TA 1: Launch Propulsion Systems

1.6 Balloon Launch Systems – Follow-up

Debora Fairbrother
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NASA GSFC’s WFF

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Senior Program Executive for
Suborbital Research, NASA HQ
• What information does NASA have regarding the expected benefit of proposed improvements in balloon technologies compared to the capabilities of sounding rockets, high-altitude unmanned aircraft, cubesats, and smallsats in terms of the types of missions that could be flown, scientific return, affordability, risk, etc.? The desired comparison would consider the current state of the art as well as potential improvements that could arise from investments in technologies related to each of these systems.
SMD’s Research Program

- Conducting strategically planned and competed Earth and Space science flight program investigations.
- Developing precursor instrument technologies for future science measurements.
- Developing and demonstrating new carrier technologies and capabilities to enable NASA’s missions.
- Conducting R&T, providing suborbital launch opportunities to the U.S. science community. Calibration/validation of satellite measurements.
- Fostering Innovation across NASA/community. Promoting STEM and inspiring students through hands-on student flight research missions.
Science @ NASA executes:

- 95 missions
- 121 spacecraft
- 12 Balloon launches (FY 2015)
- 20 Sounding rockets (FY 2015)
- 4,200 Airborne hours (FY 2015)
SMD Missions utilize the spectrum of observing regimes

**SMD is Science Driven, not Platform Driven**

- Proposed investigations undergo a competitive science/merit and feasibility external peer review.
- The PI proposes the platform as part of the proposal. SMD does not appoint the carrier for the investigator.
- SMD offers STMD commercial suborbital vehicles along with the NASA/SMD managed “core vehicles”.
- **SMD community develops science, technology and people along a continuum from the lab to the suborbital platform to the orbital flight project.**
Science Platforms

INTERNATIONAL SPACE STATION
- 250 miles

SOUN丁NG ROCKETS
- Up to 900 miles

BALLOONS
- Up to 130,000 feet

EXPENDABLE LAUNCH VEHICLE
- Low-Earth orbit

SPACECRAFT

CUBESATS

SMALLSATS

UAV
- Up to 65,000 feet

AIRBORNE SCIENCE
- Up to 30,000 feet

IN-SITU SCIENCE
NASA’s Airborne Science Program (ASP) conducts frequent global aircraft investigations in support of the NASA Earth Science community.

- Advance Earth System Science
- Field Campaigns to complement Satellite Measurements
- Developing technologies to improve Earth Observation capabilities.

Aircraft Offices: ARC, DFRC, GSFC/WFF, GRC, JSC, LaRC
Altitudes: up to 21 km; Duration: up to 30 hr

FY2015: Conducted 4200 flight operation hours (>20 missions/deployed field campaigns), utilizing more than 15 NASA aircraft and UASs.
The NASA Balloon Program provides near space access at a fraction of the cost of a satellite.

- Project Office: GSFC/WFF
- 15 launches per year
- Float altitudes: 30-45 km
- Large payload volumes
- Payloads masses up to 3600 kg
- Mission durations up to 50 days (100 days planned)

Carrier Technologies driven by the Science Community
- Higher data-rate telemetry.
- Finer Pointing: Sub arc-second pointing
- Longer Flights (> 60 days) super pressure balloon capable of one hundred day missions (in development toward 100 days, any latitude)
Zero Pressure Balloons

Up to 3,630 kg (8,000 pounds)

Altitude (km)

Suspended Weight (kg)

1.12 mcm (39.57 MCF)
0.33 mcm (11.82 MCF)
0.83 mcm (29.47 MCF)
0.97H mcm (34.43H MCF)
0.11 mcm (4.0 MCF)
0.33H mcm (11.82H MCF)

mcm = million cubic meter
MCF = million cubic feet
Super Pressure Balloons

Up to 2,268 kg (5,000 pounds)

Altitude (km)

Suspended Weight (kg)

1.12 mcm (39.57 MCF)
0.83 mcm (29.47 MCF)
0.33 mcm (11.82 MCF)
0.33H mcm (11.82H MCF)
0.97H mcm (34.43H MCF)

SPB 0.53 mcm (18.8 MCF)

SPB ~0.74 mcm (26 MCF)

0.11 mcm (4.0 MCF)

In Development

Designed

mcm = million cubic meter
MCF = million cubic feet
Sounding Rockets

- Program Office: GSFC/WFF
- Payload capabilities
  - Masses up to ~600kg
  - Sub arc-second pointing
  - Diameters limited to <1m
- Apogee altitudes between 100-1400km
  - Up to 20 minutes of ballistic flight
- Supports complex & hazardous payloads
  - Deployable & multi bodies
  - Chemical deployments
  - Advanced Technology demonstrations
- FY2015: NASA conducted 20 rocket launches during 5 launch campaigns
Sounding Rocket Performance

Typical Altitudes and Weights for Auroral Physics Payloads

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

100 Km

Typically Chemical release and educational payloads

Experiment Weight (lbs)

Apogee Altitude (km)

Time Above 100 Km (seconds)
Suborbital Research Program
Utilization

- Balloon launches in FY14 affected by Gov’t shutdown (cancellation of Antarctic campaign). Decadal average is 13 launches, with an average 29 funded missions/year.
- Sounding Rocket Decadal average is 17 launches, with an average of 42 funded missions/year.
- Airborne science flight hours have increased 114% over past 4 years.
SMD Balloon missions have contributed in essential ways to NASA spacecraft missions.

- **Over 30 spacecraft instrument in the last 4 decades first flew on balloons.**
- Balloon flights of the differential radiometer and Far IR spectrum of the CMB laid the critical ground work for the design of instruments for COBE and WMAP.
- Detectors on the RHESSI mission were first developed and demonstrated on balloon-borne instruments.
- The scintillating fiber trajectory detector on the ACE Cosmic Ray Isotope Spectrometer was demonstrated first in a balloon flight.
- On the EOS-Aura satellite to study the atmosphere's chemistry and dynamics, the MLS, TES, and HIRDLS instruments all trace their heritage to instruments that first flew on balloons.
- GSFC In-Focus Balloon flights of the cadmium-zinc-telluride CZT array led to the design the Swift Burst Alert Telescope (BAT) instrument.
- Balloon flights developed precursor instrumentation for ISS payloads CALET, CREAM, and JEM-EUSO.
SMD Aircraft missions that have led to the development of Earth Science spacecraft instruments

- Aircraft flights in the 80’s and 90’s led to the GSFC laser altimetry design of the Mars Orbiter Laser Altimeter, or MOLA on the Mars Global Surveyor and the Lunar Orbiter Laser Altimeter (LOLA).
- LaRC aircraft flights developed precursor SAGE instruments.
- Laser altimetry by the WFF Airborne Topographic Mapper (ATM) started to map the height of the ice caps operationally in 1993 and has since then provided the data set that first showed the loss of the Greenland ice mass and is the primary instrument for Operation IceBridge.
- ATM was also critical for the development of ICESat and will be a key instrument for ICESat-2 cal/val efforts. The 20+ year ATM Greenland time series is baseline data set for all cryospheric missions and science efforts.
- Aircraft flights of the MODIS Airborne Simulator (MAS) MASTER, AirMISR and MOPITT instruments lead to the MODIS, MOPITT and MISR instruments on the EOS- Terra and Aqua satellites.
- The Cloud-Aerosol Lidar on the CALIPSO/CloudSat satellite was demonstrated first on NASA aircraft flights.
The Global Hawk is NASA’s high altitude unmanned aerial platform. Reaching altitudes of 18.3 km (60,000 feet) the vehicle has a 8,500 nautical mile range and 24-hour endurance. The 13.4 m (44 foot) long Global Hawk has a wingspan of more than 35.4 m (116 feet), a height of 4.6 m (15 feet), and a gross takeoff weight of 12,133 kg (26,750 pounds), including a 680 kg (1,500-pound) payload capability.

http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-098-DFRC.html
SmallSats and CubeSats

- Cube Sats began as low cost student platforms, and are evolving into low cost platforms for scientific research in Heliophysics, Astrophysics, and Planetary Science
- Current plans include launches from ISS; deployment at the moon, Mars, and beyond.
- Communication evolving from UHF to X/S band and lasercom
- Constellations of CubeSats can create distributed networks that can do the work of a large satellite at a fraction of the cost.
- Standardized architectures, communications, and power are still evolving.
The Earth Science Technology Office (ESTO) is a targeted, science-driven, competed, actively managed, and dynamically communicated technology program and serves as a model for technology development.

Competitive, peer-reviewed proposals enable selection of best-of-class technology investments that retire risk before major dollars are invested: a cost-effective approach to technology development and validation. ESTO investment elements include:

**Observation**

- **Instrument Incubator Program (IIP)**
  - Provides robust new instruments and measurement techniques (TRL 3-6)
  - 16 active projects; total funding ~$85M over 3 years; new solicitation now open

- **Advanced Component Technologies (ACT)**
  - Provides development of critical components and subsystems for instruments and platforms
  - TRL 2-5; 15 active projects; total funding ~$16M over 3 years

**Information**

- **Advanced Information Systems Technology (AIST)**
  - Provides innovative on-orbit and ground capabilities for collecting, processing, and management of remotely sensed data and the efficient generation of data products
  - TRL 2-6; 18 active projects; total funding ~$39M over 3 years

**Validation**

- **In-Space Validation of Earth Science Technologies (InVEST)**
  - Provides in-space, orbital technology validation and risk reduction for small instruments and components (in lieu of ground/aircraft testing)
  - TRL 5-7; First awards imminent
SMD is selecting cubesat investigations across its four science disciplines to enable scientific discovery, develop precursor spaceflight technologies, and to foster hands-on student flight research.

<table>
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<th>Year Selected</th>
<th>Sponsor</th>
<th>Mission</th>
<th>PI</th>
<th>Institution</th>
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</table>
The need to space-validate new technologies is critical to reduce risk for future Earth science measurements. The InSpace Validation of Earth Science Technologies (InVEST) program is intended to fill the gap. The first InVEST solicitation sought small instruments and subsystems that advance technology to enable relevant measurements and targeted the CubeSat platform.

The Microwave Radiometer Technology Acceleration (MiRaTA) Cubesat will validate multiple subsystem technologies and demonstrate new miniature microwave radiometers operating near 52-58, 175-191, and 206-208 GHz that could dramatically enhance the capabilities of future temperature and humidity measurements. - K. Cahoy, MIT; Launch NET 2016

The Radiometer Assessment Using Vertically Aligned Nanotubes (RAVAN) project will demonstrate a bolometer radiometer that is compact, low cost, and absolutely accurate to NIST traceable standards. RAVAN could lead to affordable CubeSat constellations that, in sufficient numbers, might measure Earth’s radiative diurnal cycle and absolute energy imbalance to climate accuracies (globally at 0.3 W/m2) for the first time. - W. Swartz, JHU/APL; Launch NET 2016

The objective of the Cubesat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat) is to demonstrate in space, a new detector with high quantum efficiency and single photon level response at several important remote sensing wavelength detection bands from 1 to 2 microns. - R. Fields, Aerospace Corporation; Launch NET 2016

The HyperAngular Rainbow Polarimeter HARP-CubeSat will validate a technology required by the Aerosol-Cloud-Ecosystem (ACE) mission concept and prove the capabilities of a highly-accurate, wide-FOV, hyperangle, imaging polarimeter for characterizing aerosol and cloud properties. - J. V. Martins, UMBC; Launch NET 2016

IceCube is a three unit (3U) CubeSat under development to validate a 874-GHz radiometer receiver for future use in ice cloud measurement missions. This submillimeter wave radiometer technology could directly benefit an ice cloud imaging radiometer such as that called for by the Aerosol-Cloud-Ecosystem(ACE) mission concept. - D. Wu, NASA Goddard Space Flight Center; Launch NET 2016
International Space Station
Science Instruments

CLARREO PF (2019-TBC)
DEISIS-30/MUSES*** (2016)
SAGE III (2016)

***HEOMD data purchase, SMD solicitations/archiving

JEM-EUSO*(2019-TBC)
OCO-3 (2018-TBC)
GEDI (2018)
ECOSTRESS (2017)
CREAM (2016)
CALET* (2015)
CATS** (2015)

*JAXA developed, SMD science/data analysis
**HEOMD/ISS-developed/SMD science/data analysis

External Logistics Carriers – ELC-1, ELC-2, ELC-3
External Stowage Platforms – ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility

11/9/2015
## ISS Science Payloads

<table>
<thead>
<tr>
<th>Mission</th>
<th>Primary Sponsor</th>
<th>PI Institution</th>
<th>Discipline</th>
<th>Acquisition</th>
<th>Launch Date</th>
<th>ISS Location</th>
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### CY 11-20

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Balloon Technologies

State of the Art: Zero Pressure Balloon

Technology Development: 1.6.1 Super Pressure Balloon

1.6.2 Materials

1.6.3 Pointing Systems

1.6.4 Telemetry Systems

1.6.5 Balloon Trajectory Control

1.6.6 Power Systems

1.6.7 Mechanical Systems: Launch Systems

1.6.8 Mechanical Systems: Parachute

1.6.9 Mechanical Systems: Floatation
Mid-latitude balloon-borne observations are the single best platform (including ground-based telescopes from, for example, Chile) for measurements of CMB polarization whose science aim is to constrain the optical depth to reionization. This cannot be done from the south pole, or from the Antarctic LDB, because polar studies require nearly full sky coverage which can only be had from mid-latitudes.

The mid-latitude SPB is the only platform that provides nearly full sky coverage for more than one night. Even Kiruna, Sweden flights cannot provide a significant amount of flight time without Russian overflight.

The science drivers for the measurements are broad, and include early universe physics as well as the neutrino sector.
The SPB is the only platform that offers a persistent capability in the near UV and IR. Flights of 30 to 100 nights offer a unique capability to provide wide-field, sub-arcsecond imaging in the UV to near IR. The recent test flight of SuperBIT demonstrated 150 milliarc second stability of the point spread function (PSF) with a prototype optical system, which will be improved upon with SuperBIT SPB. Once the Hubble is no longer available (ie, any moment), there will be no facility other than SPB capable of this.

The science opportunities for this are myriad, but include imaging in the near UV to support the photometric capabilities of the large ground-based surveys (like HyperSuprimeCam, etc), as well as the flagship missions like Euclid and AFTA. Wide field surveys with highly stable PSFs offer opportunities in weak and strong lensing studies, which is the focus of SuperBIT.
Explorer MoO: GUSTO

Observation Objectives: [CII], [OI], & [NII] Surveys of MW and LMC

Above: Single line of sight (LOS) spectra of [CII] (Herschel) taken toward a Galactic sources. GUSTO’s surveys will observe \( \sim 100,000 \) LOS.

The Large Magellanic Cloud (LMC) in HI (blue), CO (green), Spitzer 160\( \mu \)m emission (Red). The solid box represents the area for the large-scale mapping with GUSTO. The dashed are the proposed deep integration maps.
The Large Magellanic Cloud (LMC) in HI (blue), CO (green), Spitzer 160μm emission (Red). The solid box represents the area for the large-scale mapping with GUSTO. The dashed are the proposed deep integration maps.
Planetary Observatory Model

- Planetary science is intending to follow an “Observatory in the sky” model
- System is an asset for the community and PI’s and missions to be competitively selected
- Requires a highly capable, robust, and modular design
  - Implies strong desire to recover safely with minimal damage

Required or highly desired technologies:
- Capable, strong, modular and light – weight systems
- High in-flight science return
- Robust landing and recovery systems
Planetary Science From Stratospheric Balloons

- High-Altitude balloon missions offer several unique advantages for Planetary Science observations over ground, air, and sounding rocket-based observations
  - Increased transmission and lower downwelling radiance in critical portions of the electromagnetic spectrum, specifically NUV-Visible – Mid IR
  - Long duration flights provide a unique opportunity to study planetary atmospheres, and their dynamics
  - Space-like imaging – at stratospheric altitudes diffraction-limited imaging in the visible is expected
  - Highly competitive cost for science returned, particularly for long flights

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Detecting and measuring compositions of elements on planetary bodies is key to addressing planetary decadal questions. Observations in the NUV - MIR is vital to achieving these decadal goals – This requires stratospheric altitudes and time on target.

Required technologies:
- Precise and stable pointing (1 arc-sec or better for minutes at a time)
- Many targets require night observations and mid latitude launches
- Larger payloads for super pressure balloons (carry a 1m or larger telescope and instruments)
- Float durations on the order of weeks or more
Planetary Science: Long Duration Flights

- Enable temporal science not practical any other way
  - Study Jupiter storms, Venus clouds & superrotation, methane or water cycles on Mars or Moon, and more
- Offer more science / dollar

Without atmospheric disturbances, space-like imaging is expected:

- For example: The Sunrise mission used Shack-Hartmann array to measure wavefront errors – “Couldn't tell that we weren't in space…” (Peter Bartoll, Sunrise PM) *
- There is 40X more atmosphere overhead at 40K ft then 125K ft. or 140X more at 14K ft (Mauna Kea)
- Image quality is critical for resolving and tracking planetary features, atmospheric dynamics, detecting and resolving small and faint bodies (comets, asteroids, Near Earth Object’s, etc…)

A host of high-value planetary science can be achieved from a stratospheric balloon-based observatory.

Many planetary targets prefer views in the ecliptic (mid-latitude launches) and many require night observations.

Continuous or consistent observations spanning weeks is highly desired and a unique contribution of long duration balloons.

The planetary observatory model needs repeated / robust flights.

Required or highly desired technologies:
- Precise and stable pointing (1 arc-sec or better for minutes at a time)
- Float durations on the order of weeks of more
- Capability to lift heavy payloads to ~ 35.7 km (117 kft) or more
- Flights in mid-latitudes with night observations
- Robust designs and reliable recovery approaches
1.6.1 Super Pressure Balloon

1.6.1.1 Extended Duration Super Pressure Balloon -> Stable float altitude for polar and mid-latitude flights. Diurnal mid-latitude flight.

1.6.1.2 Higher-Altitude Extended Duration Super Pressure Balloon -> Stable float altitude for polar and mid-latitude flights. Diurnal mid-latitude flight.

1.6.2 Materials -> Lighter-weight systems will increase mass allocation for science

1.6.3 Pointing Systems -> Arc second pointing from stratospheric platform.

1.6.4 Telemetry Systems -> Increased real-time downlink reduces burden on recovery

1.6.5 Balloon Trajectory Control -> Enable longer duration flights, avoid overflight of populated area, and facilitate safe termination locations

1.6.6 Power Systems -> Increased power and/or reduced mass for payloads

1.6.7 Mechanical Systems: Launch Systems -> Remote launch of hazardous payloads/enhanced safety of launch operations

1.6.8 Mechanical Systems: Parachute -> Maintain strength of parachute material

1.6.9 Mechanical Systems: Floatation -> Recovery of extended duration missions from the ocean.