National Aeronautics and Space Administration

NASA Sounding Rockets Annual Report 2015

Message from the Chief

Phil Eberspeaker
Chief, Sounding Rockets Program Office

This past year (2015) marks 45 years since management of the Sounding Rockets Program was relocated to NASA's Wallops Flight Center, now known as Wallops Flight Facility. Today, we are all proud to be able to continue this NASA program that has offered creative, low-cost access to space for more than four decades. Over this time much has changed. For example, early spectrographs for astrophysics missions used film cameras to record spectra from stars. This film was then developed in a darkroom according to some very specific procedures. Today, spectrograph data is telemetered to a ground station and stored on computers for later analysis by the science team. Early payloads only carried one scientific instrument, now they carry several making simultaneous coordinated measurements to unlock new scientific secrets. Since the early days, payloads have constantly become more complex with added capabilities from both science and support systems perspectives. Comparing payload weight gives an idea of this growth – a representative payload from the 70's weighed about 300 lbs, today the program frequently flies payloads of 1,000 lbs or more. Instead of single instrument payloads, multiple organizations cooperate to share space in a payload, each providing their own experiment with specific requirements for support.

Fiscal year 2015 saw three of the most complex missions ever launched by the program; Cusp-Region Experiment (C-REX), Auroral Spatial Structures Probe (ASSP) and Charged Aerosol Release Experiment II (CARE II). Each of these missions had unique engineering challenges that required our engineering teams to develop creative solutions. C-REX deployed 24 rocket propelled sub-payloads (known as ampoules), to release vapor tracers to facilitate the measurement of high altitude particle motions (referred to as "winds") and electric fields in the thermospheric region exposed to Earth's geomagnetic cusp. The "cusp" is the region where the Earth's magnetic field lines begin to converge as they descend down towards the Earth's surface. To be able to reach the cusp, the launch had to be conducted from Andoya Rocket Range in Norway. The CARE II mission simultaneously ignited a cluster of 37 small CRV7 rocket motors, near apogee to create a dust cloud to study the generation of plasma wave electric fields and ionospheric density disturbances. This launch represents a record breaking number (44) of solid rocket motors flown on a single Sounding Rocket mission. Norway proved to be the ideal location for conducting this research as well. ASSP, flown from Poker Flat Research Range in Alaska, measured both the spatial and temporal variation of the energy flow into the upper atmosphere in and around the aurora. The payload included six spinning sub-payloads, each ejected at high velocity with its own telemetry link. The resulting formation of payloads was able to take spatially distributed measurements of the aurora. This mission involved a challenging sub-payload ejection system that worked perfectly. We are also quite excited about a recent September 2015, solar mission that may have made scientific history. The early results from the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) mission indicate that the first ever measurements of magnetic field lines in the Sun's middle layers, the upper chromosphere, and the transition region have been successfully achieved. The science community, as do we, look forward to the publication of the scientific results from this mission.

We continue to invest in the evolution of our payload support system technologies with the aim to provide more options for today's scientists to accomplish their research goals. This involved the development of new high velocity ejection systems, and smart payloads that know where they are and can autonomously set event times on-the-fly to achieve more precise scientific information. We continue to strive for higher telemetry data rates, develop systems that can reduce mission costs, and implement engineering techniques that enhance scientific return. I am extremely proud of the civil servant and contractor engineers, technicians, and support staff that apply their dedication, creativity, and skills to solve these engineering challenges day after day, year after year, to keep this program vital and successful.

I am also very pleased to say that we were able to once again challenge and inspire hundreds of students and teachers over this past year. Education and workforce development has always been a hallmark of the sounding rockets program. Most of the Principal Investigators have at least one graduate student as a science team member; some teams include undergraduate students as well. Approximately 100 undergraduate and graduate students participated in this year's science missions through their Universities. Three dedicated student flight missions were flown in 2015, with a combined participation of approximately 250 undergraduate students and faculty. The RockOn student mission flown in June also included Cubes-in-Space middle school experiments. Eighty cubes were competitively selected for flight, and an estimated 1,600 middle school students participated. As in the past several years, the Sounding Rockets Program also offered an exciting, hands-on workshop for high school teachers. The Wallops Rocketry Academy of Teachers and Students (WRATS) hosted 20 teachers from across the nation, where they learned about rocket physics, electronics, computer programming, and flight operations. Countless school visits, tours, and community events rounded out the busy year. I can't think of any other organization that provides such prolific, hands-on educational opportunities than the NASA Sounding Rockets Program. The neat thing about it is that the same engineers and technicians that send the scientific instruments into space are the ones working hand-in-hand with the teachers and students.

It is safe to say that 2015, has been a year full of programmatic, operational, and technical challenges. And, as usual, the NASA and contractor team has stepped up to overcoming those challenges while maintaining the excellence and flexibility traditionally inherent in the program. I have served this program for over 30 years, and I have never been more proud of the men and women who strive on a daily basis to maximize scientific and technical return on a shoestring budget.

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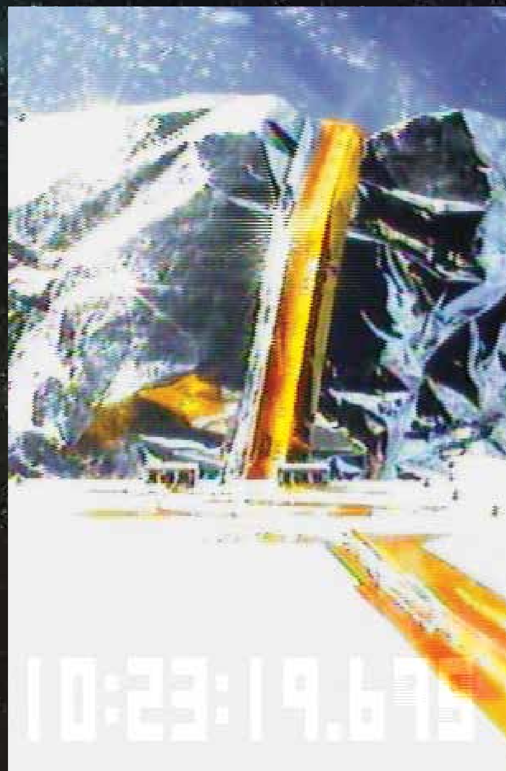
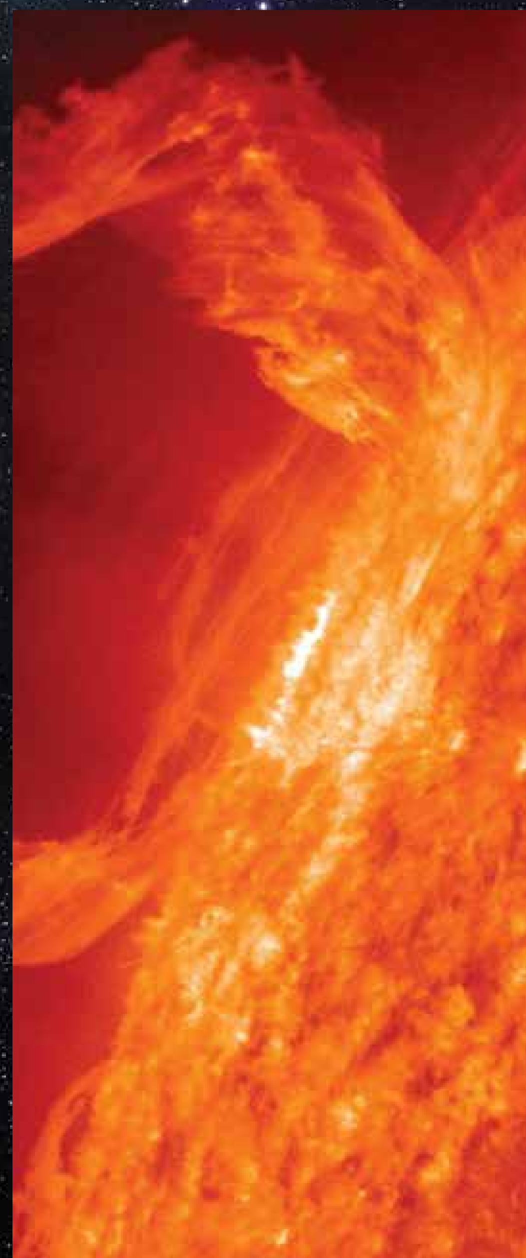
The Sounding Rockets Program Office (SRPO), at NASA Goddard Space Flight Center's Wallops Flight Facility, provides suborbital launch vehicles, payload development, and field/launch operations support to NASA and other government agencies. SRPO works closely with the Sounding Rocket User Community to provide launch opportunities facilitating a broad spectrum of science and technology applications.

The Sounding Rockets Program supports the NASA Science Mission Directorate's strategic vision and goals for Geospace science, Heliophysics, and Astrophysics. The approximately 20 suborbital missions flown annually by the program provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting worldclass scientific research. Operations are conducted primarily from fixed launch sites such as Wallops Test Range (Virginia), Poker Flat Research Range (Alaska), and White Sands Missile Range (New Mexico) as well as sites such as Andoya Space Center (Norway), Esrange (Sweden) and Kwajalein Atoll, Marshall Islands. Launch operations are also conducted from mobile sites set up in partnership with the Wallops Test Range. Mobile "campaigns" have been conducted from Australia, Puerto Rico, and Brazil. The mobile capability allows scientists to conduct their science "where it occurs". Coupled with a hands-on approach to instrument design, integration and flight, the short mission life-cycle helps ensure that the next generation of space scientists receive the training and experience necessary to move on to NASA's larger, more complex space science missions. The cost structure and risk posture under which the program is managed stimulates innovation and technology maturation and enables rapid response to scientific events.

With the capability to fly higher than many low-Earth orbiting satellites and the ability to launch on demand, sounding rockets offer, in many instances, the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the program enables researchers to conduct missions from strategic vantage points worldwide. Telescopes and spectrometers to study solar and astrophysics are flown on sounding rockets to collect unique science data and to test prototype instruments for future satellite missions. An important aspect of most satellite missions is calibration of the space-based sensors. Sounding rockets offer calibration and validation flights for many space missions, particularly solar observatories such as NASA's latest probe, the Solar Dynamics Observatory (SDO), RHESSI, Hinode and SOHO.

Introduction





Missions 2015

20 vehicles were flown supporting 18 missions in 2015. Seven geospace investigations, one astrophysics mission, five solar physics missions, three technology fligths and three education flights were accomplished.

Geospace Science Flight Missions

Six science investigations with a total of eight rockets were flown in 2015. The investigations included the study of density increases in the cusp region, mesospheric turbulence, and measurements of the spatial and temporal variation of the energy flow into the upper atmosphere in and around the aurora.

Additionally the NSRP suppported the Air Force Research Laboratory (AFRL) with a launch vehicle and payload support systems for the AIC mission flown from White Sands Missile Range, NM.

C-REX

Principal Investigator:
Dr. Mark Conde
University of Alaska
Mission Number(s):
52.001 UE
Launch site:
Andoya Space Center, Norway
Launch date:
November 24, 2014

Payload integration at NASA GSFC Wallops Flight Facility.

The C-REX payload dispersed vapor trails of barium and strontium across a location about 500 km southwest of Longyearbyen, Norway, at altitudes in Earth's thermosphere varying from 150 to 400 kilometers. The trails were photographed by observers stationed at the Unis Kjell Hendriksen Observatory in Longyearbyen, the NIPR Rabben Observatory in Ny Alesund, and aboard a NASA twin-engined turboprop aircraft. The images were used to triangulate the three-dimensional position and motion of each cloud, in order to measure winds and electric fields in the thermospheric region that is exposed to Earth's geomagnetic cusp. The mission required the deployment of 24 individual canister sub-payloads. Each canister was propelled away from the main payload by a small rocket motor. Barium produces a cloud with a mixture of blue-green colors. Strontium in combination with neutral barium creates a bluish-purple color cloud. Tracking the strontium/barium drifts will show neutral winds, whereas the barium drift will show ion velocities.

For reasons that are currently not understood, there is a permanent density increase in this part of Earth's thermosphere, which is expected to cause small but important and currently unpredictable perturbations to the orbits of spacecraft flying through it. By measuring winds and ion motion at multiple locations inside the density enhancement, further understanding of the flows that are responsible for creating and sustaining it is gained.

Results showed very dynamic ion convection that was producing substantial Joule heating per unit mass at around 250 km altitude. Surprisingly, the resulting vertical flows were only very weak and, if anything, directed downward. Nevertheless, a picture is emerging in which Joule heating associated turbulent convection in the cusp is a major contributor to the processes that enhance the neutral density.

Photo of vapor trails and an active aurora taken from Ny Alesund.

MTEX

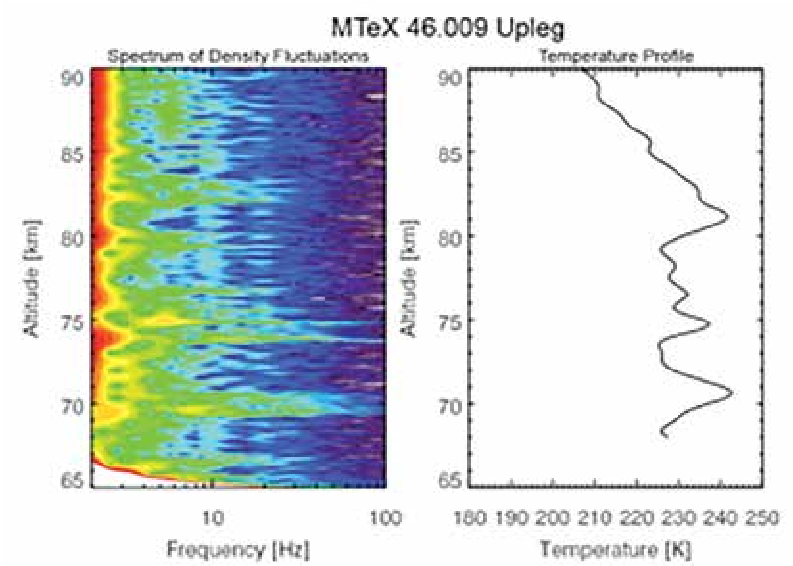
Principal Investigator:
Dr. Richard Collins
University of Alaska
Mission Number(s):
46.009 & 46.010 UE
Launch site:
Poker Flat Research Range, AK
Launch date:
January 26, 2015

MTEX science team at Wallops Flight Facility.

The Mesosphere-Lower Thermosphere Turbulence Experiment (MTEX), in conjunction with the Mesospheric Inversion-layer Stratified Turbulence (MIST), explores the atmosphere's response to auroral, radiation belt and solar energetic particles and associated effects on nitric oxide and ozone.

Recent solar storms have resulted in major changes to the composition of the upper atmosphere above 49 miles (80 kilometers), where enhancements in nitrogen compounds have been found. These compounds can be transported into the middle atmosphere where they can contribute to ozone destruction. However, the meteorological conditions do not always allow such transport to occur. Thus, the impact of solar activity on the Earth is not just about how the Sun is a source of energetic particles but, also how the Earth's meteorological conditions determine the fate of these particles in the atmosphere.

Current circulation models show that the transport cannot be explained without the small-scale processes of turbulence and diffusion. These processes remain poorly described in the models, and current observations show a wide variation in measurements of turbulence. The turbulence is generated by breaking waves and has characteristics that vary strongly with the background atmospheric conditions. Describing such processes in circulation models is of broad interest, as turbulent and diffusive processes contribute to transport of heat and constituents throughout the atmosphere impacting everything from pollution studies at the surface of the Earth to satellite drag in space.



MTeX measurements of spectrum of density fluctuations and tempetrature profile from ion–guage instrument onboard 46.009.

PI Dr. Richard Collins (left) inspects science instruments.

The MTEX rockets were launched on January 26, 2015 into mesospheric inversion layers that were detected by the ground-based lidar at Poker Flat Research Range. The onboard ion guage measured the atmospheric density at high resolution (~20 cm) allowing retrieval of both small-scale turbulent fluctuations as well as the density profile along the flight. Specifically, the turbulence measurements show enhanced regions of turbulence, where the turbulent spectra extend to higher frequencies, corresponding to regions of temperature inversions, where the temperature increases with altitude. The combined turbulent and temperature measurements will allow characterization of the the energy dissipation and diffusion associated with the turbulence. The lidar measurements made over the whole night characterize the evolution of these inversion layers and associated waves. The ultimate goal of the experiment is to determine the relationship between the wave activity and the generation of the turbulence.

The measurements from MTEX will be used to frame fluid dynamic simulations where characteristics of breaking waves and turbulence are resolved and the characteristics of turbulence generation, dissipation and diffusion in the middle and upper atmosphere are determined.

M–TeX, MIST and ASSP teams at Poker Flat Research Range, Alaska.

MIST

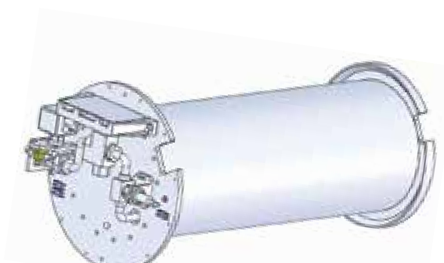
Principal Investigator:
Dr. Miguel Larsen
Clemson University
Mission Number(s):
41.111 & 41.112 UE
Launch site:
Poker Flat Research Range, AK
Launch date:
January 26, 2015

A composite image of MTex and MIST missions launches.

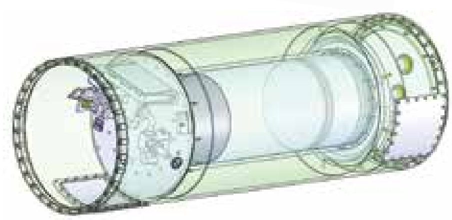
The MIST payloads were launched in sequence with the MTEX payloads. The first M-Tex rocket, a NASA Terrier-Improved Malemute sounding rocket, was launched at 4:13 a.m. EST and was followed one-minute later by the first MIST experiment payload on a NASA Terrier-Improved Orion. The second M-TeX payload was launched at 4:46 a.m. EST and also was followed one minute later by the second MIST payload

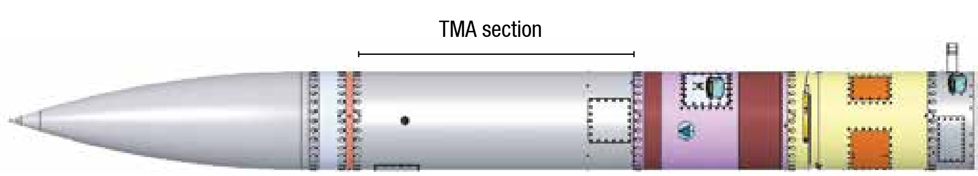
MIST data will aid in characterizing atmospheric turbulence in the atmosphere/space transition region, and enhance understanding of the way atmospheric properties are mixed vertically. The payload deployed trimethyl aluminum (TMA) vapor trails between 50 and 87 miles above the Earth. The vapor trails were photographed from several ground stations.

All four rockets in the MTEX/MIST mission were successfully launched and data is currently being analyzed.



TMA section detail drawings.





MIST payload drawing.

ASSP

Principal Investigator:
Dr. Charles Swenson
Utah State University
Mission Number(s):
49.002 UE
Launch site:
Poker Flat Research Range, AK
Launch date:
January 28, 2015

ASSP launches from Poker Flat, Alaska.

PI Dr. Charles Swenson with the ASSP payload. Three deployable sub–payloads are on the left.

The Auroral Spatial Structures Probe mission is very different than the other hundred or so rockets that had been launched into the Aurora over the last 50 years. Its mission is to answer questions about the voltages and current surrounding the Aurora and how they change over time. To do this NASA had to take a entirely new approach.

The "Visible Aurora" is very active, and beautiful, you can see changes that happen in fractions of seconds and over a minute arcs can explode across the whole sky or simply disappear. We think the underlying voltages and currents, the "Invisible Aurora", are equally active but we do not know. For example, features in the aurora that are 10 to 100 meters in size might last a few seconds while something that is 1km to 50 km in size might persist much longer, seconds to minutes, but we just don't know. If it were physically possible scientists would have instruments that remain stationary above the Earth at about 200 to 300 km within the aurora and make measurements over time within the evolving Aurora. Even better, they would have whole constellations of them spread out and taking data at different locations, but that is not possible. We don't have an anti-gravity device that will allow the payloads to just hover at some spot over the Earth in space. The next best thing is to have multiple payloads, which follow the same path through the Aurora. Each payload makes measurements within in the Aurora as it passes by which is repeated by the next payload following the same track.

This is what was done with the Auroral Spatial Structures Probe mission; NASA shot multiple small payloads in precise directions away from the main payload so that a formation of sensors was created where individual payloads pass through the same locations in space. NASA engineers at the Wallops Flight facility built an ejection system based on compressed air to shoot away small payloads at high speed. They get hit with 200 g of acceleration as they are kicked off and travel the length of a football field in 2 seconds. A combination of graduate and undergraduate students working side by side with professionals at the Utah State University Space Dynamics Lab built the small payloads and science instruments to measure voltages and currents around the aurora and the density of the ionosphere. Six small payloads, three on each end, were ejected in pairs from the rocket. Four were placed in a line with the main payload making the fifth in that string. The other two were sent out to the sides. This has been one of the most complex sounding rocket missions NASA

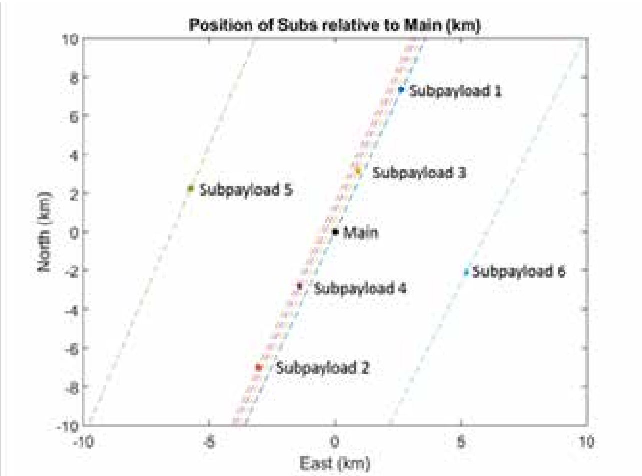


Figure 1 Relative location of the payloads as they passed over the active aurora. Direction of travel is from bottom to top.

has ever done. It was like flying seven sounding rockets at once over the aurora. NASA provided in additional telemetry dishes and equipment to the Poker Flat Research Range to augment the existing capability to support this mission.

The Auroral Spatial Structures Probe was successfully launched on January 28th, 2015 from Poker Flat Research Range during an active auroral event occurring over the northern part of Alaska. The constellation of seven payloads was successfully deployed and encountered an active auroral arc above Kactovic, Alaska. The Auroral Spatial Structures Probe (ASSP) was a collaborative effort between NASA, Utah State University, University of Alaska and ASTRA. It was designed to study spatial and temporal variation of the energy flow into the upper atmosphere in and around the aurora. The six small payloads were ejected at high velocity and had separations of about 3 km between payloads with a maximum separation of 12 km when within the active auroral event (See Figure 1). The constellation was configured to provide multiple time-separated measurements of electric and magnetic fields and plasma density at the same spatial location as well as spatially different measurements at the same time.

The processing of the in-flight data is on-going, but initial results show a significant correlation between the magnetic and electric field measurements on each of the payloads. In particular, one strong event about six minutes after launch was observed by six of the payloads. The temporal/spatial evolution

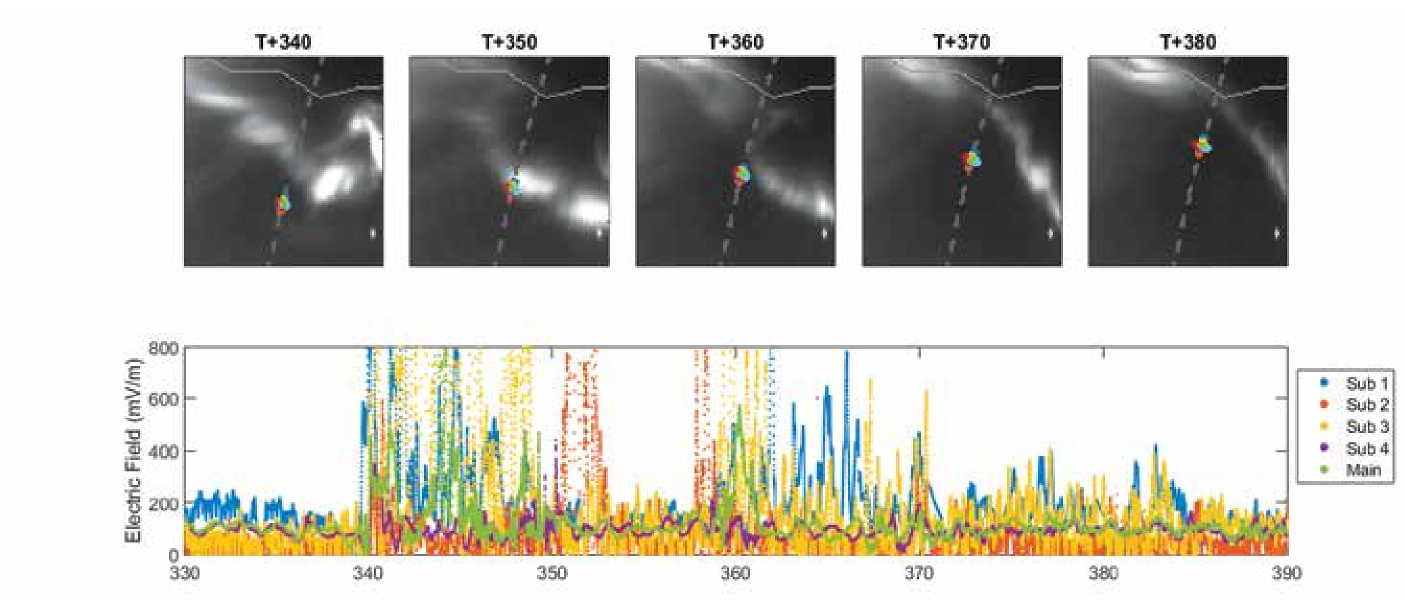


Figure 2 Electric and magnetic Field Results from 5 payloads passing over the same auroral event.

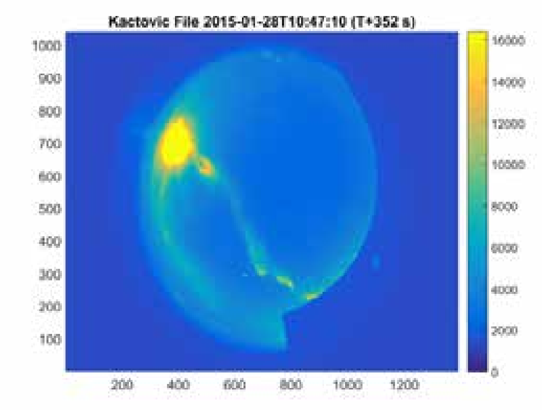


Figure 3 All sky camera image of the aurora over Kactovic Alaska during the Auroral Spatial Structures Probe flight.

Students at Utah State University integrating ASSP subpayloads.

of the event can be clearly seen by comparison of the multiple observations (See Figure 2). We expect a more complete comparison of the magnetic and electric fields measured by the payloads as the motion of the payloads is more accurately modeled. This will also allow for calculation of the Poynting flux, or electromagnetic energy flow, giving insight into the energy transfer during the auroral event.

Electromagnetic energy is generated when the solar wind interacts with the Earth's magnetosphere and flows into the Earth's upper atmosphere. There the energy is ultimately deposited in the form of heat within the thin gasses of the upper atmosphere causing them to expand outward to higher altitudes. One result of this expansion is an increase in the ephemeral drag on satellites due to the Earth's upper atmosphere. Satellite drag is difficult to predict without a precise understanding of the energy input and temperature limiting the ability to forecast satellite trajectories. This is especially true during geomagnetic storms when large amounts of electromagnetic energy are dumped into the thermosphere and dissipated through the Joule heating process. ASSP is focused on understanding the importance of small spatial scale and rapid temporal fluctuations of electromagnetic fields relative to slow and larger-scale electrodynamic processes. The data from ASSP is being combined with ground-based observations of winds, large-scale electric field patterns, and auroral images to create a complete picture of the interactions taking place.

ASSP team with payload at Poker Flat Research Range, Alaska.

Principal Investigator:
Dr. Todd Pedersen
Air Force Research Laboratory
Space Vehicles Directorate
Sponsor: DoD Space Test Program
Mission Number(s):
36.299 DR
Launch site:
White Sands Missile Range, NM
Launch date:
February 25, 2015

Rocket leaving the launch pad at White Sands in the pre–dawn darkness.

The Department of Defense's Space Test Program, based at Kirtland Air Force Base in Albuquerque, New Mexico, flew a Black Brant IX rocket which carried a payload designed by scientists and engineers from the Air Force Research Laboratory's Space Vehicles Directorate also at Kirtland Air Force Base.

The launch vehicle, which was designed to reach an altitude over 250 km, released small amounts of ionizable vapor at multiple locations near the solar terminator to better understand chemical and photochemical processes responsible for the formation of the Earth's ionosphere. The plasma source material diffused through the near-vacuum of space at ionospheric altitudes to create a large pink cloud over the White Sands launch site which could be seen from Texas to Nevada.

The ionosphere is a region of the upper atmosphere, from about 85 km to 600 km altitude, characterized by presence of a significant amount of ionization. Disturbances in this region can play havoc with radio signals bouncing around the Earth and to and from satellites. The fluctuating nature of the ionosphere is largely a result of solar radiation interacting with the upper atmosphere, so events such as solar flares, geomagnetic storms, and lightening can impact the performance of radio equipment which interacts with the ionosphere.

Air Force researchers and other team members, including a contingent of scientists from the U.K., monitored ionospheric conditions during the experiment with ionospheric sounders, optical systems, and other instruments from a number of sites across the Southwest USA.

A key aspect of the experiment was to compare ionization produced in darkness by chemical reactions before the terminator crossing with ionization produced by ultraviolet radiation after the cloud was illuminated by sunlight. Past ionization experiments were all carried out with the payload already in sunlight and were therefore unable to separate out the contributions from the different ionization mechanisms. Signatures of ionization were detected by an ionospheric sounder located near the White Sands launch site while the clouds were still in darkness, indicating that chemical ionization processes were active even in the absence of sunlight. Additional ionization was created when the sun rose on the released vapor to produce the glowing pink cloud observed against the morning twilight by observers across the Southwest.

In the last few decades, these kinds of experiments have become increasingly important because of the effect the ionosphere has had on radio communications, including GPS systems. Recent advances in meteorology have given us the ability to predict weather accurately a few days out. The ionosphere acts much like terrestrial weather systems except it is vastly more complicated and difficult to predict. The addition of electric and magnetic fields makes modeling of the ionosphere very difficult and as a result it is a very active research topic.

View of the cloud from a site in Arizona.

CARE II

Principal Investigator:

Dr. Paul Bernhardt

Naval Research Laboratory

Sponsor: DoD Space Test Program

Mission Number(s):

39.012 DR

Launch site:

Andoya Space Center, Norway

Launch date:

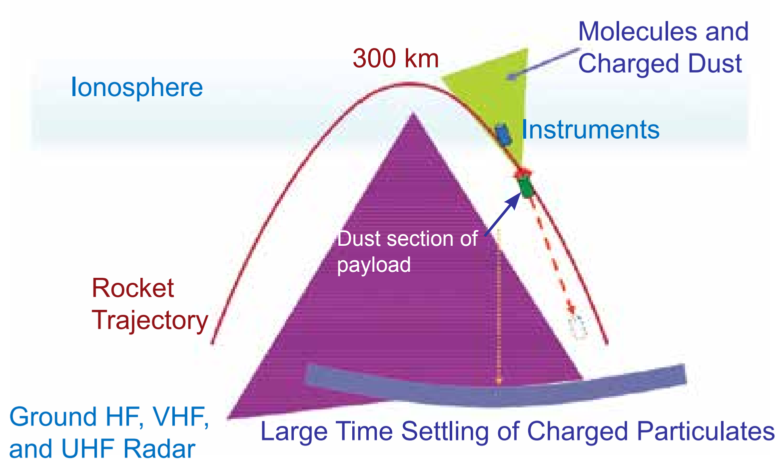
September 16, 2015

CARE II launches from Andoya Space Center, Norway.

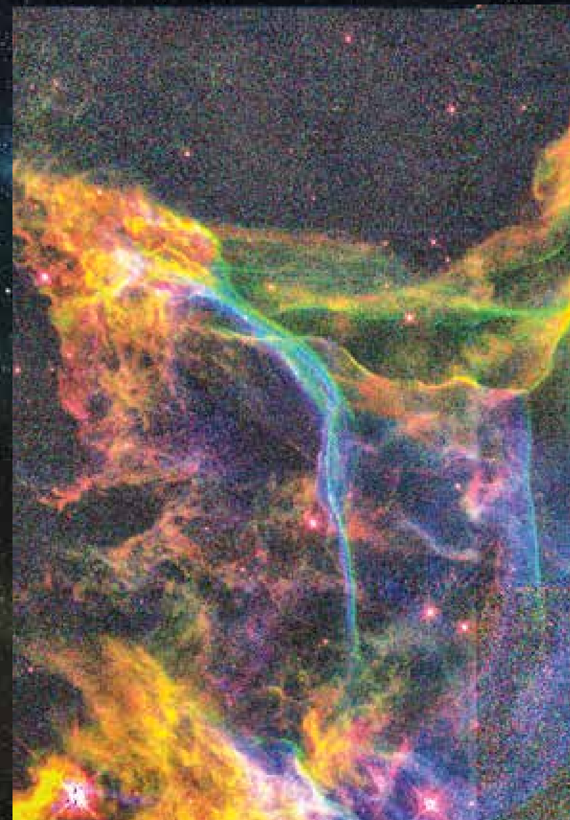
Dust cloud created by exhaust from the CRV motors.

The CARE II was launched on September 16, 2015 from Andoya Space Center, Norway using a Black Brant XI vehicle. The payload included 37 rocket motors and a multi-instrument daughter payload to study the generation of plasma wave electric fields and ionospheric density disturbances by the high-speed injection of dust particles. A primary sensor for the Charged Aerosol Release Experiment was the two SuperDARN CUTLASS radars that view the ocean north of Norway. The rocket motors firing simultaneously produced 66 kg of micron-sized dust particles composed of aluminium oxide. In addition to the dust, simple molecular combustion products such as N2, H2, CO2, CO, H20 and NO were injected into the F-layer. Charging of the dust and ion charge exchange with the molecules produced plasma particles moving at hypersonic velocities. Streaming instabilities and shear electric fields yield plasma turbulence that can be detected using ground radars and in situ plasma instruments. The instrument payload separated from the dust section soon after launch and measured electric field vectors, electron and ion densities, and integrated electron densities. The release of high speed dust was directed upward on the downleg of the rocket trajectory to intersect the bottomside of the F-Layer. Ground HF and UHF radars operated to detect scatter and refraction by the modified ionosphere. Optical instruments were used to map the dispersal of the dust using scattered sunlight. The plasma interactions are being simulated with both fluid and particle-in-cell (PIC) codes.

CARE II is a follow-on to the CARE I rocket experiment conducted from Wallops Island Virginia in September 2009.



CARE II trajectory and mission outline.

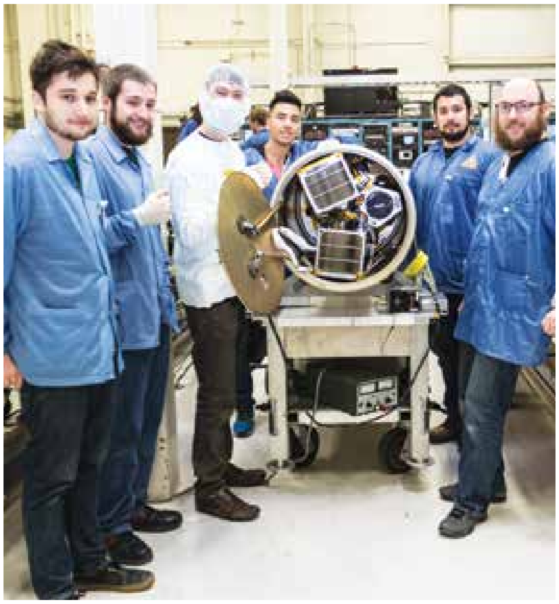


Astrophysics Flight Missions

The soft X-ray spectrograph Off-plane Grating Rocket for Extended Source Spectroscopy (OGRESS) was the sole astrophysics mission in 2015. The target for this first flight of OGRESS was the Cygnus Loop supernova remnant, one of the brightest and largest soft X-ray emitters in the sky.

OGRESS

Principal Investigator:
Dr. Randall McEntaffer
University of Iowa
Mission Number(s):
36.292 UH
Launch site:
White Sands Missile Range, NM
Launch date:
May 2, 2015



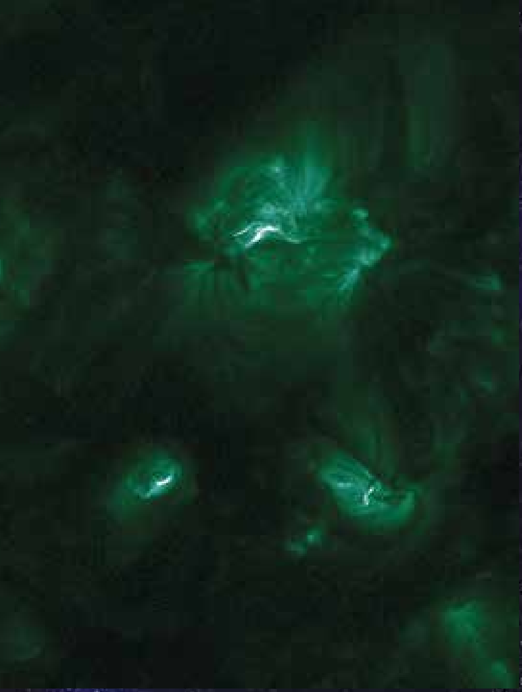
OGRESS Team at Wallops Flight Facility.

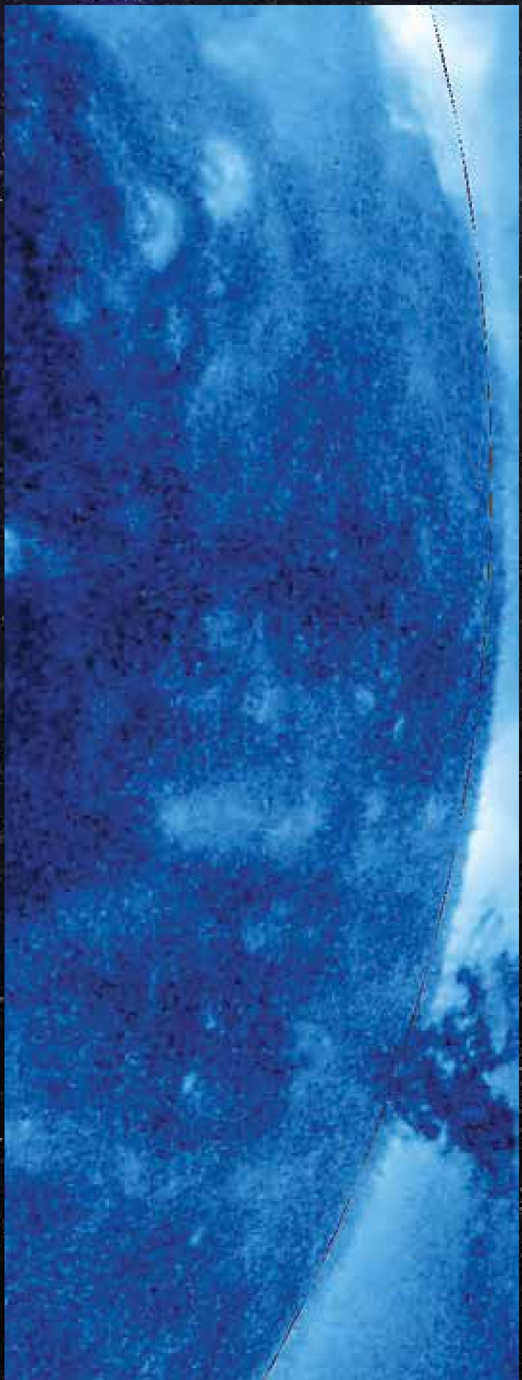
OGRESS team members with payload during recovery operations at White Sands Missile Range.

Supernova are the last phase in the life of a star. These explosive events eject matter and energy out into space where it is recycled to create new stars. It is of scientific interest to determine the types and quantities of matter in the universe. To truly understand the makeup of the universe it is necessary to increase the resolution and detail of scientific observations. As instruments improve, theoretical models can be enhanced and new insights can be obtained.

The Off-plane Grating Rocket for Extended Source Spectroscopy (OGRESS) instrument was designed to improve the fidelity of observations of extremely large, diffuse objects such as supernova. Its purpose is to capture soft X-rays emitting from these sources and split them into individual wavelengths for analysis. This spectrum is used to identify what kind of matter is present in the target of interest. The OGRESS telescope uses a novel collimator, an off-plane reflection grating, and gaseous electron multiplying (GEM) detectors in concert to provide a significant increase in spectral resolution. The science team used its expertise in optical development to create the necessary gratings, each with a specific pattern. While the analysis of the Cygnus Loop was the goal of this particular mission, the ultimate goal of this development effort is to create a larger telescope to aid in the search for Dark Matter.

During the flight, a high count rate was recorded that masked the spectrum from the Cygnus Loop. The data is currently being analyzed in an attempt to recover usable data.





Solar Physics Flight Missions

Five solar physics missions, all from White Sands Missile Range were flown in 2015. Investigations focused on gather ing information about the Sun in the EUV, UV and X-ray parts of the spectrum.

RAISE

Principal Investigator:
Dr. Donald Hassler
Southwest Research Institute
Mission Number(s):
36.253 US
Launch site:
White Sands Missile Range,
New Mesico
Launch date:
November 5, 2014


RAISE in the clean room before launch.

The Sun's surface can be very active with massive eruptions known as solar flares. These solar flares are born from areas of intense and complex magnetic fields. Knowing how material is being heated and moved around the Sun is of high scientific interest, and one way to observe how materials is moving is to create a spectrogram. A spectrogram separates light into its component wavelengths. The different wavelengths correspond to differing temperatures and velocities of the material.

The Rapid Imaging Spectrograph Experiment (RAISE) was designed to capture such spectrograms at a very high image rate. The RAISE imager is capable of capturing 1,500 images of the Sun in five minutes, which makes it the fastest scanning-slit imaging spectrograph flown in space to date. It is capable of observing the dynamics and heating of the solar chromosphere and corona on time scales of 100-200 msec., with arc-second spatial resolution and velocity sensitivity of 1-2 km/sec. This data can help scientists better understand what creates regions of high dynamics and possibly what causes solar flare eruptions. The RAISE telescope makes its observations in the extreme ultraviolet spectrum, which does not penetrate the Earth's atmosphere. As a result, these measurements can only be made using space-based instruments. Sounding rockets serve as excellent tools for developing these new technologies which may eventually make their way onto future orbiting observatories.

The RAISE telescope employs an off-axis parabolic mirror, a near-normal incidence toroidal grating, and two intensified Active Pixel Sensor (APS) detectors. This configuration allows two full spectral passbands over the same one-dimensional spatial field to be recorded simultaneously with no scanning of the detectors or grating. The lack of scanning is one means by which the high image rate can be achieved. The new grating employed by this instrument was coated with a new material called boron carbide, which makes it more effective at separating light into its component wavelengths.

This was the second flight of RAISE, the first of which was conducted on August 23, 2010. Data from the 36.253 mission is currently being analyzed.

FOXSI 2

Principal Investigator:
Dr. Sam Krucker
University of California-Berkeley
Mission Number(s):
36.295 US
Launch site:
White Sands Missile Range,
New Mesico
Launch date:
December 11, 2014

FOXSI prior to launch at White Sands Missile Range.

FOXSI team with rocket.

The outer layer of the Sun (known as the corona) has a temperature over one million degrees Kelvin (K) while the visible surface of the Sun, the photosphere, is a mere 6,000 deg K. This is contrary to intuition because temperature usually decreases as the distance from the heat source increases. This phenomena is known as the "coronal heating problem". The mechanisms that heat up the corona are not understood and unlocking the secrets will tell scientists a lot about the dynamics of the sun. The Focusing Optics X-ray Imager (FOXSI) is designed to look at barely visible nanoflares, which are much smaller, but more frequent than the large solar flares most people are familiar with. These nanoflares may serve as the seeds for the cascade that cause much larger flares, and may be connected to the physics that causes the Sun's corona to be hotter than its surface.

The FOXSI-2 telescope collects information on these nanoflares by collecting high energy X-rays in the 4-15 KeV energy range. To do this requires high resolution focusing optics and fine-pitch imaging sensors. The required resolution is achieved by combining a fine-pitch Double-sided Si Strip Detector (DSSD) with a low-noise front-end Application-Specific Integrated Circuit (ASIC). The end result is a sensitivity that is two orders of magnitude better than Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite, the most recent NASA spacecraft studying solar flare high energy processes.

FOXSI is a pathfinder for the next generation of solar hard X-ray spectroscopic imagers. Future space-based observatories leveraging the FOXSI technology will be able to image the paths of non-thermal electrons as they move through the corona.

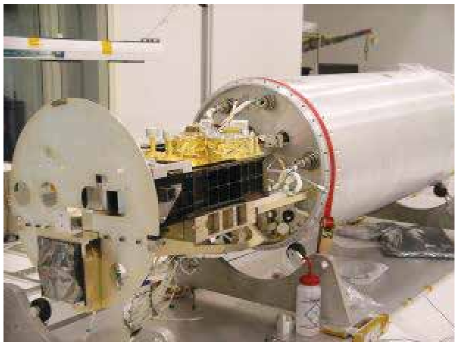
This was the second flight of the FOXSI telescope. On its first flight made in November 2012, the telescope successfully viewed a flare in progress. Data from the 36.295 missions is still undergoing analysis.

EVE

Principal Investigator:
Dr. Thomas Woods
University of Colorado
Mission Number(s):
36.300 UE
Launch site:
White Sands Missile Range, New Mesico
Launch date:
May 21, 2015

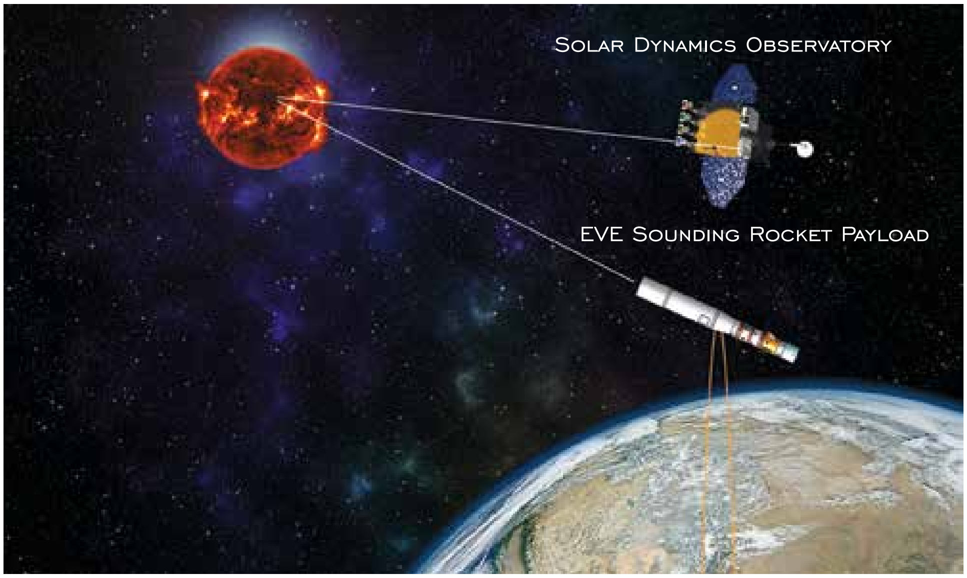
Sounding rockets are excellent tools for developing instruments that are eventually utilized on longer duration satellite missions. They also serve as excellent tools for enhancing satellite data and extending missions. A good example is the EUV Variability Experiment (EVE) sounding rocket mission. This was one of several calibration underflight missions for the Solar Dynamics Observatory (SDO) satellite. The EVE sounding rocket mission flies an Extreme Ultraviolet (EUV) instrument that is nearly identical to the instrument on the SDO satellite. The Sounding Rocket instrument is calibrated just before launch and then makes an identical solar observation as SDO flies overhead. Upon recovery the sounding rocket instrument is then recalibrated to provide an absolute data reference. The calibrated sounding rocket data is then compared to the satellite data. The absolute calibrated data from the sounding rocket flight serves as a very accurate reference point to establish any long-term degradation in the satellite instrument. This results in higher quality data and can extend the life of the orbital instrument.

Due to an issue with the S-19 boost guidance system that guides the launch vehicle for the first 18 seconds the flight was terminated. This was accomplished using the on-board destruct system that is flown on all Terrier-Black Brant missions at White Sands Missile Range. As a result, no scientific data was obtained. As designed, the payload survived the termination event and safely parachuted to the ground. The payload will be refurbished and reflown at a later date in 2016.



EVE sounding rocket instrument (2012).

EVE instrument onboard SDO imaged before flight.



Underflight calibration graphic. The EVE instrument in the sounding rocket payload measures Extreme Ultraviolet radiation from the Sun simultaneously with the EVE instrument onboard the Solar Dynamics Observatory.

MOSES-2

Principal Investigator:
Dr. Charles Kankelborg
Montana State University
Mission Number(s):
36.282 US
Launch site:
White Sands Missile Range,
New Mexico
Launch date:
August 27, 2015

The MOSES payload being prepared for flight at White Sands Missile Range, NM.

The outer layer of the Sun (known as the corona) has a temperature over one million degrees Kelvin (K) while the visible surface of the Sun, the photosphere, is a mere 6,000 deg K. This is contrary to intuition because temperature usually decreases as the distance from the heat source increases. This phenomena is known as the "coronal heating problem". The Multi-Order Solar EUV Spectrograph (MOSES) is used to investigate this issue by making observations in the Extreme Ultraviolet (EUV) spectrum. The region of interest for this experiment is the transition region where explosive events similar to solar flares occur. These solar events are thought to be caused by magnetic reconnection, a sometimes violent process which releases heat and energy. It is hypothesized that observations of the magnetic reconnection will be easier in the transition region where material is more dense.

The MOSES instrument was finely tuned to measure light being emitted at a specific temperature and wavelength - specifically light at 465 Angstroms, which represents material at a temperature of approximately 500,000 degrees K. Since temperatures are related to various layers of the sun and its atmosphere, the target temperature corresponds to the target layer - the transition layer.

One unique aspect of the MOSES detector is that it is a Multi-Order slitless spectrograph, which captures whole images of the Sun rather than just "slices" as in a typical spectrograph. This approach avoids the issue of having to scan across the Sun, a process that takes time. The scanning time creates a problem in that over the time period it takes to complete a full scan, the features of the sun have changed. As such, the scanning process of the conventional spectrograph cannot produce a co-temporal image, where the Multi-Order slitless spectrograph can. While slitless spectrographs are not new, the MOSES instrument eliminates a previous problem of overlapping Sun images on the detector. The MOSES instrument uses multiple detectors that are spaced at three different diffraction orders rather than just one, eliminating the problematic ambiguities associated with multiple images on a single detector. The MOSES instrument was tuned to observe Ciii 459.3 Angstroms and Ne vii 465.2 Angstroms over a 20′ x 10′ field of view.

This was the second flight of the MOSES instrument, the first of which was conducted on February 8, 2006. Data from the 36.282 mission is currently being analyzed.

CLASP

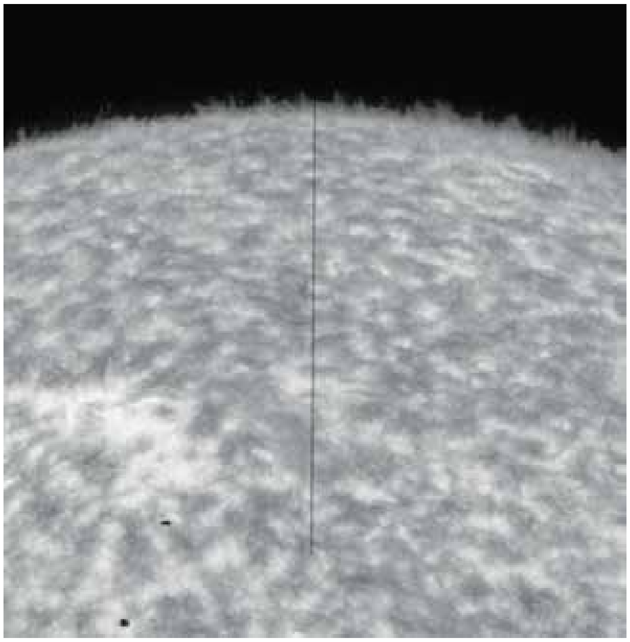
Principal Investigator:
Dr. Amy Winebarger
NASA Marshall Space Flight Center
Mission Number(s):
36.291 US
Launch site:
White Sands Missile Range,
New Mesico
Launch date:
September 3, 2015

The experiment team attending the launch of the CLASP instrument (inside white box) mounted on the launch rail. Team members attending launch include (bottom row) Ken Kobayashi (NASA MSFC), Yukio Katsukawa (NAOJ), Patrick Champey (UAH), Brent Beabout (NASA MSFC), Dyana Beabout (NASA MSFC), Takamasa Bando (NAOJ), Gabriel Giono (NAOJ), Masahito Kubo (NAOJ), Shin–nosuke Ishikawa (JAXA ISAS), (top row) Ryouhei Kano (NAOJ), Amy Winebarger (NASA MSFC), Noriyuki Narukage (NAOJ), Javier Trujillo Bueno (IAC), Ryoko Ishikawa (NAOJ), and Harlan Haight (NASA MSFC).

The atmosphere of the Sun is composed of hot plasma which is hundreds of thousands of degrees hotter than the Sun's surface. While the corona (outer atmosphere) is hotter than the chromosphere (inner atmosphere), the higher density of the chromosphere requires 10 to 100 times more heating than does the corona. As with other solar physics missions, the mechanisms that drive this extreme heating are of great scientific interest.

Satellite observations have discovered various dynamic events (jets and waves) in the chromosphere, and it is possible that these dynamics may be responsible for the observed chromospheric heating. Magnetic fields seem to play a significant role in these dynamics. The Chromospheric Lyman-Alpha Spectro Polarimeter (CLASP) sounding rocket payload was developed to detect the Hanle effect polarization caused by the magnetic fields. The Hanle effect is more sensitive to weaker magnetic fields, which makes it better suited for detecting the complex magnetic field dynamics. CLASP was designed to provide Lyman-Alpha polarization measurements with an unprecedented accuracy of 0.1%, and 0.01 nm wavelength resolution.

This mission was highly successful and initial indications are that excellent science was obtained. As a result of this mission, there is high confidence in the CLASP technology that will be integrated into the Solar-C satellite which is under development.



The quiet sun region observed by CLASP. This image is taken with the slitjaw camera with a broad band filter centered on the Lyman alpha spectral line. The black line in the image is the slit.

Technology Flight Missions

Three technology test flights were completed in Fiscal Year 2015. The Taurion vehicle was developed specifically to gather high subsonic and transonic flight data at various Reynolds numbers. Two experiments supported by the NASA Space Technology Mission Directorate were flown onboard a Black Brant IX from Wallops Island and a mission for the Naval Surface Warfare Center Port Hueneme Division was flown from White Sands Missile Range, NM.

Principal Investigator:
Mr. Carsell Milliner
NASA Wallops Flight Facility
Mission Number(s):
36.313 NP
Launch site:
Wallops Island, Virgina
Launch date:
July 7, 2014

Science team from NASA Ames Research Center integrating the SOAREX–8 experiment.

Image capture from onboard video of the Exo–brake experiment deployment.

Two experiments sponsored by NASA's Space Technology Mission Directorate (STMD) Flight Opportunity program were supported by this mission. Sounding rockets enable rapid development and testing of new technologies, thereby increasing the Technical Readiness Level (TRL) of instruments intended for future space flight missions. Additional SRPO/NSROC internally developed technologies were tested on this flight. Ridesharing reduces mission cost to users and provides additional flight opportunities.

Experiments on this flight included:
Sub-Orbital Aerodynamic Re-entry EXperiments (SOAREX) 8
Radial Core Heat Spreader (RCHS) experiment
NSROC High Definition video system
NSROC new improved quality video camera
NSROC developed Radially Ejecting OGIVE System (REOS)

Sub-Orbital Aerodynamic Re-entry EXperiments (SOAREX) 8

Marcus Murbach from Ames Research Center conducted the Sub-Orbital Aerodynamic Re-entry EXperiments (SOAREX) 8 experiment. SOAREX-8 was designed to test an Exo-Brake system that can passively de-orbit an object in space. The Exo-brake utilizes nano-satellite technology housed in a Cubesat ejector pod, and is a self-stabilising exospheric de-orbiting mechanism that will allow return of a payload to earth fairly rapidly from an orbital platform, like the International Space Station. This was the first full-scale Exo-Brake test flight. SOAREX-8 also tested Iridium Short Messaging Service (SMS), GPS tracking, and wireless sensors using the ZigBee protocol to connect analog sensors for temperature, air pressure and acceleration measurement wirelessly to the payload telemetry system.

Radial Core Heat Spreader (RCHS) experiment

Marc Gibson and team (Jim Sanzi, Max Briggs, Damir Ljubanovic) from Glenn Research Center provided the Radial Core Heat Spreader (RCHS) experiment.

The RCHS technology is a passive thermal control device designed to couple a Stirling convertor to the heat rejection system of a power generator. The design incorporates a hollow disc made of two titanium foil halves and a titanium powder wick that provide the necessary vapor space and capillary wick structure for two-phase heat transfer using water as the working fluid. The

The Radial Core Heat Spreader experiment section.

inner diameter of the RCHS receives heat from the Stirling engine, which is simulated with an electrical heater in this experiment, and transfers the heat to the condenser located at the outer diameter and coupled to the cold side heat exchanger. The RCHS technology provides a lower mass option to the current state of the art technology with increasing benefits at higher power levels.

Two RCHS units were integrated into this mission. The test units successfully demonstrated thermal performance throughout the flight, proving that the RCHS technology could cool a Stirling Radioisotope Generator (SRG) during the hypergravity forces of launch and zero gravity. The testing matured the RCHS technology to a Technology Readiness Level (TRL) of 6.

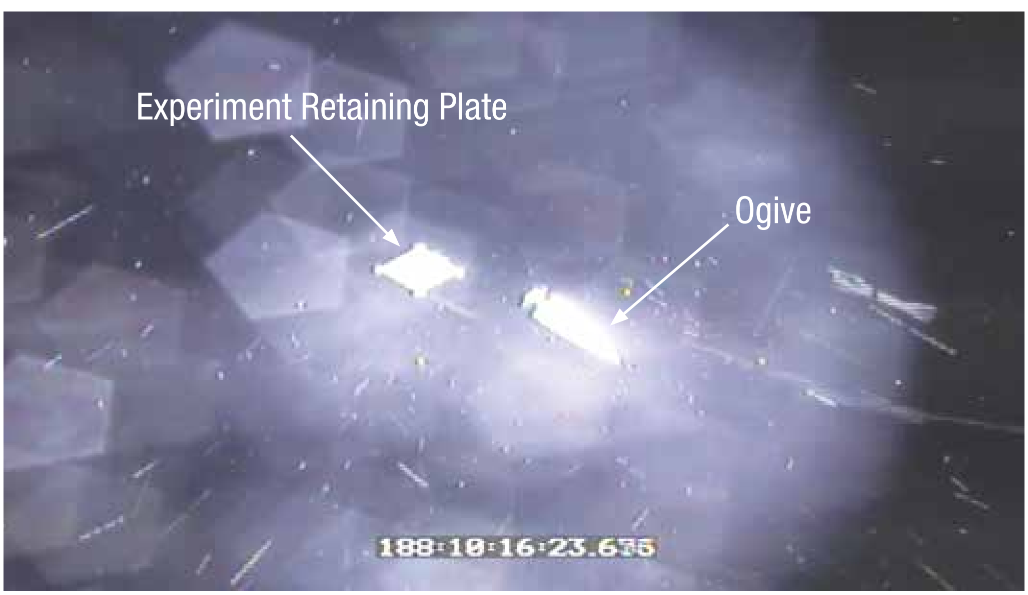
SRPO/NSROC Technologies

Two different video camera systems were tested on this flight, an aft looking High Definition video to view the rocket exhaust plume, and an analog video camera to view the SOAREX-8 deployment.

REOS test unit (left) and REOS installed in the nose cone.

Radially Ejecting OGIVE System (REOS)

This mission validated the new REOS ejection system. The REOS is used for science flights that require the nose cone to be removed from the payload flight path as well as on vehicles using an exo-atmospheric rocket motor where the nosecone is removed prior to final stage burn in order to reduce weight and gain performance. The REOS replaces a legacy sounding rocket system and uses modernized surface mounted components, a rechargeable battery pack, and optional in-flight monitors.

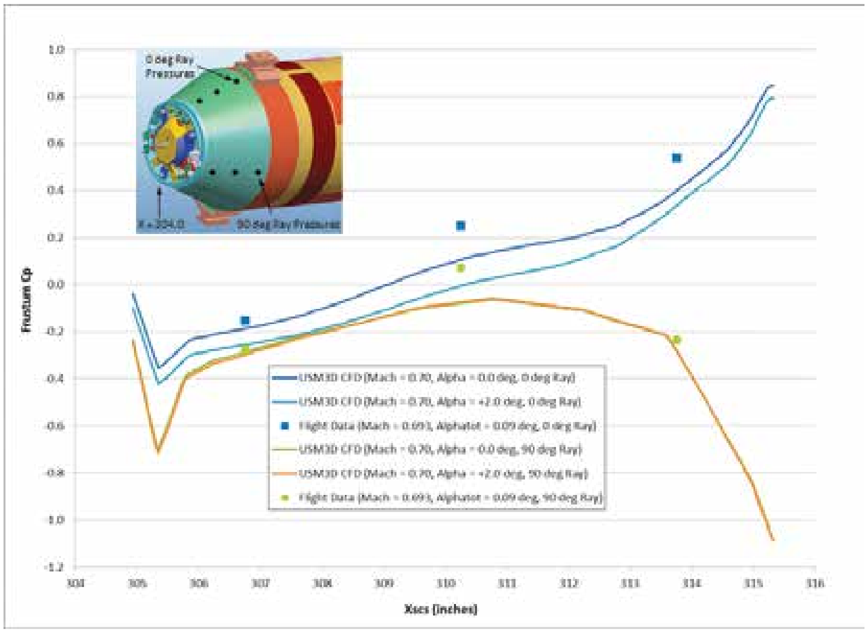


Screen captured from onboard video camera of the REOS ejecting the ogive.

Principal Investigator:
Dr. Michael Gilbert
NASA Engineering and Safety Center
Mission Number(s):
12.082 CR
Launch site:
White Sands Missile Range, New Mexico
Launch date:
December 17, 2014

An inert Orion motor is test fitted into the Taurus motor casing at Wallops Flight Facility.

The NASA Sounding Rockets Program (NSRP) is a national asset that converts surplus hardware into useful configurations to assist with research and development efforts. NSRP developed the Taurion vehicle to support the NASA Engineering Safety Center (NESC), Alliant Techsystems Inc. (ATK) and the Navy suborbital launch group. This effort combined an inert Taurus rocket casing with an Orion motor to meet specific flight parameters. The concept was to use the high weight and drag of the Taurus case to reduce the performance of the Orion motor installed inside the larger case to achieve the desired flight conditions. The vehicle flight trajectory was designed to burnout at apogee, 0° elevation angle, slightly subsonic velocity, and just below 10,000 ft altitude. The concept repurposes the Taurus hardware designated for disposal and makes use of the existing tactical fins (first use by NASA), lugs, and standard rail interface configuration. NESC's goal was to collect flight data in the form of pressure measurements to be used for validation of state-of-the-art Computational Fluid Dynamics (CFD) simulations. In particular, there was a desire for high subsonic and transonic flight data at various Reynolds numbers. By validating the CFD simulations, the uncertainty of the CFD results may be decreased when applied to future vehicles where wind tunnel or flight data is not available.



The results in the figure above show the CFD predictions are very close in magnitude and follow the trend in Cp observed from the frustum pressure sensors. This demonstrates the ability of the CFD analysis to capture the effects of the flow expansion from the stagnated nose region onto the conical surface of the frustum. In addition the CFD analysis captures the increase in Cp from the flow compression on the 0 degree location in the region of separated flow in front of the forward launch lug. Also captured by the CFD analysis is the decrease in Cp at the end of the frustum on the 90 degree location resulting from subsonic flow expansion around the aft corner of the frustum.

C-Band Telemetry Experiment

CTREX

Principal Investigator:
Mr. Troy Gammill
Naval Surface Warfare Center,
Port Hueneme Division
Mission Number(s):
30.076 DR
Launch site:
White Sands Missile Range,
New Mexico
Launch date:
December 17, 2014

Image 1. Ground segment equipment on location at White Sands Missile Range, NM.

The Naval Surface Warfare Center (NSWC) requested launch vehicle support from NASA SRPO for this mission. NASA provided a single stage Orion launch vehicle.

In 1993 the Department of Defense (DoD) controlled Radio Frequency (RF) spectrum began to be valued for more than its usefulness as a transmission medium for missile and aircraft telemetry. DoD has given up much of the L-band, some of the S-band, and currently the band from 1755-1780 and 2155-2180 MHz has been auctioned for 4G-LTE. Some spectrum in the C-band was offered as replacement for loss of lower frequency bands. Testing at the frequencies of interest would be required in order to understand and mitigate the unique problems associated with missile and rocket tracking. Examples of these unique problems are wrap around antenna designs, spinning missiles, varying multipath, and high dynamics. The CTREX mission was designed collect flight data to study these problems.

Test Elements

The CTREX experiment entailed a tightly scheduled single flight of a heavily instrumented highly dynamic Orion vehicle transmitting 5125.5 Mhz (mid C- band) and 2251.5 Mhz (mid S-band). The antennas were of a new conformal design. Additional onboard systems provided inertial measurements, GPS position, and magnetometer measurements transmitted on an additional S band frequency (2215.5 Mhz). This data was required to be collected for post test data analysis of vehicle attitude, along with antenna pattern analysis, and definitive position data.

Test Assessment

The time period for all data comparisons was selected as T-0 to T+ 380 seconds. The baseline systems 7.3 meter, and 2.7 meter S band systems achieved very close to 100 percent data recovery. Actual percentage of data recovered remains under analysis investigation, but preliminary observations suggest a number above 98 percent PRN code recovery. The C band data was also recovered at a high percentage level, but in final analysis is expected to be some percentage less recovered than S band data as recovered on the baseline systems. Analysis should be able to provide a determination as to whether the percentage of recovered levels retain a close correlation to data observed during site acceptance testing of the systems.

Education Flight Missions

Three education mission were flown in 2015 and included one RockOn/RockSat-C payload, and two RockSat-X payloads. The RockOn payload included Cubes in Space experiments from Middle School students. These experiments were competitively selected.

Principal Investigator:
Mr. Christopher Koehler
Colorado Space Grant
Mission Number(s):
41.113 UO
Launch site:
Wallops Island, Virgnia
Launch date:
June 25, 2015

RockOn workshop experment construction.

RockOn workshop experment construction.

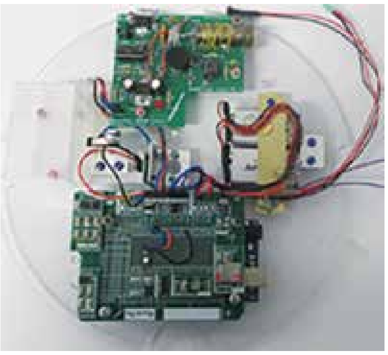
Experiments returned to students after vibration testing.

RockOn and RocKSat-C is a hands-on, university-level educational project conduced as a collaborative effort between the Colorado Space Grant Consortium (COSGC), the Virginia Space Grant Consortium (VSGC), and the NASA Sounding Rockets Program. The 41.113 UO mission is the eighth in the on-going series that was begun in 2008. Since its inception, over 300 university students and instructors from 38 states have participated. Participants have come from over 125 universities and colleges. This mission also included Cubes-In-Space, which is an international STEM education initiative. Hundreds of students from the United States created autonomous science experiments that fit into 1"x1"x1" cubes. Eighty cubes were mounted in a container which was installed under the payload nose cone.

RockOn is a week-long workshop where participants build kit experiments that include data loggers, accelerometers, thermistors, gyro chips, and Geiger counters. 15 experiment teams (typically 3 members each) built and flew experiments. Participants arrived on Sunday, and then watched their experiments launched on a Terrier-Improved Orion launch vehicle on the following Thursday.

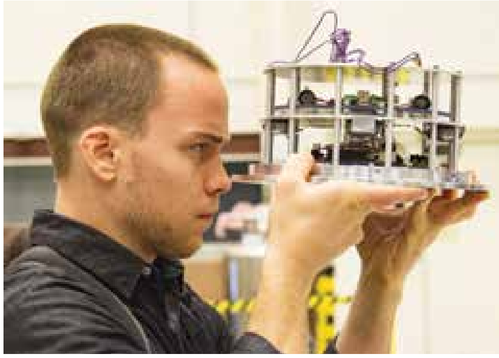
RockSat-C is a follow-on step that builds on experience obtained from RockOn. Universities, as teams in many cases, design and build custom experiments which are flown on the same vehicle along with the RockOn experiments. The experiments must be designed to fit within the canisters used to house the RockOn kit experiments. All experiments must be self-contained with their own power and data recording. The experiments are contained with a skin section, but they can have access to the space environment through ports in the skin. The payload is recovered after flight. Ten RockSat-C experiments were developed and flown by 10 universities and colleges.

Stack of Kit experiments.



RockOn Kit experiment.

Students waiting for their RockSat–C experiments to be returned after vibration testing at Wallops.



Post vibe RockSat–C experiment inspection.

The RockSat-C experiments included the following:

- Cosmic radiation detection – Linn-Benton Community College
- Tardigrade reaction to microgravity – Oregon State University
- CubeSat gravity gradient boom – Mitchell Community College
- Effect of rocket flight on bacteria / graphene coated electronics – Stevens Institute of Technology
- Measurement of Muon flux at various altitudes – Hobart and William Smith Colleges
- Capture earth images and measure magnetic field – West Virginia Universities
- Collection of biological samples at various altitudes – Temple University
- Observation of normal field instabilities in a ferrofluid suspension – Carthage College
- Assessment of small spacecraft sensors, solar cells and transmitters – Old Dominium University
- Electromagnetic Counter Rotating Platform - Community College of Denver

Once again the RockOn and RockSat-C flight was a resounding success. The mission was launched on time and recovery from the Atlantic Ocean was completed in only a few hours.

Waiting for rocket to launch on Wallops Island, June 25, 2015.

Principal Investigator:
Mr. Christopher Koehler
Colorado Space Grant
Mission Number(s):
46.008 UO
Launch site:
Wallops Island, Virgnia
Launch date:
April 18, 2015

Northwest Nazarene University team loading their 3D printed airfoils into the ejector for the April 2015 RockSat–X flight.

University of Nebraska team with their experiment ready for integration in April 2015.

University of Puerto Rico students and faculty preparing experiment for launch in April 2015.

RockSat-X is the third tier in the educational pipe line. This flight opportunity accommodates custom experiments that are given full space exposure via a deployable skin fairing. The payload carrier, which is more sophisticated than the RockOn payload, allows the student teams to sense the space environment, deploy detectors, or even eject free-flying devices. The reusable payload carrier, which was developed by the NASA Sounding Rockets Program, includes power, telemetry, and attitude control for pointing once the payload leaves the atmosphere. Experiment selection and management is provided by the Colorado Space Grant Consortium. This approach minimizes the impact on the NASA Sounding Rockets Program and provides valuable project management experience for the student management team. This is the fifth flight of RockSat-X.

RockSat-X (V) experiments included the following:

- Generating an immiscible alloy in low gravity – University of Colorado
- Free-flying airfoils in low atmospheric conditions – Northwest Nazarene University
- Micrometeorite detection and collection – University of Puerto Rico
- Crystal growth in low gravity – University of Nebraska Lincoln
- Pressure Sensor Aperture Cover Release Mechanism and Optical NO Sensor test – Virginia Tech
- HD Payload Video monitor – University of Colorado

This mission was originally planned for August 2014, but higher priority programmatic needs caused the mission to be slipped into 2015. This is the nature of the educational missions. In order to conduct them on a low-cast and low-impact basis, they are assigned a lower priority in the manifest. The 46.008 flight was successfully launched and recovered, and the students were able to assess the performance and success of their experiments.

Principal Investigator:
Mr. Christopher Koehler
Colorado Space Grant
Mission Number(s):
46.012 UO
Launch site:
Wallops Island, Virgnia
Launch date:
August 12, 2015

Colorado University team packing up after a successful launch.

Puerto Rico experiment pre–flight preparations.

VT inspects experiment after flight.

The 46.012 RockSat-X mission (the second for the year) was conducted on August 12, 2015. This mission utilized the same support payload as the 46.008 mission launched in April 2015, but included a new set of student experiments. This mission demonstrated the agility of the program to be able accommodate educational missions on a low-impact basis. The reusable support payload was used in April 2015 to support the 46.008 mission, and was turned around with a new set of experiments in just a few months. This is possible due to the fact that the student experiments must meets specific electrical and mechanical interface requirements - essentially making the experiments interchangeable. The student teams are aware of the possibility of a launch slip, but the Sounding Rockets Program does everything it can to launch the mission on schedule. This was the sixth flight of the RockSat-X payload.

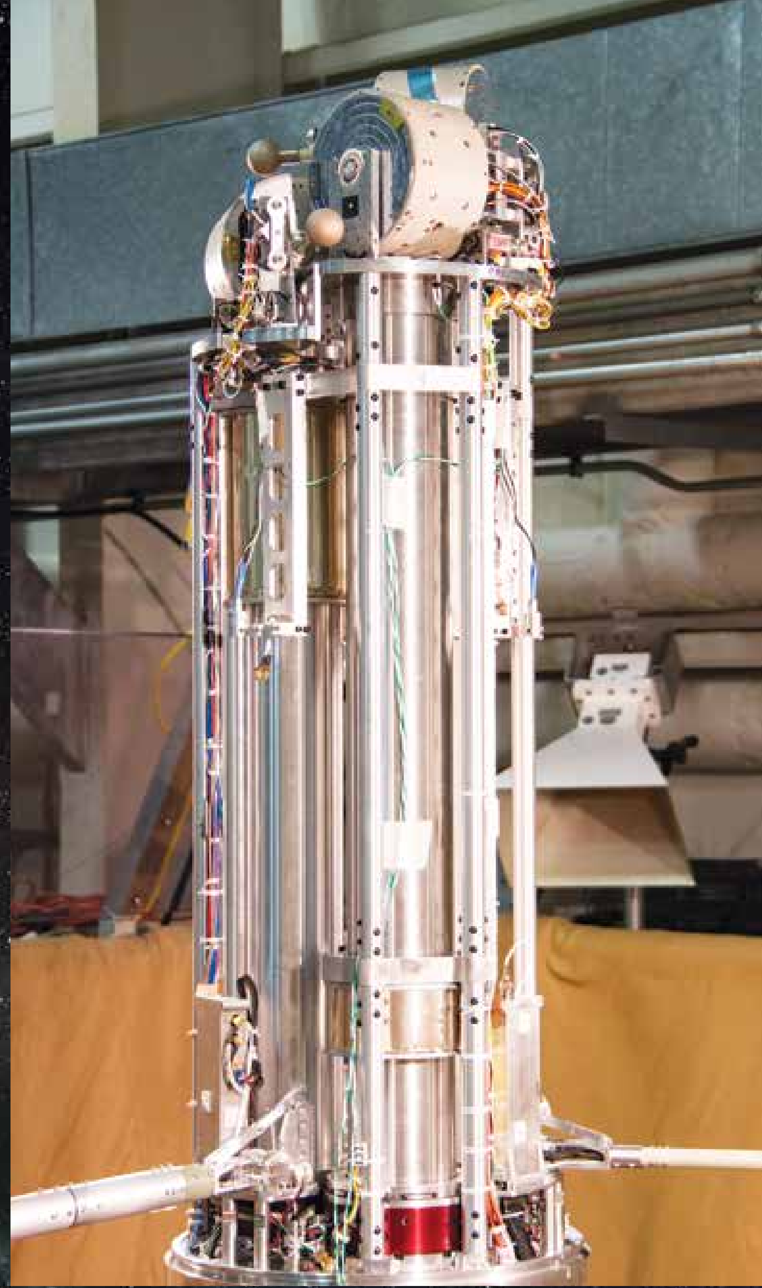
RockSat-X (VI) experiments included the following:

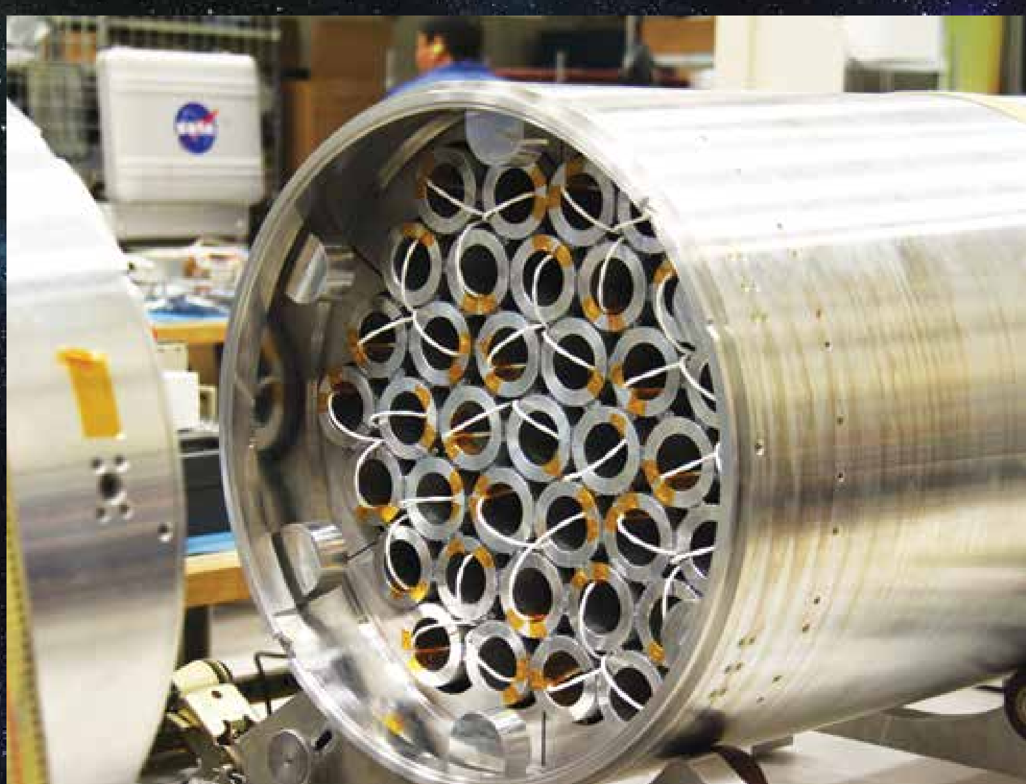
- Onboard Hot Spot Communications – Capitol Technology University
- Direct measurement of solar UV spectrum – University of Hawaii Community College System
- 3D printing in zero-G – Virginia Tech
- Crystal growth in low gravity – University of Nebraska Lincoln
- Assessment of flexible electronics in spaceflight applications – Northwest Nazarene University
- Micrometeorite detection and collection – University of Puerto Rico
- HD Payload Video monitor – University of Colorado

Once again the payload was launched on time with a very successful flight and payload recovery from the Atlantic Ocean. While one experiment experience a problem during flight, all others achieved their technical goals. Regardless of success or failure, the primary goal is to expose students to space flight projects, and once again this mission was 100% successful.

Technology Development

Technology development efforts in 2015 focused on increasing telemetry data rates, and observation times, new sub systems and constellation flight missions. Several complex missions were flown and utlized sub-payload deployment technologies developed by the program.

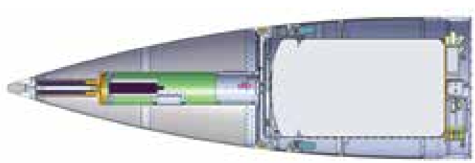




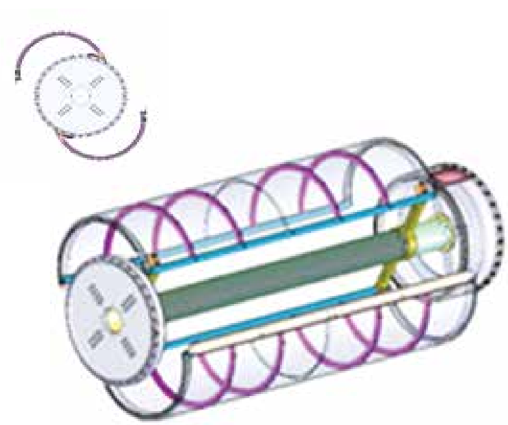
The NASA Sounding Rocket Program continues to assess new technologies in order to expand the capabilities for our science and technology customers. The major initiatives of the NSRP technology roadmap involve providing increased scientific observation time for Solar and Astrophysics missions and increasing the telemetry data rate from the current capability of 10 to 20 Mbps to systems with rates ranging from 40 to ~400 Mbps.

The Solar and Astrophysics sounding rocket missions are typically flown from a White Sands Missile Range which offers land based recovery for reliable recovery of the scientific instrument and the data collected. Recovery is necessary to get access to the critical data recorded on board since only a portion of the data can be telemetered to the ground station during the mission flight. Recovery is also necessary to refurbish and re-fly the high-value science instruments on future sounding rocket missions, thereby reducing the overall lifecycle cost of the research and allowing for more frequent missions. In order to provide these communities increased observation time the NSRP must address challenges on the sounding rocket payload systems and address challenges associated with the launch ranges. Providing additional observation time requires that the missions be launched on a different class sounding rocket moving from the two-stage Black Brant IX to the three and four stage Black Brant XI and XII. The additional performance and associated impact dispersion precludes conducting the launches from the primary launch range for these missions, White Sands Missile Range. This requires these missions to be launched from a larger land-based range or a water-based range, such as Wallops Flight Facility. Studies point to WFF as being the most suitable launch range; however given that WFF is a water-based range the NSRP must reduce the risks associated with water recovery. As such, the NSRP is investing in flotation technologies, over-the-horizon location aides, and alternate recovery vessel capabilities.

The NSRP, through NSROC and the NASA Applied Engineering Directorate (AETD), is in the process of assessing and developing several technologies to address obsolescence and introduce new capabilities in the avionics systems. The major goal of the new capabilities assessment is to increase the telemetry system data rates and to provide high data rate on-board storage. The program typically utilizes 10Mbps S-band telemetry to transmit data from the sounding rocket payload to the ground stations. In recent years, NSROC has introduced a 20 Mbps capability and is working toward higher rate capabilities on the order of 40 Mbps, while is working on higher rate systems (up to 400 Mbps) in alternate frequency bands.
A summary of some of the other avionics technologies currently being developed or assessed is provided below.



1250 lb NFORSe Assembly.



Depiction of Clamshell skin sections rotating at release.

Flight Data Recorder: An 800 Mbps flight data recorder is current under consideration by the program. The purpose of the recorder is to provide backup for the telemetry downlink and offer high data rate on-board recording.

High Rate PCM Encoder: NSROC is working with vendors to develop a new PCM encoder capable of 50 Mbps. The development process is anticipated to span ~2 years.

TDP/GDP replacement: NSROC has procured new Ulyssix Altair Systems with DEWEsoft to replace the existing TDP/GDP systems. The systems address issues with the heritage systems and increases functionality and efficiency. This system has been successfully implemented for several WSMR missions.

Transmitters: NSROC is in the process of qualification and acceptance testing for a new transmitter. The Quasonix TIMTER transmitter is slated to replace our existing transmitters. The new transmitter offers decreased cost and physical size, while providing higher efficiency. The transmitter also allows for future expansion of the telemetry data rates.

Major Subsystem Developments:

NFORSe- NSROC Forward Ogive Recovery Section

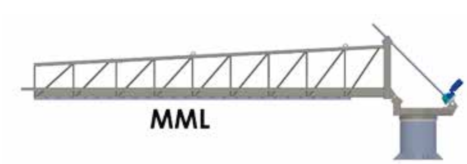
NSROC Forward Ogive Recovery Section (NFORSe) is being developed as an in house solution to the Ogive Recovery System Assembly (ORSA) that is currently in use. This technology development effort allows the program more control over cost, availability, adaptability, and modernization. This translates into cost saving of close to 50% in some cases. The addition of a new suite of electronics packaging, the ability to accept various capacities of parachutes, and reduce the cost of manufacturing proves to be a welcomed addition to the inventory of NSORC flight hardware capabilities.

Clamshell Skin Development

The clamshell skin is intended as a replacement for both long skirts and large deployable doors. By replacing a conventional skirt, the clamshell skin removes the chance of the skin touching the structure as it deploys. When used to replace a large blow-off door, the clamshell provides the structural support of a skin while allowing the same working volume as a blow off door. As the clamshell uses standard separation systems to hold the clamshell closed, this design ensures that all instruments it

Clamshell skin deployment testing.

Model of vacuum door (left) and payload 36.305 Galeazzi with doors open during testing.



covers remain protected during launch. In addition to these uses, the clamshell skin has been adapted for use with the Ejectable Deployment System in order to reduce overall cost and system complexity.

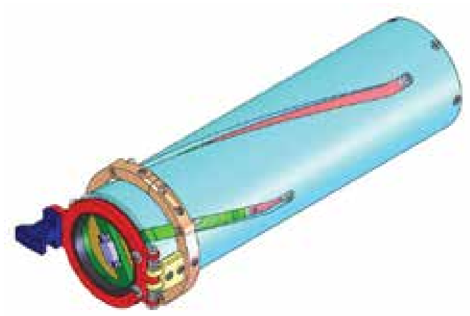
Following on the heels of the successful testing of the 36" prototype in 2013, a full size 54" clamshell skin has been fabricated along with two test setups: a deck-and-longeron structure and a mast. The 54" clamshell was subjected to the standard series of tests including vibration, bend and deployments from both structures. Having completed these tests, the design has been proven to work for the full range of typical internal structures. Along with the prototype testing, the clamshell skin design has been adapted for use with the Ejectable Deployment System. With the addition of access doors, it is now possible to work on the covered systems without removing the entire clamshell skin. The use of a clamshell skin to cover the Ejectable deployment system reduces the number of parts to be made, the number of pyrotechnics needed, and the number of hours needed for assembly. All of these combine to create a significant cost savings when compared to the previous design. At this time, the clamshell skin has passed all mechanical testing and is awaiting its maiden flight.

Vacuum slide-looking shutter door

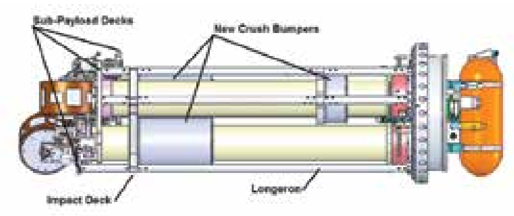
NSROC developed a vacuum side-looking shutter door assembly for the 36.305 Galeazzi mission which is scheduled to launch in Nov/Dec 2015. The purpose of the doors is to open a field of view for multiple scientific instruments. The doors are required to hold vacuum down to 10-6 Torr during ground operations and open during the mission to expose the instrumentation. Upon completion of the design, NSROC conducted a battery of functional and structural tests on the door assemblies to ensure operation and worthiness for flight. The side-looking shutter door design will offer a new capability for the science community.

Medium Mobile Launcher (MML)

NSROC completed the design review for a new class of sounding rocket launchers. The Medium Mobile Launcher is being developed to fill a gap between small mobile launchers (HAD, MRL) and the larger capacity launchers (50k, AML, Athena). The new MML is designed to support launches of two and three stage vehicles, including the Black Brant X. As with the existing HAD and MRL mobile launchers, the more capable MML is also designed for shipment and reassembly at launch sites worldwide. The MML is scheduled for first use during the Woomera campaign tentatively slated for 2017.



Ampoule exterior view.



Model of gas spring deployment system.

Sub-payload deployment system development

Several new sub-payload deployment systems are under development by NSRP. In 2015 two of the systems were flown operationally on geospace science missions.

Rocket propelled deployment system

The rocket propelled ejection system was flown on the C-REX mission from Andoya Space Center in Norway. All 24 ampoules deployed as designed with 10 vapor trails observed. Further refinement and development of this systems is ongoing and flights are planned on future missions.

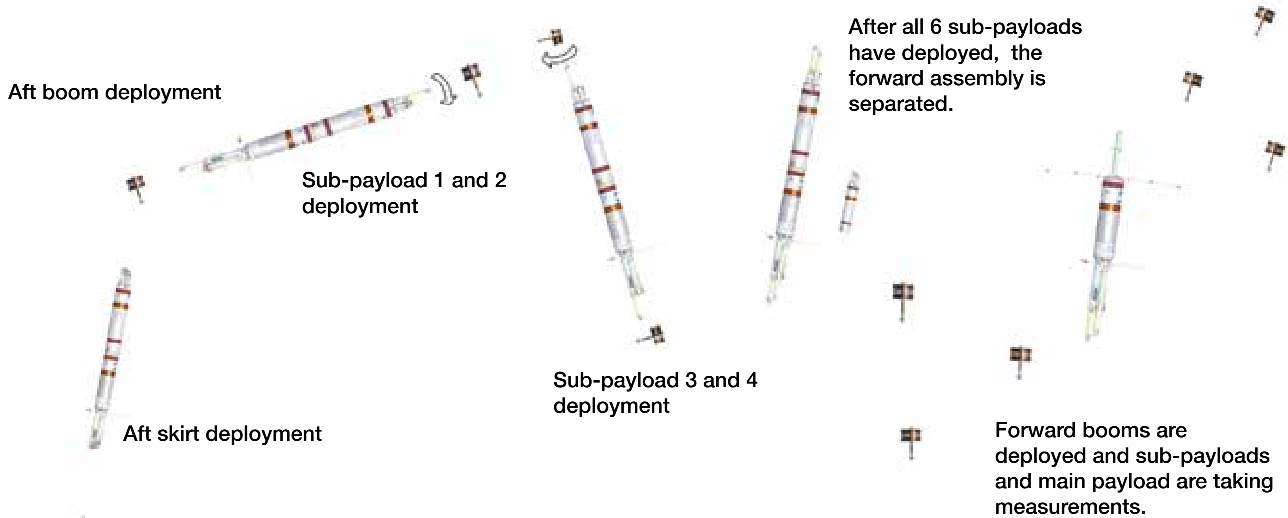
High velocity gas spring deployment system

The second deployment system, a gas spring system, was flown on the ASSP mission from Poker Flat Research Range in Alaska. Six sub-payloads were deployed to form a cluster around the main payload to measure spatial and temporal variations of the energy flow into the upper atmosphere in and around the aurora.

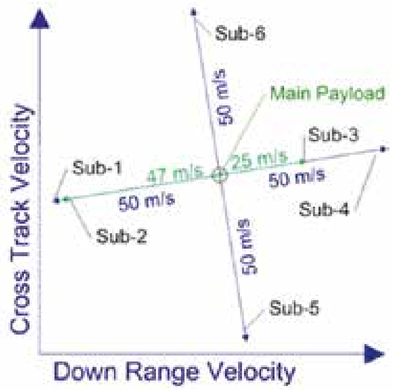
The gas springs use compressed nitrogen to deploy sub-payloads. The requirement of a deployment velocity of approximately 38 m/s caused significant engineering challenges. The first pair of gas springs had an initial (static) force of 2400 lbs while waiting to be released. They reached 38 m/s (125 ft/s or 85 mph) in 0.028 seconds and produced an acceleration of 170 g. To maintain a seal on the pressure system for subsequent sub-payload deployments, the gas springs had to be stopped at the end of their stroke. The aluminum honeycomb material required to stop the gas spring piston had a crush strength of 3700 lb (it could hold up the average family sedan without collapsing). Stopping the gas spring piston at the end of its stroke crushed 5.5 inches of this material. Significant ground testing of the system lead to high confidence that the system was ready for flight. All six ASSP sub-payloads deployed and transmitted data as designed and the mission met the comprehensive success criteria.

Constellation Flight Missions

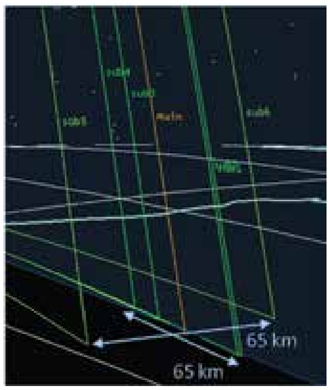
In addition to complex deployment systems, the requirement for numerous sub-payloads is a recent development for sounding rockets. For example the ASSP mission required one telemetry link for the main payload and six telemetry links and six gps link for the sub-payloads, one on each sub-payload.



Oriole IV lift-off
The Oriole IV consists of a Talos-Terrier-Oriole-Nihka stack.



Looking down on the constellation after deployment. The sub-payloads are separated from the main in both horizontally and verically.



Pre-mission simulation of the re-entry spread of the sub-payloads.

Covered by an aluminum nosecone or skin, each set of forward and aft sub-payloads had to re-radiate their telemetry and gps signals through the wrap around antennas mounted on the outside of the main payload skin during ascent. This was a significant Electrical Engineering/Telemetry accomplishment.

Autonomous timed deployments are used to separate payload assemblies, skirts and other components. These deployments are mission specific and the ASSP mission is used to illustrate (above) the multitude of events that occur in flight.

- After lift-off the motors, in this case four, are separated after burn-out. The nose cone and aft skirt are separated from the payload.
- To achieve the required path for the sub-payloads the Attitude Control System (ACS) orients the payload before deployments.
- All six sub-payloads were spun up to 100 Hz prior to deployment.
- When all six sub-payloads have been deployed the constellation of instruments transmit science data to the ground on separate telemetry channels.
- Re-entry occurs down-range from the launch site.

Education & Workforce Development

Sounding rockets are used for training students in both engineering and science disciplines. In addition to student flight opportunities like RockOn and RockSat-C and X, the program supports internships both through NASA and the NASA Sounding Rocket Operations Contract (NSROC). A High School teacher workshop was arranged for the 5th time in 2015, with 20 teachers attending.

University Programs

RockSat–C post flight data review.

RockOn and RockSat–C teams with vehicle on Wallops Island.

RockSat–X Hawaii team with their experiment after the flight.

As noted in the Education Flight Missions section the NSRP supports University student flight projects. This includes RockOn!, RockSat-C, and RockSat-X.

RockOn! & RockSat-C

Experiments built by student in the RockOn and RockSat-C University level programs are flown on the same sounding rocket payload launched annually in June. RockOn! experiments are built and tested by students during a week long workshop held at NASA’s Wallops Flight Facility in June. The students complete sensor integration with an Arduino based data logger and three sensors. All experiment boards are fitted into a cannister specially developed for student missions. The goal of the workshop is to provide the necessary training for students and faculty to return the following year to fly a payload of their own through the RockSat-C and RockSat-X Programs. Faculty members attending RockOn! are given the tools to continue participation in either the workshop level missions or the more advance RockSat-C and RockSat-X flights.

Part of the payload space in the RockOn! mission is allocated to RockSat-C experiments. RockSat-C is a competitive opportunity and student groups submit proposals for a project. Over the course of five months, participants undergo numerous sub system reviews and teleconferences to ensure that designs are maturing as expected. The program culminates in late June when experiment teams travel to Wallops Island to test and launch their payloads. into space.

RockSat-X

RockSat-X is the most advanced of the University level flight oppotunities. While some modularity is inherited from the RockOn! payload structures, i.e. the payload deck system, the students are enabled to design and develop their experiments with fewer constraints than in the lower level programs. In contrast to the RockOn paylaod, RockSat-X allows experiments full exposure to the space environment through an ejectable skin and nose cone. NASA provides power to all sub-systems and experiments and also includes a telemtery system for experiment data retrieval during flight.

The RockOn, RockSat-C and RockSat-X program are managed by the Colorado Space Grant Consortium: **http://spacegrant.colorado.edu/.** This partnership opptimizes NASA's investment by reaching the maximum number of participants at the national level.

Internships

Testing and Evaluation Lab engineer Nate Wroblewski teaches Henry Burth (left) and Genesis Mlakar (right) how to operate the mass properties measurement equipment.

Over 180 students have participated in the internship program managed for the Sounding Rockets Program Office by NSROC. The program, now in its 16th year, provides internships and co-op opportunities for students studying engineering, computer science, electrical or mechanical technology as well as business disciplines. Students work side-by-side with experienced engineers and managers to perform significant, valuable tasks, leading to a better understanding of the work in a highly technical environment. Almost 90 percent of undergraduate students who intern or participate in the co-op program return for additional employment. Several participants in the program have gone on to pursue higher education in the engineering and science fields.

In 2015 NSROC provided oppotunities for nine internships involving all engineering disciplines and one business internship. Interns returning for the second time were rotated into new departments to gain experience in a different engineering discipline thereby providing a broader understanding of the sounding rockets program as a whole.

Dan Browning, NSROC Attitude Control Systems group intern with an ACS system.

K-12 Programs

Lindsey Buck, NASA Pathways engineering intern oversees WRATS model rocket construction.

Phil Eberspeaker/SRPO Office Chief presents rocket thrust calculations.

Twenty WRATS rockets ready to go.

Preparing for launch on Wallops Flight Facility airfield.

Wallops Rocket Academy for Teachers and Students (WRATS)

The NASA Sounding Rockets Program Office offered the WRATS teacher training program for the fifth year. This training program is geared towards High School teachers and was attended by 20 participant from around the country. The program provides the teachers with knowledge, curriculum materials, and hardware that enables them to bring space-based lessons into their classrooms.

WRATS is a multi-faceted workshop that provides a unique hands-on experience in rocket physics and space science. Elements include the following: Basic Rocket Physics - Participants learn about Newton's Laws, rocket propulsion, trajectories, and flight dynamics.

- Rocket Construction and Testing – Participants build E-powered model rockets and design parachute recovery systems. The rockets carry electronic payloads. Participants conduct various tests to ensure the rockets work properly.
- Experiment Development – Participants are exposed to basic electronics concepts and build data loggers that collect pressure and acceleration data during the rocket flight.
- Trajectory Software – Participants are taught how to write their own rocket simulation software to assess the performance of their rocket. This activity takes the participants beyond being "users" and introduces them to software tool development.
- Lessons and Tours – Participants learn from actual engineers engaged in the Sounding Rockets Program. They also participate in several tours showing actual rocket activities are Wallops.

The week concludes with the launch of the Rock-On two stage rocket. Participants get up close and personal with the rocket and the launch operations. As in years past, the 2015 WRATS program was a smashing success and participant feedback was very positive.

AETD team members integrate instruments prior to testing,

Preparing for post–vibe sequence testing.

West Virginia University students integrating their experiments.

Multiple User Suborbital Instrument Carrier (MUSIC)

NASA has long recognized the utility of sounding rockets with respect to workforce training and development. Sounding rocket mission and instrument development provide hands-on experience for technicians, engineers and managers. Design, fabrication and testing phases of a sounding rocket mission, while technically rigorous, are relatively fast compared with other spaceflight opportunities, with a mission completion time from design to launch of about 18-months.

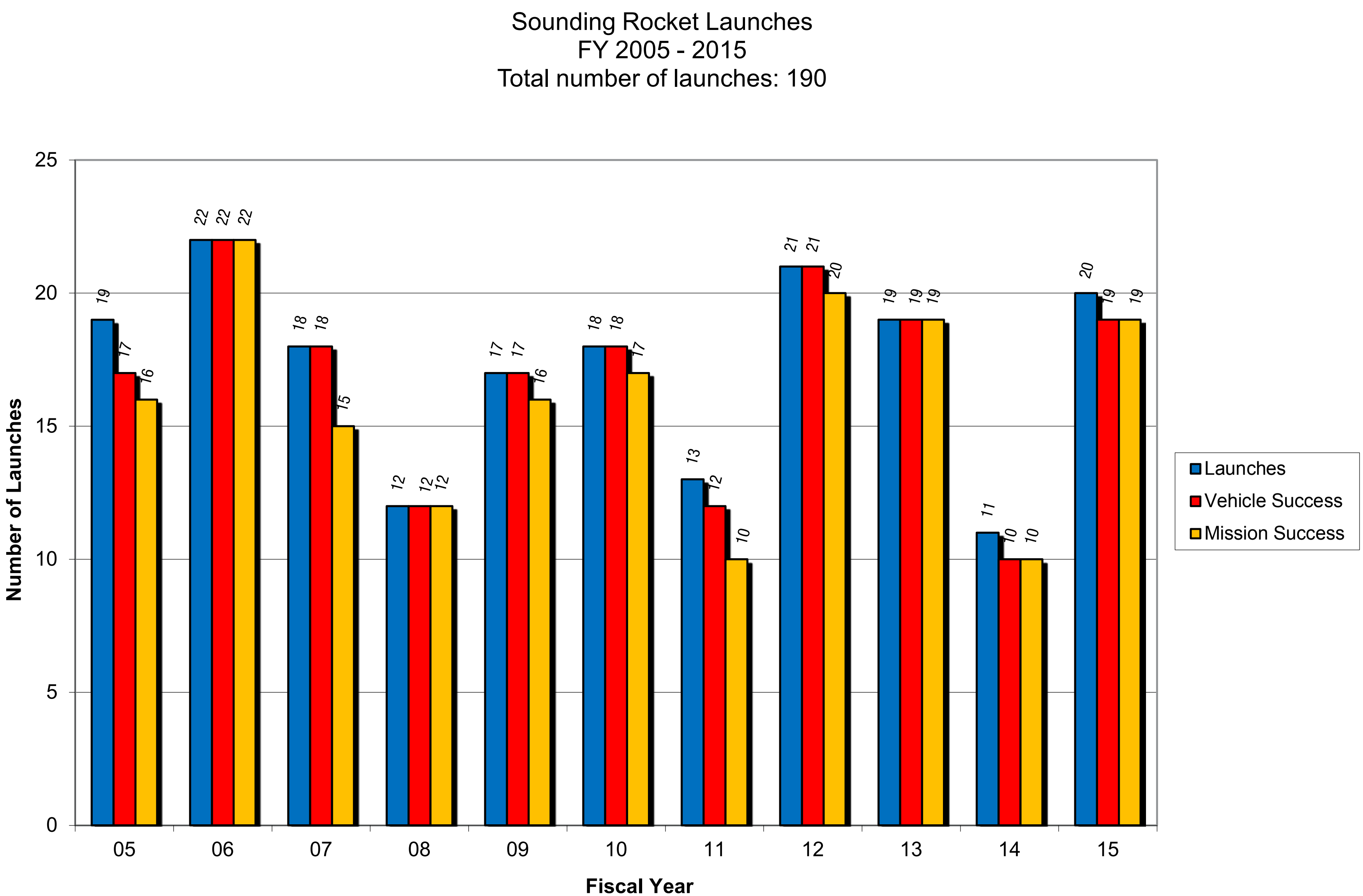
MUSIC provides NASA Applied Engineering and Technology Directorate (AETD) personnel an opportunity to gain experience in developing sounding rocket technology, conduct systems engineering processes and test NASA AETD experiments. This mission will result in a standard payload carrier with predefined mechanical, telemetry, power, and attitude control capabilities to be offer to reimbursable customers and other Wallops Flight Facility organizations.

The payload carries experiments/instruments developed by AETD and include, High Data Rate X- Band, Wheel Tracker Experiment (WTE), Diminutive Assembly for Nanosatellite deploYables (DANY) TM Wet/Sealed Nosecone, Temperature and Strain measurement, Strain Gauge management System (SGMS) and Iridium GPS Beacon, and the Solid State Altimeter experiment. Additional experiments from West Virginia University's Undergraduate Student Instrument Project (USIP) include instruments for Plasma Physics and Flight Dynamics with GPS and camera.

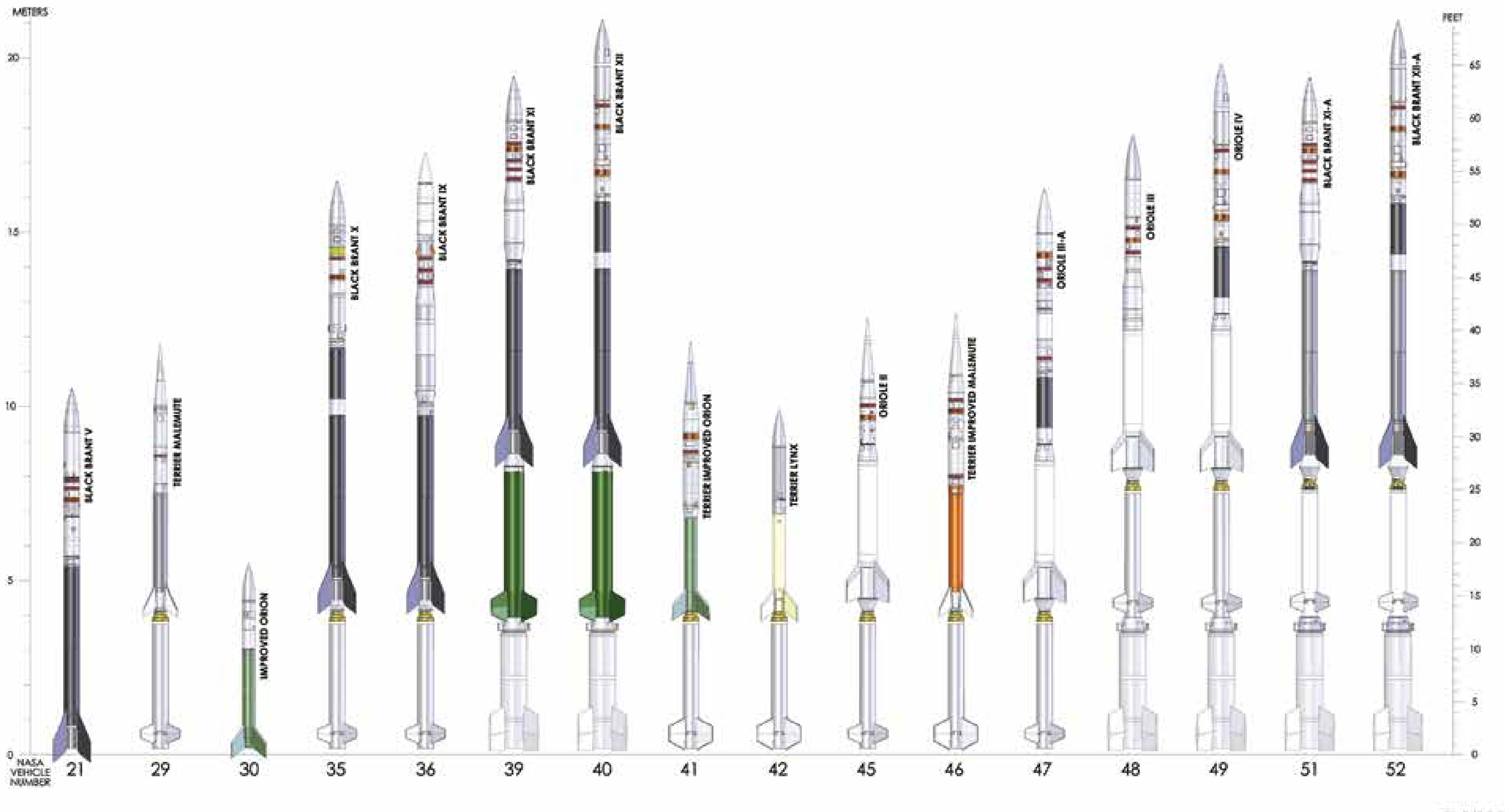
The MUSIC mission will launch in FY 2016.

Charts

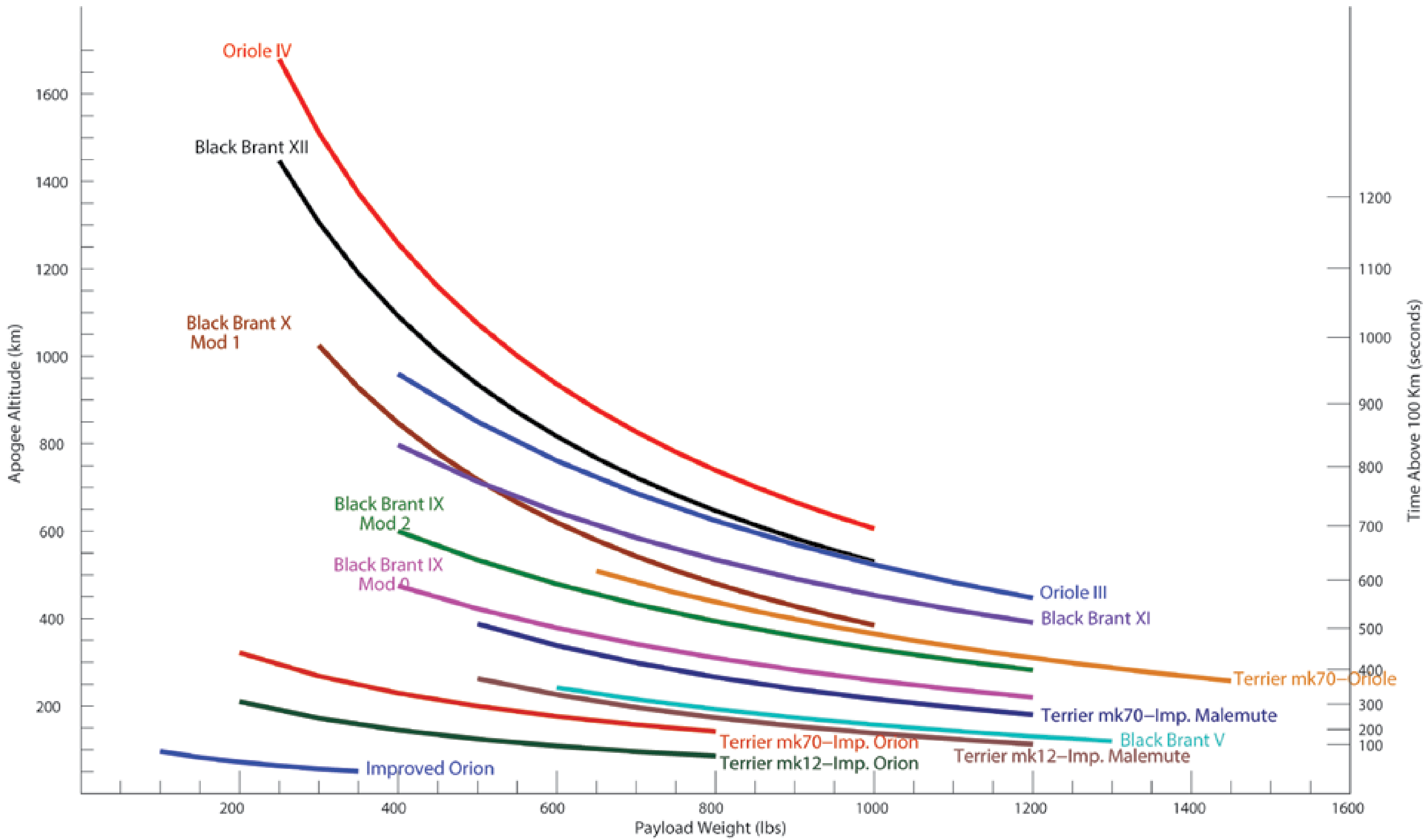
Mission Success History



Sounding Rocket Vehicles 2014



Sounding Rocket Vehicle Performance



Sounding Rocket Launch Sites

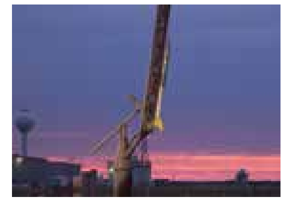

Poker Flat, Alaska


Esrange, Sweden


Kwajalein, Marshall Is.


Andoya, Norway


Woomera, Australia


Wallops Island, Virginia

Past and present world wide launch sites used by the Sounding Rockets Program to conduct scientific research:

1. Kwajalein Atoll, Marshall Islands
2. Barking Sands, HI
3. Poker Flat, AK
4. White Sands, NM
5. Punta Lobos, Peru *
6. Alcantara, Brazil *
7. Camp Tortuguero, Puerto Rico *
8. Wallops Island, VA
9. Fort Churchill, Canada *
10. Greenland (Thule & Sondre Stromfjord) *
11. Andoya, Norway
12. Esrange, Sweden
13. Svalbard, Norway
14. Woomera, Australia

* Inactive launch sites

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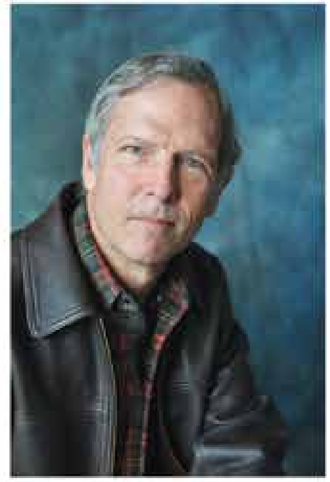
Secretary

Philip Eberspeaker
Chief



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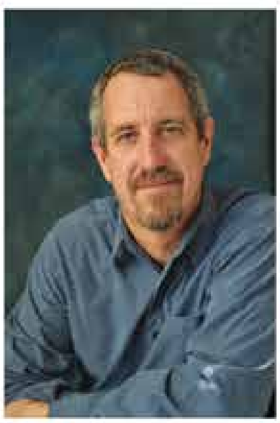

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7	Vapor trails photo: Manbharat Dhadly
9	Team photo: Jamie Adkins/NASA
10	Launch photo: Jamie Adkins/NASA
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17	Hubble Space Telescope/NASA/ESA
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19	Solar Dynamics Observatory, NASA
20	RAISE payload: NASA
21	All images: White Sands Missile Range Visual Information Branch
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39	Ampoule model: Andrew Mandigo/NSROC
40	Solid works models: Shane Thompson/NSROC
40	Insert trajectory images: Dr. Swenson
42	Group photo middle: NASA Wallops Imaging Lab
48	Vehicle stable grahic: NSROC Mechanical Engineering
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51	John Brinton

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Science mission information submitted by Principal Investigators.


EXIT

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