

# **Experiment Memorandum of Understanding and Requirements Document**

**for**

## **FIREBIRD IMM Solar Cell Experiment (FISCE)**

DRAFT 10/22/13

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### **1.0 INTRODUCTION AND SCOPE**

This Memorandum of Understanding is a summary of various aspects of the FIREBIRD IMM Solar Cell Experiment (FISCE). It provides experiment requirements in the

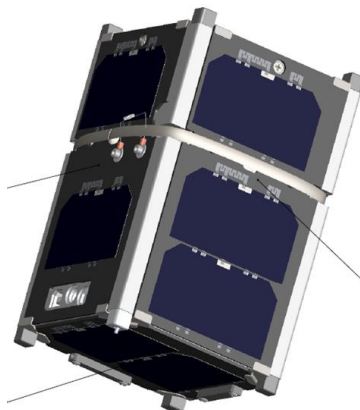
following areas: physical and functional interfaces, roles, roles and responsibilities and schedule and experiment Concept of Operation (Con-ops). The responsibilities outlined in this document will be performed on a best-effort basis and do not represent contractual commitment by either party. No exchange of funds is intended or implied by anything within this agreement.

Inverted Metamorphic (IMM) solar cells hold the promise for high efficiency because of their ability to optimize the bandgap of each subcell of a three or four bandgap cell design, but need flight data to provide additional confidence in the functionality and durability of the cells when bonded into a practical array configuration and operated in the space environment. The objective of this experiment is to fly IMM solar cells in the space environment to demonstrate their applicability, and to collect performance data over time for some of the IMM cells on the flight.

## 2.0 EXPERIMENT OVERVIEW

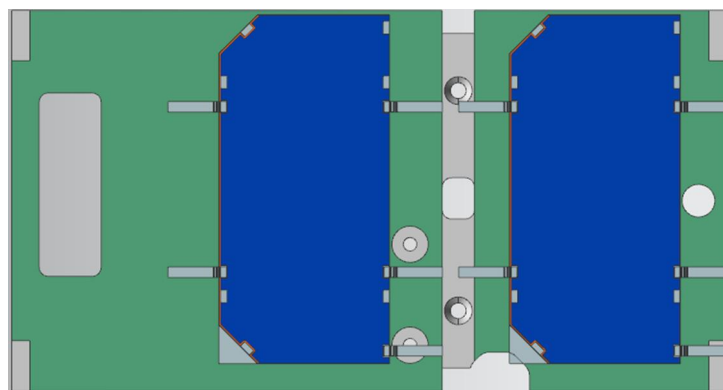
### 2.1 Mission and Experiment Description

The FIREBIRD mission comprises two 1.5U Cubesats, each of which has 5 solar panels, a bottom solar panel (which is not part of FISCE), and four side panels, three of which have 3 cells in series and one of which has 2 cells in series. It is anticipated that FIREBIRD will be launched into a high inclination LEO orbit – e.g. 400 x 600km, 123deg retrograde inclination - which will provide a high radiation environment for the spacecraft and its solar cell assemblies.

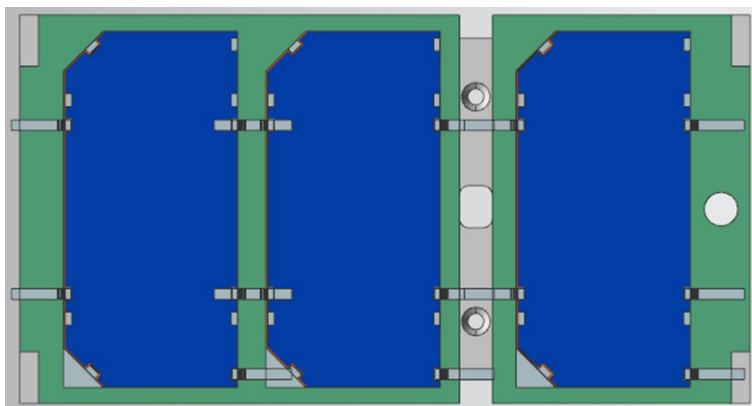


**Figure 1. FIREBIRD spacecraft**

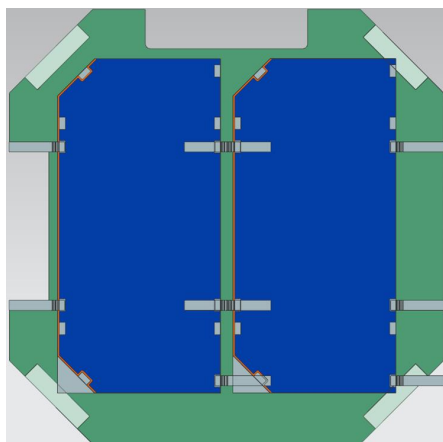
The FIREBIRD Cubesat has 5 sides containing solar cells, as shown in Figure 2, with 3 sides (+X, -Y and +Y) containing 3 cells each, and 2 sides (-X and -Z) containing 2 cells each, thus a total of 13 cells per spacecraft.



**-X panel**



**+X, -Y, and +Y panels**



**-Z panel**

**Figure 2. Five of six sides of FIREBIRD have solar panels, each with 2 or 3 cells.**

For the FISCE experiment, Vanguard will be providing cells and cell integration for +X, -X, +Y and -Y – a total of  $3+3+3+2=11$  cells – and MSU will provide the 2 cells and cell integration for -Z. One of five solar panel sides – the +Y side (TBR) – of each of the two Cubesat spacecraft shall be known as the FISCE Instrumented Panel, and will be instrumented to measure solar panel I-V, sun irradiance or pointing, and temperature on

that side. One of the 3-cell panels (+Y, TBR) will be instrumented to provide information about cell performance and state-of-health periodically.

## 2.2 Experiment Objectives and Approach

Objective	Approach
Demonstrate ability to integrate IMM cells on to composite substrate	MSU supplied FR4 (G10) substrates will be populated by Vanguard
Demonstrate power delivery of IMM cells	Accomplished thru ground testing and initial on-orbit performance
Characterize the ability of the array to provide the expected power over the primary mission	Accomplished thru on-orbit performance monitoring and ground predictions
Characterize the performance of new solar cell and panel technologies in a combined space environment that includes high radiation levels	Accomplished thru on-orbit performance characterization at the module level

## 2.3 Operational Concept

The IMM cells will be used for prime spacecraft power. The data requirements outlined below assume that the orientation of the spacecraft with respect to the Sun is known, within some tolerance (TBD), at least for the instrumented panel.

The following data collection activities have been developed to meet the preceding objectives:

- Pre-Launch verification of successful cell integration will include a sample data set obtained from each of the panels when illuminated by a TBD light source
- Spacecraft supplied electronics aboard the spacecraft will measure current-voltage (I-V) characteristics, and temperatures one panel on each of the two spacecraft
- Electronic transfer of data on a monthly or more frequent basis
- High rate data phase following launch
  - 1 I-V per day (TBR) for the 15 days following vehicle check out
  - Data is taken at near-normal illumination of the instrumented panel (within 20 degrees of sun normal TBR)
- Low rate data phase following high rate data phase
  - 1 I-V taken per week
  - Data is taken at near-normal illumination of the instrumented panel (within 20 degrees of sun normal TBR)
- Data set
  - Spacecraft ID
  - Date & Time
  - Instrumented Panel Temperature
  - Sun Sensor Reading

-I-V Curve (15 point minimum)

Spacecraft I-V electronics target specifications:

Voltage measurement accuracy: 1% (TBR)

Voltage drift over operational temperature range and radiation exposure: 0.25%

Current measurement accuracy: 1% (TBR)

Current drift over operational temperature range and radiation exposure: 0.25%

Temperature measurement accuracy: +/- 4°K (TBR)

## **2.4 Orbit Requirements**

### **2.4.1 Standard orbit parameters**

FISCE is targeting a LEO environment and requests a highly inclined orbit to maximize radiation exposure to trapped particles.

### **2.4.2 Launch Window**

Any

### **2.4.3 Required Mission Life**

Min of one year of operation is requested. Testing beyond one year is desirable.

## **3.0 Interfaces**

Vanguard shall provide add-on mass of each of the 5 experiment patters

### **3.1 Mechanical Interfaces and Integration**

The FISCE panels will use MSU supplied substrates – MSU will be responsible for identifying keep-out zones to assure that all spacecraft interfaces can be accommodated and that the panels can be mounted to the spacecraft body appropriately. Vanguard shall be responsible for mounting the cells on to the panels, either directly or via a Kapton layer, without interference to the keep-out zones

### **3.2 Temperature measurement device interface**

The FISCE Instrumented Panel shall have a hole drilled of TBD diameter and at TBD location to allow the insertion and potting of a temperature measurement device with intimate contact to the back of one of the solar cells.

### **3.3 Grounding and Isolation**

The FISCE experiment has no specific grounding requirement. Vanguard shall be responsible to assure that the cells are isolated from any substrate conductors that are not part of the solar cell electrical circuit

## **4.0 ENVIRONMENTAL REQUIREMENTS**

#### **4.1 Launch Vehicle Environments**

Per Cubesat guidelines

#### **4.2 Temperature Requirements**

The FISCE panel shall be capable of handling temperatures from -70 to +90C

#### **4.3 Cleanliness Constraints**

Hardware shall be handled with gloved hands and with no direct contact to active solar cells. FISCE panels shall not be taken outside of a laboratory, visibly clean environment.

#### **4.4 Humidity Constraints**

Non-condensing atmosphere.

#### **4.5 Thermal Interface Requirements**

N/A.

### **5.0 INTEGRATION AND TEST**

#### **5.1 Pre-Spacecraft Integration Inspection and Test**

Vanguard shall perform cell string characterization tests prior to delivery to MSU. MSU will perform an I-V test of the Instrumented Panel flight hardware following receipt at the integration facility.

#### **5.2 Post-Spacecraft Integration and Test**

A full experiment functional test shall be performed to assure that integration was successful. This data will be compared to measurements made with GSE before integration.

#### **5.3 Electrical Safety**

N/A Solar cell strings on FISCE do not have sufficient voltage to present a safety hazard

#### **5.4 Material Safety**

Vanguard and MSU shall use their standard procedures for identifying and safe handling of all materials associated with the FISCE experiment.

### **6.0 SCHEDULE**

Schedule milestones (TBR)

- Preliminary cell layout – by 10/31
- Final cell layout – by 11/7
- FISCE substrates to Vanguard – by 1/7
- Populated panels to MSU – by 2/27

### **7.0 SECURITY – EXPORT CONTROL**



All FISCE experiment hardware is Vanguard Proprietary and UNCLASSIFIED. Experiment with advanced Inverted Metamorphic Multijunction (IMM) solar cells may fall under ITAR regulations. All persons involved in accessing design information or ITAR related hardware must be US Persons.