Suborbital Capabilities for Science & Technology

Small Missions Workshop @ Johns Hopkins University

June 10, 2019

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Introduction

AGENDA

- Purpose
- History & Importance of Suborbital Carriers to Science
- Suborbital Platforms
- Sounding Rockets
- Balloons (brief)
- Aircraft
- SmallSats
- WFF Engineering
- Q & A
Purpose of the Meeting

Define the utility of Suborbital Carriers & “Small” Missions

- Sounding rockets, balloons and aircraft (manned and unmanned) provide a unique capability to scientists and engineers to:
  - Allow PIs to enhance and advance technology readiness levels of instruments and components for very low relative cost
  - Provide PIs actual science flight opportunities as a “piggy-back” on a planned mission flight at low relative cost
  - Increase experience for young and mid-career scientists and engineers by allowing them to get their “feet wet” on a suborbital mission prior to tackling the much larger and more complex orbital endeavors

- The Suborbital/Smallsat Platforms And Range Services (SPARS) Line Of Business (LOB) can facilitate prospective PIs with taking advantage of potential suborbital flight opportunities
Value of Suborbital Research – What’s Different?

Different Risk/Mission Assurance Strategy

- Payloads are recovered and refurbished.
- Re-flights are inexpensive (<$1M for a balloon or sounding rocket vs >$10M - 100M for a ELV)
- Instrumentation can be simple and have a large science impact!
- Frequent flight opportunities (e.g. “piggyback”)
- Development of precursor instrument concepts and mature TRLs
- While Suborbital missions fully comply with all Agency Safety policies, the program is designed to take **Higher Programmatic Risk**
  - Lower cost
  - Faster migration of new technology
  - Smaller more focused efforts, enable Tiger Team/incubator experiences.
Science Results from Suborbital Missions

Suborbital missions have produced important new science

- Cosmic-ray anti-protons were identified - early detections of:
  - Gamma-ray lines from SN1987A
  - Positron emission from the Galaxy
  - Black-hole X-ray transients in the galactic center region
- Balloon flights mapped the anisotropies of the Cosmic Microwave Background.
  - Result confirmed the inflation model of the early universe.
- Suborbital (aircraft and balloons) confirmed the CFC ozone-depletion theory.
- EUNIS sounding rocket mission was named in Discover magazine as #14 of 100 top science breakthroughs
Opportunities to Provide Hands-On Training

Suborbital Platforms have demonstrated a long history of providing opportunities to Scientists and Engineers

- Iconic science names like Grunsfeld (Emeritus, Astronaut, AA SMD, NASA Chief Scientist), Mather (2006 Nobel Prize for Physics), Sellers (2011 Most Excellent Order of the British Empire), etc. all began with early experience using suborbital platforms for science and engineering that laid the groundwork for them to achieve bigger and better things.

- Like opportunities still exist today and are in many ways even better than they were when these scientists incorporated suborbital into their portfolios.
“As an undergraduate and as a graduate student I had the great fortune to perform experiments in high-energy astrophysics using high altitude balloons as a platform for access to space. The NASA scientific ballooning program provided me with the complete and quintessential scientific experience, going from concept to hardware, observations, and scientific analysis of the results. All in the time frame of a few years. The rich environment that NASA's sub-orbital program supports not only enables top quality science, but is also crucial as a training ground for the scientists who will be the principal investigators of tomorrow.”

John M. Grunsfeld
Emeritus, Astronaut, AA SMD, NASA Chief Scientist
Suborbital Carriers

Three (3) Primary Carriers

Sounding Rockets
• 16 different vehicles that can carry 100-1500 pounds of payload into space at altitudes to 60-900 miles for durations of up to 30 minutes

Balloons
• Platform that can carry small to very large payloads (up to 8000 pounds) to various atmospheric levels up to “near space” at 160,000 feet. Flights last from a few hours up to 100 days (ULDB)

Aircraft
• Platform that can carry small to very large payloads (up to 1000 pounds) to various atmospheric up to commercial air levels at ~35,000 feet. Flights last from minutes to hours
NASA Sounding Rockets Program
Capabilities Overview
(Astrophysics focus)

Giovanni Rosanova
Program Manager

June 10, 2019
Nature of the NASA Sounding Rockets Program

• Characteristics
  – Low cost
    o Part of the NASA Low Cost Access to Space (LCAS) program
  – Quick turn around
  – Rely on military surplus rocket motors as much as possible to reduce cost
  – Acceptance of higher technical risk
    o Lower consequence
    o Higher probability of issues or failure
  – Minimalistic project teams
  – Highly flexible and agile
  – Non Mil-Spec components
  – World-wide mobile operations
  – Implemented via the NASA Sounding Rocket Operations Contract (NSROC)

• Highly successful for Science and Technology Development/Demonstration
  – Cutting edge science is being conducted
  – Enables instrument development that ports into future orbital missions
  – Scientist development
  – Technology demonstration
The Sounding Rocket Program “goes to where the science is…”
Sounding Rocket Performance

Typical Altitudes and Weights for Astronomy, Planetary, Solar, and Microgravity Payloads

NASA Sounding Rockets Program
Sounding Rockets Program Services

• **Payload Development**
  – Standard Systems
    – Attitude Control Systems
    – Telemetry Systems
    – Payload Recovery Systems
    – Boost Guidance Systems
    – Experiment Structures
    – Deployment Systems
  – Customized Systems and Development as missions require
• **Mission & Safety Analysis**
  – Flight performance
  – Ground and Flight Safety
• **Launch Vehicles**
• **Operations Support**
  – Mobile range development
  – Launcher assembly and servicing
  – Field operations
• **Technology Development**
Typical Payload Systems

- **Attitude Control Systems**
  - Cold gas systems used to orient the payloads during the science data period
  - Cold gas thrusters
  - Multiple system designs to support varied mission requirements
    - Magnetic
    - Inertial (coarse pointing and velocity vector tracking)
    - Celestial (sub arc-sec pointing)
    - Solar (sub arc-sec pointing)

- **Recovery Systems**
  - Forward and aft mounted systems
  - Systems available for land-based and water-based recovery
  - Typical recoverable payload up to ~1250 lbs

- **Boost Guidance Systems (Ruag – Sweden)**
  - Aerodynamic control for early portion of powered flight
  - Effectively reduces flight dispersion; predominantly utilized at White Sands Missile Range

- **Custom Telemetry Systems**
  - Custom development to meet unique mission requirement
  - Provide housekeeping and science data processing and transmission
  - Leverage standard component systems & designs

- **Custom Experiment Structures**
  - Internal & external structures

- **Custom Mechanisms & Deployment Systems**
  - Standard and custom separation & deployment systems
  - Standard and custom door/aperture systems
    - Deployable, single use doors
    - Mechanized doors/apertures
    - Vacuum sealed design options

- **Custom skins/fairings/nosecones**
  - Typical outer diameters include 14”, 17.26”, and 22”
  - Custom diameter options are feasible
Attitude Control Systems

- Rate Control
  - Less than 10 micro-G’s
- Magnetic
  - Orient perpendicular or parallel to magnetic field
  - Absolute pointing error < 5deg
- Celestial
  - +/- 1 Arc-Sec Pointing
  - Sub Arc-Sec Stability
  - Uplink Command
    - In-flight touch screen control options
    - Enhances pointing for science target
    - Enables event triggering and control of power systems
- Solar
  - +/- 0.5 Arc-Sec Pointing
  - Uplink Command
- Coarse Inertial
  - Pointing within 3 deg - advertised, but routinely better

The SR Program ACS can be easily altered to accommodate various mission requirements. Typical customizations include additional gas tanks, remote control nozzles,...

Precise alignment is required to ensure the object of scientific interest is placed on the sensitive detectors. The SR program support complex alignment activities.
Telemetry Systems

• Telemetry
  • Data rates up to 20 Mb/sec
  • Up to 4 links per payload
  • Video down link
  • Command uplink for experiment control
  • 40 Mb/Sec near term development goal with potential long term goal of up to 300-400 Mb/sec systems
  • Onboard recording typically provided by science team if desired

• Power
  • Customized to customer needs
  • Predominantly custom rechargeable NiCad systems
  • +/- 28V typical

• Event timing
  • Customized to customer needs
  • Essentially limitless by adding multiple digital timers
  • GPS event triggering available
Typical Parameters for Astrophysics & Solar Missions

• Typical Mission Overview
  • Terrier-Black Brant Launch Vehicle (typical)
  • White Sands Missile Range (typical); occasionally from WFF, PFRR, and RTS/Kwajalein

• Mission Capabilities
  • Sub arc-sec pointing and stability
  • Vacuum pump-down just prior to launch
  • Vacuum Motorized Doors
    • Aft looking (typical)
    • Side opening
  • Uplink command
    • real-time pointing adjustments, power and event control
  • Payloads typically recovered and re-flown
  • Payload envelopes (includes experiment & NASA support Systems)
    • Weights of 800-1300 lbs typical; experience up to 2800 lbs
    • 17.26 and 22 inch outer diameter typical
    • Payload lengths 200 – 325 inches typical
  • Internal clearance parameters:

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<th>Inner Clearance of Female Radax</th>
<th>Inner Clearance of Manacle Joints</th>
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Questions?
NASA Scientific Ballooning

- The NASA Balloon Program provides low-cost, quick response, near space access to NASA’s science Community for conducting Cutting Edge Science Investigations

- Serve as a technology development platform

- Excellent training for NASA scientists and engineers
Balloons – Standard Balloons

Balloon Volumes Noted in Million Cubic Feet (MCF)

- 60 MCF
- 39.57 MCF
- 29.47 MCF
- 34.43-H MCF
- 11.82-H MCF
- 11.82 MCF
- 4.0 MCF

Suspended Weight (kg)

Altitude (ft)

Altitude (m)
Balloons – Launch Locations
The Aircraft Office is responsible for operations, maintenance, airworthiness, aviation safety, project management and mission support functions of GSFC NASA and non-NASA aircraft/UAS.

Aircraft are available to support airborne science research, technology development, logistical airlifts, surveillance and recovery operations, and a wide array of other possible flight activities conducted CONUS and OCONUS.

The Aircraft Office manages the WFF Airfield consisting of three runways (two 8,000’+ and one 4,800’+) with access to restricted airspace and two hangars with project support spaces.

Total mission cost may include flight hour fee, fuel (if dry), and other mission peculiar costs (engineering, travel, overtime, airport fees, etc.)

**General Aircraft Characteristics:**

- Very small (<1lb.) to very large (20,000lb.) payloads
- Flight durations ½ to 10 hours
- Altitudes up to 32,000 feet
- Airspeeds up to 300 KIAS
- Multiple instrument mounting points
  - Nadir & zenith ports
  - Side fuselage ports
  - Wing pylon mounts
  - Pressurized and unpressurized ports
  - Dropsonde tubes
- 120V 60Hz & 400Hz, 28VDC power
- Aircraft data systems available
  - GPS tracking and positional data
  - Timing, wind, temperature & water vapor data
  - Aircraft roll, pitch, yaw data
  - Video cameras
  - Satellite phone and uplink/downlink of data
  - Air to air and ground to air text messaging

**P-3 Orion**
Airborne Science Program Funded - $3,500/hour (wet)

**C-130 Hercules**
Reimbursable Funded - $9,500/hour (dry)

**C-23 Sherpa**
Reimbursable Funded - $2,100/hour (dry)

**Viking 400 UAS**
(Under Construction, Reimbursable Funded)

**B-200 King Air**
CMO Funded - $1,200/hour (wet)

**Cessna 206**
Reimbursable Funded - $500/hour (wet)

**B-200 King Air**
CMO Funded - $1,200/hour (wet)
Aircraft Albedo Pod 2 (Nowicki/Code 548)

Description and Objectives:
• Development of an electrically de-bondable integration concept (ElectRelease™) for an aircraft science pod that minimizes structural impacts to the host aircraft.
• This project seeks to shift the aircraft integration paradigm away from traditional bolting and riveting methods that typically require significant structural modifications to an aircraft.

Key Innovation:
• ElectRelease™ epoxy has a unique property that allows it to release its bond between two conductive surfaces with the application of electrical current.

Cost
• Pod.................................................$ 1.5k
• Installation Kit (10x uses).....$ 200
• Albedo Science Package.....$ 1.8k
• Total...............................................$ 3.5K

Steps to Flight
1. Epoxy Rails
2. Bond Workmanship Test
3. Install Pod
4. Fly
5. Remove Pod
6. Release Rails

* Currently working with WFF Code 830 for flight authorization on P-3, C-130 and C-23.
Portfolio Services
Management:

• In November of 2017, NASA’s Goddard Space Flight Center (GSFC) established the Small Satellites Projects Office located at Wallops Flight Facility (WFF)
  • Responsible for the project management of individual small satellite missions and the center-wide integration of small satellite activities
  • Conducting Engineering Peer Reviews
  • Applying and successfully being selected for CubeSat Launch initiative (CSLI)
  • Interface for FCC/NTIA Licensing

• In March of 2019, NASA’s Science Mission Directorate (SMD) appointed the office to assist with the management and oversight of Heliophysics and Astrophysics small satellite missions
  • Includes holding monthly SmallSat/CubeSat Principal Investigator tag-up
  • Serving as Technical Officer for Grants

• Goals of the Small Satellite Project Office are:
  • Ensure a robust project portfolio of in-house work that includes fast paced, risk tolerant hands-on work to develop our workforce and our technologies
  • Provide critical project management to NASA, Other Government Agency (OGA), Academia and industry that enable mission success
    • Missions with a risk tolerance ranging from Do-No-Harm (DNH) to NASA Procedural Requirements (NPR) 7120.8A, NASA Research and Technology Program and Project Management Requirements
  • Achieve a mission success rate at or above 80 percent
  • Continue and expand NASA’s partnerships with OGA, Academia and industry to facilitate growth of small satellites
  • Maximize use of innovative, cost-effective best practices
Portfolio Services (Cont.)

Operations:

- Started supporting CubeSats in 2009 with Wallops 18M Ultra High Frequency (UHF) Ground Station
  - UHF band ground station supports UHF radios, which are often used by CubeSat developers
- Operational 24x5
- Conduct more than 100 passes per week
- Currently tracking the following CubeSat missions:
  - HaloSat
  - Tempest-D
  - CubeRRT
  - Dellingr
  - STF-1
  - Shields-1
  - ELFIN-A
  - CeREs
- Anticipate tracking 5 additional satellites by year's end
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<th>Mission</th>
<th>Description</th>
<th>Science Objectives</th>
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| petitSat        | A NASA CubeSat mission to study density irregularities in the mid and low-latitude ionosphere, which occupies a tiny fraction of the atmosphere. | • Investigate the link between these two phenomena — enhanced plasma density measurements, or blobs, and the wave action in the thermosphere  
• When petitSat is deployed 249 miles above Earth — consistent with the International Space Station’s orbit — the resulting data will be compared with that gathered by other ground and space based assets.  
• Planned delivery is winter 2020-2021                                                                 |
| GTOSat          | To advance quantitative understanding of acceleration and loss of relativistic electrons in the Earth’s outer radiation belt from a low inclination GTO. |                                                                                                                                                                                                                  |
| BurstCube       | A NASA CubeSat mission to detect gamma-ray bursts generated by amalgamation of orbiting neutron stars and collision of giant stars. | • Rapid localizations for high-significance LIGO/Virgo detections coincident with short GRBs  
• Correlate short GRBs with LIGO/Virgo subthreshold signals, increasing volume  
• Search of gamma-ray transients  
• Planned delivery is summer 2021                                                                 |
ETD-Wallops Support

Engineering and Technology Directorate (ETD) Wallops support

- ETD-W personnel have significant experience with suborbital platforms/systems. Available to support as part of PI teams in the development of and/or accommodation of instruments or payloads
- Wallops branches include:
  - Code 548/Mechanical Systems Branch
  - Code 569/Wallops Electrical Engineering Branch
  - Code 589/Wallops Systems Software Engineering Branch
  - Code 598/Guidance Navigation & Control & Missions Systems Engineering Branch (WFF)
- Broad range of skills – microcosm of each ETD Division
- Mission Planning Lab (similar to MDL but focused on SmallSats and lower-cost missions)
Mission Planning Lab (MPL)

- MPL provides an environment that facilitates multi-disciplinary, concurrent, collaborative, space system engineering design & analysis activities to enable rapid development of end-to-end mission design concepts.

- MPL grew out of the IRAD program and has been operational since 2014 completing over 30 studies and 7 reviews/mini-studies to date.

- Studies run ~1 week producing complete engineering mission reports for proposals and project execution.

- MPL collaborates with the Integrated Design Center (IDC) and leverages support from Greenbelt and Wallops ETD depending on staffing needs and availability.

- MPL can support mission design for suborbital carriers (sounding rockets, balloons, aircraft) and CubeSats/SmallSats.
Wallops I&T Facilities

Cleanrooms, 10K Clean Tents

Telemetry Ground Stations

Electrical Labs

Vibration Testing

Machine Shop & Fab

Thermal-Vacuum

GPS Simulator

EMI/EMC

Antenna Pattern Testing

Spin Balance
Conclusion

Suborbital carriers can be an important tool in the scientist’s and engineer’s toolkit. NASA/GSFC/WFF offers a “soup-to-nuts” array of capabilities in suborbital.
Q & A

QUESTIONS/DISCUSSION