project will assure that this capability will be continued and will include free telemetry decoding and display software.

A letter of support from the Clay Center for Science and Technology at the Dexter School and Southfield School endorsing AMSAT satellites for their educational value is included in Appendix-2.

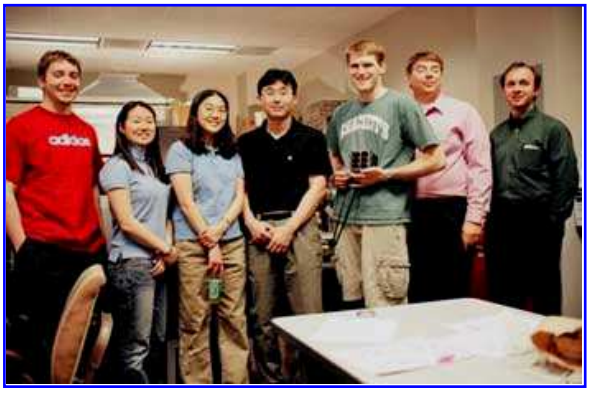
9.4 NASA Education Outcome 2 - Professional Development

Attract and retain students in STEM disciplines through a progression of educational opportunities for students, teachers, and faculty.

AMSAT is collaborating with ARRL, The National Association for Amateur Radio, to insure that timely and accurate information about *Fox-1* is included in their professional development courses for educators. Each summer, ARRL offers multiple sessions of the Teachers Institute on Wireless Technology, a 4-day expenses paid professional development seminar. The Teachers Institute has provided educators from elementary school to the university level with tools and strategies to introduce basic electronics, radio science, space technology and satellite communications in their classrooms. The TI-2 seminar, *Space in the Classroom,* focuses on space and satellite communications. Graduate credits are available through these seminars that can be used to satisfy professional growth requirements needed to maintain teaching credentials. A current program brochure and a letter of support for the *Fox-1* project from ARRL are included in APPENDIX 2.

9.5 Education Goal: Strengthening NASA and the Nation's future workforce

NASA will continue contributing to the development of the Nation's science, technology, engineering, and mathematics workforce of the future through a diverse portfolio of education initiatives that target America's students at all levels



Over the past several years, AMSAT volunteers have participated in student projects as mentors and advisors at Cornell, SUNY, Auburn, the University of Arizona and the College of New Jersey. These projects have provided undergraduate and post-graduate engineering students with exposure to spacecraft systems design and development.

Building on these successes, AMSAT is sponsoring a *capstone* project at Penn State University for the 2011-2012 academic year. AMSAT is providing funding, mentoring and technical guidance for the students. Senior engineering students will be developing the

experiment payload for *Fox-1* for graduation credits. The thrill of knowing that *your* senior project will be going into orbit is a powerful and exciting motivator for the students.

10 Merit Review

The AMSAT *Fox-1* team held a merit review. The review was conducted as an on-line, multimedia teleconference with key members of the *Fox-1* team and a review panel of academic and industry experts.

- What was the merit review process?

The AMSAT team presented a set of power point slides that included an overview of the *Fox-1* mission. Since the focus of *Fox-1* is education, we also presented a review of the NASA Education Strategic Coordination Framework including the NASA Education Implementation Framework. The aspects of the *Fox-1* project that address the NASA education goals and outcomes were highlighted. The review panel was then asked for their comments, suggestions and an overall assessment of the merits of the *Fox-1* project.

- Was the merit review competitive or non-competitive?

The merit review was non-competitive.

- What were the qualifications of the merit review committee members?

The merit review panel included the following members (alphabetical order):

1. Mr. David Hinkley is the Project Leader, Mechanics Research Office of The Aerospace Corporation.
2. Dr. Allen Katz is a Professor of Engineering Science, College of New Jersey and President of Linearizer Technology, Inc. (LTI.)
3. Mr. Jan King is a distinguished space industry veteran with more than 40 years of experience including the development of 12 large and 17 small spacecraft and one launch vehicle.
4. Dr. Robert McGwier is the Director of Research, Hume Center for National Security and Technology and a Research Professor, Department of Electrical and Computer Engineering, Virginia Tech.

Please see APPENDIX 1 for resumes of the members of the review panel.

- What factors did the merit review use to assess merit?

The panel was asked to assess the educational aspects of the *Fox-1* project that were identified as supporting the goals and outcomes identified in the NASA Education Strategic Coordination Framework.

- What was the outcome of the merit review?

The merit review panel determined that the project "*nailed*" the education goals and that the project "*meets NASA needs and goes beyond*." A panel member commented that AMSAT has a history of space education that is "*demonstrated better than just about any other organization.*" The review panel suggested that we should mention our past successes especially the ARISSat-1 and AO-51 satellites.

Another suggestion was that we should point out that in the classroom, only a teacher or an outside volunteer needs to have an amateur radio license to allow the students to make use of the satellite. They also recommended that we highlight that all of our telemetry and experiment data will be openly available on our server and has educational value for classroom use.

- How did the Respondent respond to and/or address the findings of the merit review?

We will update our Public Relations plan to include mention of the additional educational benefits suggested by the review panel.

11 Feasibility Review

The AMSAT *Fox-1* team held a feasibility review. The review was conducted as an on-line, multimedia teleconference with key members of the *Fox-1* team and a review panel of academic and industry experts.

- What was the feasibility review process?

The AMSAT team presented a set of power point slides that provided key information about the technology, people, organization, processes, risks, progress, schedule and financial support. The review panel was asked for their comments, suggestions and an overall assessment of the feasibility and likelihood of success of the *Fox-1* project.

- What were the qualifications of the feasibility review committee members?

The feasibility review panel included the following members (alphabetical order):

1. Mr. David Hinkley is the Project Leader, Mechanics Research Office of The Aerospace Corporation.
2. Dr. Allen Katz is a Professor of Engineering Science, College of New Jersey and President of Linearizer Technology, Inc. (LTI.)
3. Mr. Jan King is a distinguished space industry veteran with more than 40 years of experience including the development of 12 large and 17 small spacecraft and one launch vehicle.
4. Dr. Robert McGwier is the Director of Research, Hume Center for National Security and Technology and a Research Professor, Department of Electrical and Computer Engineering, Virginia Tech.

Please see APPENDIX 1 for resumes of the members of the review panel.

- What factors did the feasibility review use to assess feasibility?

The review panel assessed the *Fox-1* project according to the following factors:

1. Technology and technical approach
2. Engineering process
3. People and project organization
4. Major risks and mitigation
5. Progress to date
6. Remaining development and schedule
7. Project financial requirements and support

- How were the management team roles, experience, expertise, and the organizational structure of the team assessed?

The reviewers noted that the tremendous depth and breadth of experience on the *Fox-1* team far exceeds that of a typical for a CubeSat project. They also noted that although the all-volunteer staff was identified as the major project schedule risk, AMSAT has been doing satellite development this way for 40 years and has never missed a launch.

- How was the technical development risk associated with the overall CubeSat mission assessed?

The review panel was satisfied that we had addressed the major risks but suggested that we were probably being overly conservative in our space radiation concerns. Another review panel member offered to help by providing assistance in testing components.

- If the CubeSat investigation requires critical technology development for flight readiness, how were the areas assessed, and how were the plans for completing technology development assessed?

Fox-1 does not depend on any critical technology development for flight readiness.

- Concerning the development of the CubeSat for flight, how was the probability of success assessed?

The review panel assessment was that the project has a very high probability of success. They noted that AMSAT has an excellent record of accomplishment and that the people working on the team have substantial experience.

- What was the outcome of the feasibility review?

The review panel, while noting the high probability of success, offered a few suggestions for improvement. A key suggestion was to move our Critical Design Review to August 2012. This would allow the developers to address any problems found on the engineering prototype prior to construction of the flight models.

- How did Respondent respond to and/or address the findings of the feasibility review?

This proposal as submitted reflects all of the improvements suggested by the review panel.

- Is there sufficient financial support for the development of the CubeSat payload and for all other costs incurred by Respondent to support its participation in the project?

AMSAT has committed to fully funding the Fox-1 project. A letter of financial support from the AMSAT treasurer is included in APPENDIX 2.

12 Appendix

12.1 Appendix-1 Resumes

- Appendix-1A Review Panel
- Appendix-1B Key Members of *Fox-1* Team

12.2 Appendix-2 Supplementary Documents

- AMSAT Funding letter
- Letter of Support from ARRL
- ARRL Teacher Institute Brochure
- Letter of Support from The Clay Center for Science and Technology

12.3 Appendix-3 Project Documents

- AMSAT Engineering Process
- Concept of Operations
- System Requirements Specification
- Experiment Requirements Specification
- Mechanical Design
- Thermal Design
- System Design Specification
- Project plan
- Work Breakdown Structure
- Gantt Chart
- Public Relations Plan