Experience and Challenges in Implementing Stratospheric Aerosol Gas Experiment on Meteor-3M Platform

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Abstract- Implementation of the Stratospheric Aerosol Gas Experiment (SAGE) is a joint science mission between Rosavioskosmos, also called the Russian Aviation and Space Agency (RASA) and the National Aeronautics and Space Administration (NASA). Under the global collaboration agreement established by Presidents Clinton and Yeltsin in 1995 between the United States and Russia, space was one of the major areas identified for joint scientific collaboration. There were several collaborative projects identified under space, earth, human exploration of space and aeronautics. SAGE was one of the key Earth Science instruments selected common to both countries interest in ozone research. SAGE has a long space heritage, and four earlier versions of this instrument have flown in space over the last 15-year period. It has provided vital ozone and aerosol data in the mid latitudes and has contributed in the overall ozone depletion research. SAGE II, the fourth instrument is still flying in space on NASA's Earth Radiation Budget Satellite (ERBS) for the last 14 years. Ball Aerospace built the instrument under Langley Research Center's (LaRC) management. SAGE III for the Russian Meteor-3M mission is a third generation design with more spectral bands, elaborate data gathering and storage and intelligent terrestrial software. The Russian collaboration required two complete integrations of SAGE III on the Russian Meteor-3M satellite and a launch on a Zenit-2 launch vehicle manufactured in the Ukraine. The whole complex is scheduled to be launched from the Baikonur Cosmodrome around mid 2001. This cooperative mission has presented a number of management, technical and logistical challenges on both sides. This paper makes an attempt to review and document such experiences.

I. INTRODUCTION

There have been various techniques successfully used and implemented for measuring ozone and aerosol data from atmosphere using airborne and space-based sensors for the past 30 years. The instruments have involved either nadir viewing sounding to obtain the total column measurement or capturing radiance by looking at the Earth's limb on occultation of distant light source such as sun, moon or other celestial bodies with reflective properties. However, the sun occultation [1] so far has been demonstrated with a high degree of confidence. SAGE III instrument is specifically designed after this technique. There are three SAGE III instruments produced under NASA specifications by Ball Aerospace located in Boulder, Colorado. First instrument is to fly on a Russian [2] Meteor-3M class spacecraft in polar orbit in 2001. The second instrument is presently under negotiations for a flight on an Argentine satellite sometime

around 2003; and the third SAGE has been committed for a flight on the International Space Station (ISS) in 2004.

The Russian collaboration has not been an easier passage. It has required a considerable effort and overhead on both sides. Apart from the technical aspects, there have been a number of challenges due to continuously changing economic situations in Russia, language and cultural barriers, differences in design practices and standards, regulatory laws, severe climate conditions and many more factors presented significant challenges in implementing this collaborative undertaking. It has been a learning experience for both sides, particularly for the US side, since the US side has fully been dependent on the Russian side because of the Russian spacecraft. This problem is further compounded by additional difficulties due to the Ukrainian launch vehicle and Baikonur launch site. The Baikonur Cosmodrome is located in Kazakhstan but is under a twenty-year lease to the Russian government. In reality, there have been four countries directly or indirectly involved in deciding the fate of this launch. Another layer of complexity is introduced by four additional international partnerships between Russia, Pakistan, Morocco, Malaysia and a division of US Air Force European Command located in London, UK to fly their small micro satellites as piggy-back payloads on the same rocket.

II. MISSION DESCRIPTION

The Meteor class spacecraft has over thirty-year heritage in flying meteorological payloads from the Soviet days. The basic suite of instruments provide science measurements such as humidity, temperature, low-resolution land images and several other related products [3]. After the fall of the Soviet era, the support for the Meteor program has been curtailed tremendously. In fact, Meteor-3M is the first spacecraft built after the post Soviet times. The Agency responsible for designing and building this spacecraft, Electromechanical Institute (NIEM) of Istra, now under RASA, does not have plans to continue this series in the future.

The major scientific objectives of SAGE III (Fig. 1) experiment are described as below:

- Retrieve global profile of atmospheric aerosols, ozone, water vapor, nitrogen trioxide, chlorine dioxide, temperature and pressure.

- Investigate the temporal and spatial variability of these species
- Characterize tropospheric and stratospheric aerosols and cirrus and stratospheric clouds.
- Provide atmospheric data for validating other satellite sensors.

The spacecraft is a nadir pointing 3-axis stabilized bus with no propulsion. It uses a combination of sun and magnetic sensors for pointing stability. However, it uses a newly designed GPS/GLONASS receiver to compute ephemeris data, which will fly for the first time on this mission. This mission [4] will be in a helio-synchronous orbit at an altitude of 1,020 km with 9:15am local equatorial nodal crossing time.

Fig 1. SAGE III Instrument

III. PLANNING AND PROGRAM MANAGEMENT

NASA established a comprehensive management process by agreeing on a set of jointly developed technical and procedural documents. This included Interface Control Document, Contamination Control, and Integration and Test Plans. These documents were developed as a result of a series of interchange meetings held quarterly between NASA and NIIEM teams. The documents were generated in both languages and jointly approved. Teams were divided into sub-teams to address specific management, electrical, mechanical, contamination, integration and test, and operations issues. The results of each quarterly exchange were formally documented in meeting minutes known as 'protocols.' These protocols were generated in Russian and English by each disciplined team and officially approved by the team leads. These were then attached to the management team protocol to make it complete. A continuous language support was provided by NASA by hiring a contractor who was efficient not only in the language itself but with the cultural aspects and the engineering terminology. NASA experience has shown that there is a significant difference in the technical terms from English to Russian language.

IV. INTERNATIONAL COORDINATION AND LIMITATIONS

There are many entities (Fig. 2) involved in handling, transporting, integrating and launching of the NASA flight hardware in Russia. All of these required an extensive management interface on both sides, including on sight

coordination and processing by NASA designated agents in Moscow and Istra. It is important to point out that the actual process and actions that have to be taken are not under NASA or RASA's direct control. There are many different Russian government and private entities that are coordinated in order to successfully ship the instrument and the associated hardware in and out of the country. For example, among these Russian entities are: RASA program management office, RASA customs office, Baikonur Cosmodrome, NIIEM project, Russian Federal Custom services in Istra, Zelenograd and Sheremetyevo airport, Security, Immigration Services, Custom Bonded Warehouse Services, and Government Auto Inspectorate. A normal paper work processing, assuming everything is in order can take anywhere 30-60 days. The launch clearances were coordinated early on with the Russian Rocket Forces. While closer to the launch, the Government appointed launch commission gives a final launch approval.

There are additional restrictions imposed by the US Governments International Tariff and Arms Regulation (ITAR) that the SAGE-III instrument must be escorted by a US Government employee and may not be left unattended at any place.

V. PREPARATION OF THE LAUNCH VEHICLE AND FAIRING

The Zenit launch vehicle for this mission is built by NPO Yuzhnoye organization from the Ukraine. Zenit has a rather young heritage unlike Soyuz or Proton. This was first introduced around 1989 for commercial launches. The Meteor mission requires a 2-stage rocket for the designated LEO orbit and uses LOX/kerosene for propellant. The total launch vehicle height is approximately 57 meters that includes 13.6 meters for the fairing, and the gross vehicle weight without the payload is about 460,000 Kg. In addition to the rocket, a special contamination controlled fairing has been designed and built to specifically accommodate the Meteor spacecraft and its payloads. This requirement was imposed on the RASA and NPO Yuzhnoye by the SAGE instrument due to highly sensitive visible and UV optical channels [5]. The NASA team has been interactively involved in the design and inspection of the fairing. In fact, a number of verification tests have been conducted to ensure the contaminants such as adhesives; interior paint and insulation met the outgassing requirements. The rocket and the fairing are to be transported from Dnepropetrovsk, Ukraine to Baikonur, Kazakhstan in a special secure train with proper escort. The total trip will take about 2 to 3 weeks.

VI. LOGISTICS

The logistics plan requires many elements such as transportation, customs, packing, unpacking, contamination control, security, temporary storage and safety. A special container with proper environmental conditions and shock

protection is designed and built to fly the SAGE instrument from the US to Russia. There are a number of pieces of ground support equipment such as simulators, handling fixture/equipment, uninterruptible power supply, cables, calibration sphere and other test computers that are shipped well ahead of time. Also all equipment necessary to be self-sufficient (clean room supplies, electrical parts and components, medical supplies, electrostatic discharge equipment and tools) had to be sent prior to the flight equipment arrival.

Some of the major transportation concerns are listed below:

- SAGE flight model is to be triple bagged, in the shipping container using N-250-700 material.
- shipping container includes environmental sensors to monitor shock, temperature, humidity and atmospheric pressure.
- a pressurized aircraft is to be used for the transport of the SAGE flight model.
- temperature range for the SAGE flight model inside the shipping container is not to exceed the range of 0° to +45° C.
- humidity is not to exceed 80% inside the shipping container.
- shock levels in any axis are not to exceed 50 g.

The SAGE flight model has been transported by air in an environmentally monitored shipping container from US to Moscow. It was transported from Moscow aerodrome to Istra via truck under a security escort. SAGE and all the ground support equipment will be flown to Baikonur in a large size Russian chartered airplane from Moscow. While at Baikonur, it will be transported in an environmentally controlled rail car to the integration and launch facilities i.e., site 31 to 42 to 45.

VII. INTEGRATION AND TESTING

The nature of Integration and Test work is to determine the compatibility of the instrument with the spacecraft. The SAGE team negotiated with the Russian side to develop a comprehensive test plan that would prove that the SAGE instrument and the Russian Meteor-3M Spacecraft were fully functional and compatible (electrically, mechanically and operationally) to insure success after launch. The initial plan that was developed established two integrations at Istra (NIEM) and one at the launch site at Baikonur. The general plan for all integrations included the following test requirements:

- Autonomous Functional Testing of the SAGE instrument (pre/post ship, on/off the spacecraft) performed at Istra and Baikonur
- Electrical Checkout (safe-to-mate) performed at Istra and Baikonur

- Verification Test on spacecraft (SAGE specific with spacecraft) performed at Istra and Baikonur
- Complex Test (ground test) performed at Istra
- Complex Test (flight code) performed at Istra and Baikonur
- Complete Cycle Verification Test (End-to-End) performed at Istra
- On-Orbit Simulation Test (Russian Test) performed at Istra
- Electromagnetic Compatibility Test performed at Istra
- Weight & Center of Gravity Test performed at Istra

The first integration was required by the Russian side so as to establish their flight software and to provide the necessary information for their on-board computer. The US side used the first integration to verify all test procedures and compatibility for the use of Russian ground test cyclograms (Russian terminology for a test procedure). During this first integration, both sides experienced problems and the overall integration took longer to complete than planned. It was also discovered during this first integration that the Russian side does not typically work from a written schedule or procedure for the tasks that need to be performed. They looked to the US side to provide schedules and procedures for all tasks.

During the time between the 1st and 2nd integrations, the SAGE instrument was transported to the US Embassy in Moscow for storage. While at the US Embassy, the shipping container containing the SAGE instrument remained under a gaseous nitrogen purge and was monitored by personnel from the US Embassy NASA Liaison Office. The Russian side used this time to burn the new flight programs for the flight on-board computer and also disassembled the spacecraft for undefined work. Because of this disassembly of the spacecraft, the US side required additional simulator tests performed prior to integrating with the SAGE flight instrument. The spacecraft was fully reassembled just prior to the return of the SAGE instrument from the US Embassy to Istra.

Prior to the transport of the SAGE instrument from the US Embassy, a full series of simulator tests were performed with the Meteor-3M spacecraft. Autonomous testing on the SAGE instrument was successfully performed prior to installation onto the spacecraft. After installation onto the spacecraft, the Meteor-3M spacecraft and the SAGE instrument experienced many anomalies. The Verification test was attempted six times and was successful only once. The Complex test (ground code) was attempted and was not successful due to unexplained anomalies. None of the required tests for the second integration (with the exception of Weight & CG) were completed with the SAGE instrument and the Meteor-3M spacecraft. Anomalies with the Meteor-3M spacecraft were never fully defined or explained to the US side. Until required tests can be successfully completed, there is no way to determine the exact status of the Meteor-3M spacecraft. As a result of the anomalies with the SAGE instrument, the

Fig 2. US – Russian interfaces and complexity.

instrument was shipped back to the US for trouble-shooting and repair. There is now a need for a 3rd integration at Istra (after repairs are completed) prior to going to Baikour.

VIII. SUMMARY

A very little or limited documentation exists for the spacecraft and the payload. It has required NASA team to ask the same question several times in order to get a reasonable answer. In other words, it takes a great deal of patience and an iterative process to reasonably develop any converging positions on open issues. One has to be proactive and try to anticipate questions. Otherwise any critical information may not be provided on a voluntary basis. For example, during the two integrations attempted in Istra Russia, the Russian management will not work from a defined schedule or procedure, and will not openly share the status of the spacecraft or ground support equipment. On the other hand, the Russian engineers and technicians are very hard workers and will exchange technical information to the US side, however for the most part are restricted by the management. Working a joint project with the Russians is challenging. One large challenge has been due to the lack of NASA team members that can read or understand the Russian language. Team has made use of interpreters, but during several activities especially associated with Integration and Test tasks, there rarely are enough interpreters at the right locations. The travel is extensive and the differences in culture can be difficult on team members. The long flights, different foods, long work hours, delays in schedule, severe weather conditions and extended travel periods tend to create

stress for all involved. The maintenance of contamination control environment in the integration facility has also been a continuous effort for NASA. This required continuous monitoring and verification measurements in the integration facility to ensure at least a Class 10,000 environment.

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