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TRIO: Turbulent Response in Oxygen
Final Report
Period Covered: 3/03–4/05

1 August 2005

Prepared by

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Prepared for

NASA/GSFC
Greenbelt, MD 20771

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Engineering and Technology Group

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Abstract

This project was designed to build on the results from the successful launch of the Turbulent Oxygen Mixing Experiment (TOMEX) mother-daughter (instrumented and chemical-release) payload (21.126) that was launched in October 2000 from the White Sands Missile Range. The **overall science objective** was to investigate the evolution of the atmospheric response, at altitudes between 80 and 120 km, to the presence of unstable regions with vertical scales of the order of 1 to 10 km. TRIO was designed to use Na lidar measurements from the MAUI/MALT observatory on MAUI with a launch of a payload from Pacific Missile Range Facility (PMRF), located on Kauai. During this project, Aerospace participated in a Mission Initiation Conference, put together a science requirements document, performed a site visit to PMRF, prepared a CDR document, and developed a production and calibration procedure for one of the payload instruments, the 3-channel photometer. Unfortunately, NASA decided to terminate the program because of unforeseen (by NASA) range costs. This CDR document represents our view of this project at termination and provides a roadmap to perform this experiment should it be proposed again.

Contents

Figures

1. Introduction

This document describes the TRIO mission, which is a collaboration mainly between The Aerospace Corporation, the University of Illinois, and Clemson University. The objective of the experiment is to investigate the evolution of the atmospheric response, at altitudes between 80 and 120 km, to the presence of unstable regions with vertical scales of the order of 1 to 10 km. Two instrumented/ chemical-release mother-daughter payloads (21.136 and 21.137) on Black Brant VBs and three chemical-release only payloads (41.051, 41.052. 41.053) on Terrier Orions, will be launched from the Pacific Missile Range Facility on Kauai, Hawaii in November, 2004. The two mother-daughter payloads and one of the chemical-release only payloads will be launched over a period of one and a half hours on one night. The two other chemical-release payloads will be launched on other nights. Launch conditions and mission data will be obtained using a ground-based lidar operated by the University of Illinois and located on Mt. Haleakala on Maui, Hawaii. The Principal Investigator for TRIO is Dr. James H. Hecht of The Aerospace Corporation. Prof. Miguel F. Larsen of Clemson University is the Lead Co-Investigator at Clemson responsible for all the chemical release payloads. The Lead Co-Investigator at the University of Illinois is Dr. Alan Z. Liu.

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2. Science/Mission Overview

2.1 Science Overview

This project is designed to build on the results from the successful launch of the Turbulent Oxygen Mixing Experiment (TOMEX) mother-daughter (instrumented and chemical-release) payload (21.126) that was launched in October 2000 from the White Sands Missile Range. The **overall science objective** is to investigate the evolution of the atmospheric response at altitudes between 80 and 120 km to the presence of unstable regions with vertical scales of the order of 1 to 10 km.

TOMEX showed a considerable variety of atmospheric responses to the presence of unstable regions. Kelvin-Helmholtz (KH) billows were observed in a region of a dynamical instability. A large (10 km vertical), nearly well-mixed region, was found in an altitude regime that was in and out of instability for a long period of time prior to the rocket launch. These altitudes were also affected by a large-scale atmospheric gravity wave (AGW) that could also have contributed to the observed mixing. Other smaller vertical regions, which were dynamically unstable, showed enhanced turbulence and/or unusual mixing. A region above 100 km that had large winds and wind shears showed enhanced neutral-density fluctuations and energy dissipation.

These results clearly show that a sequence of rocket measurements on the same night is critical to understanding the atmosphere's response to instabilities and would allow us to address the following questions:

- Does the atmosphere respond differently to dynamically and convectively unstable regions?
- What is the temporal evolution of Kelvin-Helmholtz billows?
- What is the relative importance of AGWs and instabilities in determining the vertical structure of atomic oxygen?
- Do convectively unstable regions develop long-lived billow type structures?
- How rapidly do changes in energy dissipation/eddy diffusion occur and persist after the formation of unstable regions?
- How rapidly do changes in turbulent structures and vertical mixing occur and persist after the formation of unstable regions?

An opportunity now exists to answer these questions in more detail by building on what we learned during TOMEX and in the earlier Coqui Dos campaign in Puerto Rico. Specifically, the worlds most sensitive steerable Na wind/temperature lidar system, previously located at Starfire, has now been moved to the 3.67-m AEOS facility on Mt. Haleakala, Maui. The combination of the steerable AEOS telescope and the powerful University of Illinois lidar system allows the measurement of the fine structure of the temperature, wind, and Na density. For integration periods of about 5 min, the temperature and meridional and zonal winds can be determined at an accuracy sufficient to determine the presence of unstable regions at vertical resolutions better than 1 km over the approximate 80- to 105-km altitude region. Because the telescope can be easily pointed, the system can make measurements toward the northwest in the region over PMRF, which is about 400 km northwest of Maui.

Thus, a system exists that can make continuous measurements of the atmospheric temperature structure to determine whether an atmospheric region, at vertical scales down to 1 km or less, has a temperature gradient that exceeds the adiabatic lapse rate and therefore is convectively unstable, or has a sufficiently large enough wind shear to be dynamically unstable. The system can also measure the presence of AGWs, which can themselves alter the atmospheres constituent mixing ratio (e.g., Hickey et al., 2000).

2.2 Mission Overview

We propose to launch a chemical release module with upleg and downleg trimethyl-aluminum trails when the lidar begins to show the presence of a large unstable region forming. This will measure the atmosphere's initial response to the presence of an unstable region, with respect to energy dissipation/eddy diffusion and billow structure formation. One half hour after the first rocket, we will launch a mother/daughter payload from PMRF. The daughter payload will contain two instruments, a three-channel airglow photometer system and a five-channel ionization gauge system. The mother payload will contain an identical chemical release module. The daughter payload will separate from the mother around 70 km with a separation velocity of around 3 m/s. This configuration is identical to the payload launched during TOMEX and will allow in-situ measurements of turbulence, atomic oxygen densities, winds, eddy diffusion, energy dissipation, and billow structures, thus providing a more detailed measure of the atmospheres response to the instability. An hour after this rocket, a second mother/daughter payload will be launched to continue detailed measurements of the time evolution of the atmosphere's response. The remaining two chemical release modules will be launched on different nights during instability events to provide a context for the main event.

This project involves several institutions and a collaboration of scientists with both experimental and theoretical expertise who will provide instrumentation for the payloads, carry out supporting ground-based observations, and participate in the post-flight data analysis.

3. Instrument Descriptions (Daughter Payload)

The two instrumented payloads (21.136 & 21.137) on Black Brant VBs will each consist of an instrumented daughter payload containing two Aerospace-supplied instruments that will be ejected below 70 km at about 3m/s from the Clemson-developed chemical release mother payload.

Each daughter payload (Figure 1) will include a five-channel ionization gauge experiment and a three-channel photometer experiment. The chemical released from the mother payload will be TMA. This combination was the same as was launched on TOMEX (21.126) and JOULE (21.130). As in JOULE, the skin will be ejected along with the nosecone, and thus, unlike TOMEX, there will be no doors.

Launch conditions will be determined by the University of Illinois lidar located on Maui analogous to the situation during TOMEX at WSMR when that lidar was located in Albuquerque.

An ACS should be used to maintain the pointing as close to zenith as possible (preferably 1°). The coning should be less than 5°. The ACS should be turned off between 80 and 120 km on the upleg and downleg. The spin rate should be 1 Hz.

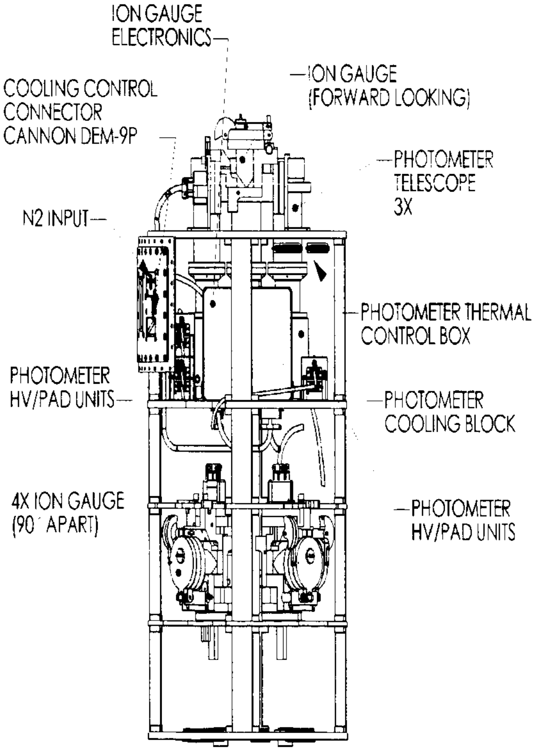

Figure 1. Daughter payload.

3.1 Ionization gauge

3.1.1 Description

The purpose of the ionization gauges (IGs) is to provide an in-situ measure of turbulent density fluctuations at vertical resolutions finer than can be seen by either of the other instruments on the rocket (below 1 km). The IG data will complement the TMA results, which have excellent horizontal but poor vertical resolution. Its principle of operation is well known: A volume of the gas to be measured is partially ionized by a stream of electrons, then the resulting ions are collected by an electrode. The density of the gas is proportional to the ratio of the electron current to the collected ion current. Improvements made by *Bayard and Alpert* [1950] allow modern-day ionization gauges to be used over pressure ranges of about 10^{-10} to 10^{-1} torr. *Lübken et al.* [1992, 1993] have recently exploited this technique to measure rapid density fluctuations in the mesosphere.

The IG uses four sensors arranged around the circumference of the payload to allow the effects of rammed flow to be compensated for, similar to that flown on missions 21.115 and 21.116. In addition a forward-looking unit, comprising two sensors, allows the ram environment to be understood. Each IG sensor utilizes a miniature gauge available commercially from Anelva Corporation. The sensor, depicted in Figure 2 is small and requires less power (2 W) than other available devices. The device is sealed before launch and opened by breaking the seal once the payload has attained altitude. A getter is used to maintain vacuum on the pad. Electronics inside the payload provide the circuitry to control and measure the emitted electron current as well as to measure the collected ion current. High-resolution, high-speed analog-to-digital converters are used in order to provide rapid (1 kHz) measurements spanning a large dynamic range (~10^6) in pressure.

3.1.2 Requirements

3.1.2.1 Mechanical Accommodation

The mechanical accommodation requirements are similar to those for the TOMEX (21.126 & 21.127) and JOULE (21.130). Figure 2 contains a schematic of this accommodation.

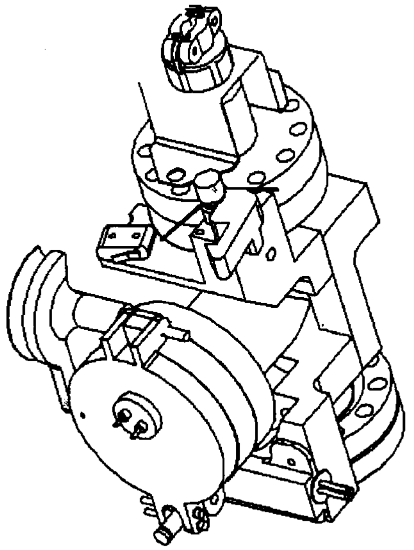

Figure 2. Ionization gauge sensor with vacuum cap sealed.

3.1.2.2 Flight Attitude

The IG requires postflight attitude knowledge accurate to 1°.

3.1.2.3 Electrical Power

The IG requires 12 V and 450 mA per sensor. For 6 sensors, the total current is 2.7 A. Only 5 getters are needed, and they are supplied only from the umbilical, and each one takes about 4.2 A @ 8 V. But they are run in series, and thus 40 V are required. Power for the getters is provide form the block house.

3.1.2.4 Telemetry

Each IG sensor requires a WFF93 differential serial channel consisting of continuous clock, enable, and major frame. Each serial channel provides 60 kbps, and 60 bit samples are expected every 1 ms. In addition, each sensor requires 8 analog housekeeping channels per sensor or 48 total telemetered at about 10 sps each.

3.1.2.5 Commanding

The IG requires a timer event to actuate the pyrotechnics used to open the IG vacuum doors at altitude. A second timer event is required to turn on the IG filaments at altitude. In addition, the getters must be commandable by an umbilical command (no need to operate the getters in flight), and the filament power must be commandable through the umbilical. This system was used for 21.126 , 21.127, and 21.130. NASA provides pull away umbilical.

3.2 Photometers

3.2.1 Description

A set of three photometers provides uplooking zenith brightnesses for the three auroral emission features. The photomultiplier tubes are all mounted in an aluminum block that is cooled prior to flight by liquid nitrogen to a temperature of approximately –20°C to reduce the dark count rates to acceptable levels. The LN_2 lines are cut at launch ,and the block stays at low temperature throughout the flight. Three filters are used to isolate channels centered on the following features. One is at 762.0 nm with an FWHM of 8 nm and therefore isolates the O2A(0,0) band. The second is at 773.5 nm with an FWHM of 5 nm and therefore isolates part of the OH(9,4) band. The third is at 820.0 nm with an FWHM of 5 nm and isolates background (non-OH or O2A airglow). Figure 3 depicts the photometers as they will be deployed.

All data will be corrected for the van Rhijn effect that was negligible for the well-pointed TOMEX launch. Following the ETON approach atomic O densities can be obtained from these data (e.g. McDade et al., 1986; Melo et al., 1996). This experiment was successfully flown on Coqui Dos and TOMEX and the same experiment but with different filters was flown on JOULE. Atomic O can be obtained at vertical resolution of about 1 km from 83 km to 105 km.

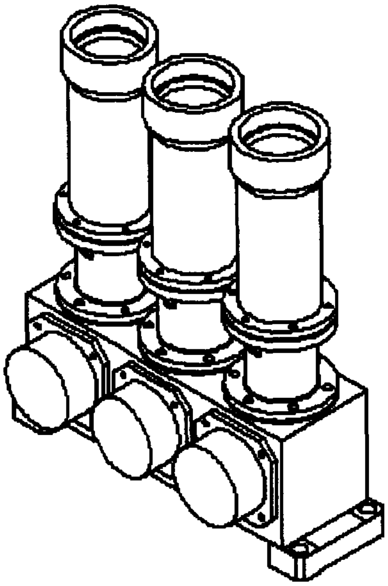

Figure 3. The photometer experiment.

3.2.2 Requirements

3.2.2.1 Mechanical Accommodation

The mechanical accommodation requirements are similar to those for the TOMEX (21.126 & 21.127) and JOULE (21.130) as depicted in Figure 3.

3.2.2.1 Flight Attitude

The photometers requires postflight attitude knowledge accurate to 1°.

3.2.2.1 Electrical Power

The photometers require 450 mA at 12 V for the photometer power. We also require 1.5 A periodically at 15.6 V for the photometer heater power. The duty cycle for the heater is about 15 s every 3 min.

3.2.2.1 Telemetry

Each of the three photometers produces counts that will be accumulated by a counter on a TM counter deck. The differential counters will be free-running (no reset), and we are requesting 18 bit counters. The sample rate for each photometer is 50 samples per second (2700 bps). We also have 17 analog channels for housekeeping to be digitized at 10 bit resolution at 50 sps (8500 bps). The telemetry is similar to what was done for TOMEX (21.126 & 21.127) and JOULE (21.130).

3.2.2.1 Ground Operations

Our previous experience with cooling of the photometers indicates that we will need approximately 100 liters of liquid nitrogen with dewars of 75-100 psi for an eight-hour period of launch readiness. Aerospace will provide insulated tubing from the dewars to the photometers and the associated hardware. NASA is to provide rigging for the pull-away photometer cooling line. We also need 110 V AC for the photometer LN_2 flow control box.

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4. Chemical Release Modules

The chemical released from this module (TMA) reacts with atmospheric atomic oxygen, which provides a visible trail that is photographed from multiple sites. An analysis of the motion of the visible trail provides a measure of winds, diffusion, and the evolution of turbulent structures. Two of these modules will be part of the mother-daughter payloads (21.136 and 21.137), and three will be released separately (41.052 CE and 41.053) on Terrier Orions

4.1 Description

The chemical tracer payloads for the TRIO mission include 17-in. payload sections on each of the 21.136 and 21.137 vehicles and 14-in. payloads on the 41.051, 41.052, and 41.053. One of the 17-in. payloads is a refurbished payload that was originally part of the TOMEX mission (White Sands Missile Range, October 2000) but was not flown. That payload section has two side-by-side 6-in. canisters with separate plumbing, explosive valves, and solenoid valves for each canister. One canister produces an upleg trail and the other produces a downleg trail.

The new 17-in. payload and the three 14-in. payloads each have a single 9-in. canister and a single explosive valve and solenoid valve. The volume of trimethyl aluminum TMA in those canisters is sufficient to produce both upleg and downleg trails (6 kg total), and the flow is controlled by the solenoid valve.

Side and end views of the 9-in. canisters in the 14-in. skins are shown in Figures 3 and 4. The layout for the 9-in. canister in the 17-in. skin is identical except for the size of the skin and is not shown.

All chemical release canisters and valves are the same on both payloads. A movable piston with O-rings provides a seal between the TMA section and the pressurized nitrogen section. The nitrogen provides the force to move the piston and eject the TMA when the explosive valve is actuated. The explosive valve is manufactured by Conax and has a 1-A for 1 second no-fire condition. The mass release rate is controlled by a combination of the nozzle orifice size and the nitrogen pressure. The plumbing for the canisters on each payload will include a Circle Seal electronic solenoid valve located between the explosive valve and the TMA exit nozzle. The purpose of the valve is to modulate the TMA flow at a duty cycle of approximately 50% for the duration of the release. The valve requires a current of 1.95 A and an operating voltage of 24 VDC.

Clemson will provide electronic timer circuitry to control the modulation sequence for the solenoid valve. The circuit design, pin outs, and connectors will be the same as those flown successfully on the 14-in. payloads in the recent HEX and JOULE missions from Poker Flat (February 2003).

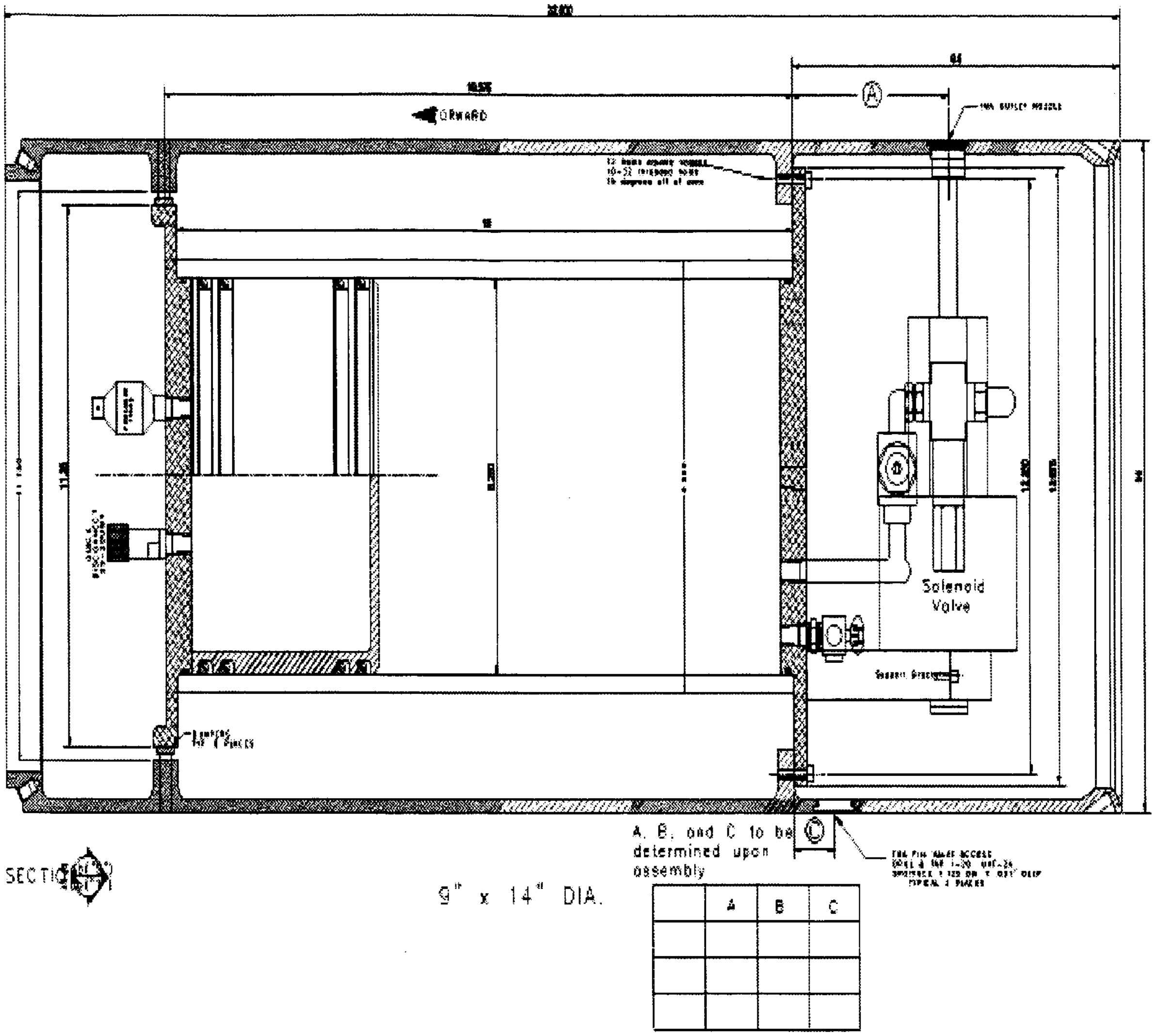

Figure 3. Chemical release canister (side).

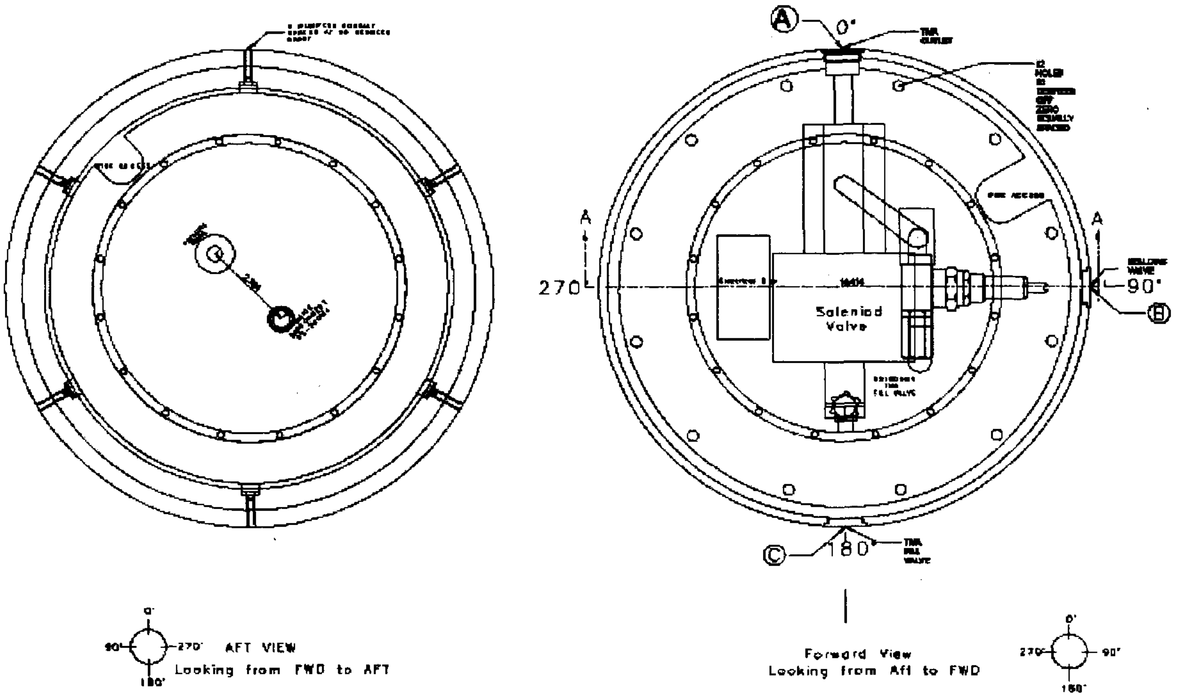

Figure 4. Chemical release canisster (forward/aft).

4.2 Requirements

4.2.1 Outgassing, magnetic sensitivity, radio frequency interference requirements

There are no special requirements for the chemical release payloads.

4.2.2 Time/altitude of experiment related events

The chemical releases will be initiated near 80 km altitude on the upleg and will cover the altitude range up to approximately 150 km when the upleg TMA canister is exhausted. The downleg release will be initiated near 150 km altitude and will continue until the downleg TMA canister is exhausted near 80 km altitude. Apogee should be greater than 160 km. The releases will be modulated by solenoid valves for the duration of the release with a nominal sequence of 2 s on/4 s off.

More detailed information about the launch scenarios is provided in the main section of the Experimenter's MIC package.

4.2.3 Instrumentation/telemetry

There are no special instrumentation or telemetry requirements for the chemical release portion of the experiment.

4.2.4 Flight qualification/operational status of experiment's subsystems

The same types of subsystems have been flown in previous experiments as described above. We do not expect any significant changes from the systems flown in the past, with the exception of the increase in the canister diameter size, as described above.

4.2.5 Restrictions, precautions, special requirements

The primary restrictions are associated with the loading of the TMA canisters at the launch site. A safe area that can be isolated is required for loading operations.

Kerosene (K-1 or JP4/5) and laboratory-grade nitrogen (5 ppm water vapor/10 ppm oxygen) are required at the launch site for the loading operations.

4.2.6 Range support

No special support requirements other than a safe area for TMA loading.

4.2.7 Launch conditions and windows

The chemical tracer experiments require a solar depression of 8° or greater and that the moon is below the horizon. The science criteria are described in more detail in the main section of the Experimenter's MIC package.

5. Ground-Based Instruments at MAUI/MALT Facility

5.1 Description

The AEOS facility houses a number of instruments used to observe the 80- to 110-km region. The key instrument is the Na lidar. However, two airglow imagers similar to those present at Starfire during TOMEX are also present on Maui that can obtain images of the airglow. Because of the distance to Kauai, an airglow imager will be placed at PMRF by Dr. Swenson. This allows observations of the horizontal and vertical wavelengths and velocities of AGWs passing through the airglow layers between Maui and Kauai.

The AEOS telescope (20.4 N, 156.1 W) is operated by the Air Force Research Laboratory at the Air Force Maui Optical Station (AMOS). The facility is located on top of Mt. Haleakala and includes a 3.67-m-dia fully steerable astronomical telescope. The Na wind/temperature lidar and airglow imager is currently deployed and operating at Maui. The lidar will be coupled to the telescope using the coude' path. This will allow the lidar to be pointed in any direction and will support a wide variety of experimental configurations, including the ability to probe selected regions of breaking wave fronts observed by the imagers. The 3.67-m telescope gives a comparable power aperture product compared to Starfire where the vertical integration was 24 m. Summing these over a 96-m range in 1.5 min. of integration time gives a root-mean-square error of better than 2K in temperature and 5 m/s in winds. Real-time output from the lidar will allow line-of-sight temperature and wind profiles to be used to determine the atmospheric stability, a key parameter in determining the launch. Nine 5-h nights of telescope time will be bought.

5.2 Requirements

The data from the lidar will be used to determine whether the proper launch conditions exist. Therefore, telephone communications must be available between the AEOS facility and PMRF. Also, NASA must arrange access to telemetry data at AEOS through a fiber link, and high-speed internet connection to Dr. Swenson's imager on Kauai.

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6. Special Launch Requirements

6.1 Lidar Pointing

The AEOS lidar facility on Maui with respect to a launch from PMRF on Kauai adapted from the AEOS manual. A schematic trajectory is shown with lidar beams (yellow) probing before and after the launch.

The AEOS facility is part of the Air Force Maui Optical Station (AMOS)located on Mt Haleakala on the island of Maui (20.42 N,156.15 W, 3058m alt). This is about 400 km from PMRF as shown in Figure 5. The elevation angle to the 95-km point of the upleg trajectory would be about 13° and thus can be viewed from this site. As in TOMEX, we would point the telescope in a sequence of 5 positions. Assuming a trajectory with the upleg and downleg both close to Kauai, two positions would be at 30° elevation angle to probe the temperature and meridional and zonal winds between Maui and PMRF. This angle should not require any FAA approval, and therefore continuous measurements would be possible. Three others would be at lower elevation angles towards the line of site to PMRF and intersecting the rocket trajectory near 95 km to probe the spatial variability of the winds and temperatures. Because of the desire to view, the launch would depend on the existence of either a large horizontal spatial scale convective or dynamic instability.

6.2 Launchers

Launch corridors exist at 140° and 210° azimuth from Kauai. Our understanding is that currently one launcher exists for the 140° azimuth, and two launchers exists for the 210° azimuth. Ideally, all three launches should go down the 140° azimuth. However, if this is not possible, the second choice would be all three down the 210° azimuth corridor. In any event, on the first launch night, two mother/daughter payloads and at least one chemical only must be available for launch.

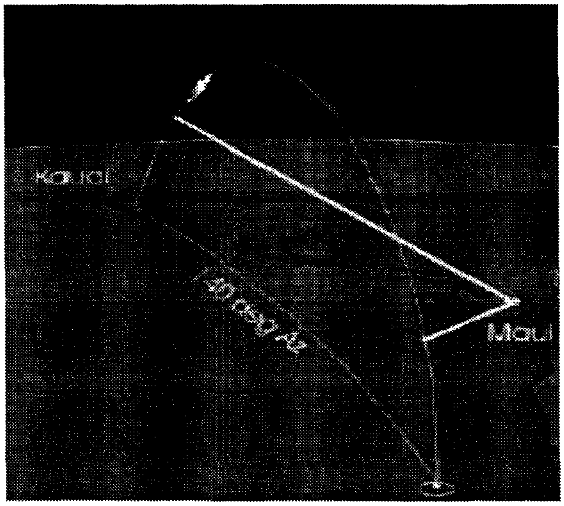

Figure 5. Trajectory.

6.3 Launch Window

We desire a full 17-night moon-down period in November 2004. The window would be from sunrise to sunset to accommodate the possibility of purchasing a full (10 h) night instead of a 5 h half night of telescope time. As in TOMEX, we would cancel a night of counting a day in advance if the weather looked bad, and if canceling is allowed by the AEOS facility director.

There would be a possibility of launches on three separate nights: 2 mother/daughter and a chemical only on one night, and chemical only on two separate nights. However, we would prefer the two chemical only rockets go on the same night. Two standard data products pointing information should also be given with respect to local zenith.

7. Payload Requirements

7.1 Overview

The TOMEX payload is a new payload, although the photometers, as well as the IG experiment, have flown successfully on previous flights including TOMEX (21.126) and JOULE (21.130). For TRIO, as in JOULE, Aerospace will provide the instruments, and NSROC will build up the payload.

7.2 Payload Layout.

Aerospace will provide the IGs and photometer experiments as discussed above. NSROC will provide the payload structure, deckplates, skin, and nosecone and connectors to the Aerospace experiments. We expect the daughter section of the payload to resemble JOULE, although in TRIO there are only two experiments, the photometers and IGs. The Appendix provides drawings of the desired placement of the instruments on the deckplates based on our experience with JOULE. It also provides pinouts to the IG and Photometer experiments.

7.3 Power System

NSROC will provide standard bus voltages with current capacities capable of powering all payload systems. The Instrumentation section and the Appendix list the power requirements for each instrument.

7.4 Payload Instrumentation

NSROC will provide the following systems:

Pyrotechnics system. The pyro events needed for the IGs are listed in the above sections. Pyrotechnics to be supplied by WFF.

Timer system. The timer events needed for each experiment are listed in the above sections. An ACS system is required. The ACS should be capable of aligning the daughter payload within 1° of zenith prior to 80 km altitude on the upleg. No gas shall be fored between 80 and 140 km on the upleg, and between 140 km and 80 km on the downleg.

Attitude gyro. An attitude gyro capable of 1° accuracy is required.

Attitude magnetometer. A magnetometer (two or more axes) is required for attitude information.

7.5 Telemetry

A PCM telemetry system supplied by NSROC is required. A 400-kbps link should be adequate to accommodate all the telemetry rates for each instrument.

7.6 Electrical Connectors

NSROC will supply electrical connectors to mate with the Aerospace experiment connectors listed in the Appendix.

7.7 Vehicle Dynamics

A roll rate of 1 Hz is required during deployment of the daughter payload from 80 to 120 km on the up and downlegs.

As was done on TOMEX (21.126), the payload should be rotated near apogee by 180° so the front of the payload faces the ground on the downleg.

7.8 Nose Cone and Skin

We require an ogive nose cone as was provided on JOULE (21.130).

7.9 Environmental Issues

7.9.1 Outgassing

Outgassing by electrical and mechanical components should be minimized to protect instrument systems and enhance the value of the scientific data. Standard practices are to be observed:

- Select low-outgassing materials from applicable NASA publications.
- Use clean, bare aluminum payload skin.
- No anodization on payload exterior parts or parts that might reach high temperatures (gold iridite acceptable).
- Scrupulously clean entire payload of flux, debris, fingerprints, etc. with an approved solvent.
- Vent potential gas pockets to allow rapid pump out.
- Seal battery packs and squibs where possible.

7.9.2 Magnetic material sensitivity

Strong magnetic fields in the vicinity of the instrument are to be avoided.

7.9.3 EMI considerations

Follow standard practice.

8. Mission Requirements

8.1 Integration

Integration will occur at WFF.

8.2 Testing and Evaluation

Standard tests are to be performed during T&E at WFF. These should include at least.

- Vibration
- Spin Balance
- VSWR
- Transmitter power and modulation index with TRADAT on/off.
- Electrical integration tests - instrumentation PCM, etc.
- Deployment tests under spinning conditions - no vacuum required.
- Mass properties
- Sequence tests with match squibs
- Bend test

8.3 Ground Support

8.3.1 Telemetry ground station

Real-time decommutation, D/A conversion, and strip chart recording of selected PCM signals are conducted at the telemetry ground station. D/A conversion and strip chart recording of all PCM telemetry is required after each pre-launch check and post flights. Recorder formats will be supplied for the flight requirements plan. We require at least one 8-channel strip chart recorder for payload checkout and prelaunch diagnostics. We also require a parallel interface to a TDP bit sync for this purpose in the operation center at PMRF and access to telemetry at the science center at AEOS on Maui. This will probably need to be a fiber-optic link from PMRF on Kauai to AEOS on Maui.

Control of the instrumentation will be provided by WFF by an appropriate control panel.

8.3.2 Imager at Kauai

A high speed internet connection is needed between PMRF and AEOS to allow retrieval of the imager located at PMRF.

8.4 Other Range Support

- Dry nitrogen purge
- Alcohol and acetone for pre-launch cleaning

8.5 Post-launch Requirements

The following are to be delivered to the Experimenter in a timely fashion after launch:

- Telemetered data on standard data medium.
- Trajectory information accurate to 100 m or better.
- Attitude information accurate to 1° or better.
- In addition to standard data products, attitude information must also be given with respect to local zenith

9. Success Criteria

9.1 Comprehensive Success Criteria

9.1.1 Campaign

Two Mother/Daughter Payloads and one TMA-only Payload launched on one night in sequence meeting the following criteria.

9.1.1.1 Instrumented Vehicle Performance.

- Apogee within 20 km of nominal 140 km.
- Coning half angle of less than 5°.
- Daughter Payload Pointing within 3° of zenith.
- Despin to 1±0.25 Hz.

9.1.1.2 Instrumented Daughter Payload System Performance.

- All payloads function nominally.
- Nominal deployment of daughter payload at or below 65 km.
- Separation velocity of daughter payload 3 m/s nominal.
- Attititude sensors allow reconstruction of attitude to an accuracy of 2° or better.

9.1.1.3 Science Instrument performance.

Both the IG and photometer function nominally throughout flight.

9.1.1.4 Mother/Chemical Release Payload Performance.

- TMA release on both upleg and downleg in the altitude range from 80 to 120 km.
- At least one of the trails is puffed between 80 and 105 km.

9.1.1.5 Ground System Performance.

- Reception of Telemetry for at least 95% of the time the payload spends above 75 km.
- Tracking information good enough to determine trajectory to an accuracy of 100 m or better.

9.2 Minimum Success Criteria

9.2.1 Campaign

One Mother/Daughter Payload and one TMA only Payload launched on one night in sequence meeting the following criteria.

9.2.1.1 Instrumented Vehicle Performance

- Apogee above 110 km140 km.
- Coning half angle of less than 5°.
- Daughter Payload Pointing within 10° of zenith.
- Despin to 1±0.25 hz.

9.2.1.2 Instrumented Daughter Payload System Performance

- Nominal deployment of daughter payload at or below 65 km.
- Separation velocity of daughter payload 3m/s nominal.

9.2.1.3 Science Instrument Performance

- At least two of the photometer channels function nominally .

9.2.1.4 Mother/Chemical Release Payload Performance

- TMA release on either upleg and downleg in the altitude range from 80 to 110 km.

9.2.1.5 Ground System Performance

- Reception of telemetry for at least 85% of the time the payload spends above 80 and below 120 km. Reception at least 95% of the time between 85 and 100 km.
- Tracking information good enough to determine trajectory to an accuracy of 100 m or better.

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