COBE: Lessons Learned from the Management of FIRAS

by Mike Roberto

On November 18, 1989, NASA launched the COsmic Background Explorer (COBE) from Vandenburg Air Force Base in California. COBE's mission is to orbit 559 miles above the Earth for one year to study the origin and dynamics of the universe by measuring diffuse infrared radiation and microwaves, including the cosmic background. COBE will also test the "Big Bang" theory of the origin of the universe, predicated 15 billion years ago.

COBE is carrying three principal instruments to map the sky at 100 microwave and infrared wavelengths. The Differential Microwave Radiometer (DMR) is looking to see whether the original explosion was equally bright in all directions, or whether patchy brightness will unveil the origins of galaxies, clusters of galaxies, and clusters of clusters of galaxies. The Diffuse Infrared Background Experiment (DIRBE) is searching for the light of the oldest stars and galaxies by measuring the collective glow of millions of objects, accounting for all known sources of emissions, and seeing what signals remain. The third instrument is the Far Infrared Absolute Spectrophotometer (FIRAS), which measures the spectrum of the cosmic background radiation from the "Big Bang" and intergalactic dust. A smooth black body spectrum with small deviations is predicted. Any deviation may indicate other powerful energetic events from the period of universal history shortly after the "Big Bang," such as annihilation of antimatter, matter swallowed by black holes, or supermassive exploding objects.

FIRAS was designed, built, and integrated at NASA Goddard Space Flight Center. The entire process was kept in-house, the first time such a complex project had been done this way. While the outcome was successful, the process did not always go smoothly. Following are some of the lessons learned from this experience.

1. Matrix management

Problem: Four divisions and numerous branches of Goddard's Engineering Directorate provided excellent support to FIRAS. However, the support personnel had other concurrent responsibilities and were not under the direct control of the FIRAS management team. Because they were not always available, more flexibility was needed in the schedule.

Solution: With limited personnel resources, there is no easy solution here. There is a trade-off between keeping support personnel in their organizations where they can interface with peers on technical problems and co-locating a team to support the instrument.

2. Breadboarding vs. system modeling

Problem: Too much time was spent developing breadboard subsystems, making the project too much like experimental research. A lot of time was spent varying parameters to arrive at the right recipe for the operation of temperature controllers.

Solution: Have good analytical capability for modeling from the beginning. Then you can run computer simulations, changing parameters and predicting results. Use system modeling extensively in the beginning of the process, before breadboarding. During most of FIRAS integration and testing, we did not have an analysis program to predict the proper temperature controller settings. After the analytical model was developed, establishing settings became routine and quick.

3. Peer level design reviews

Problem: The design reviews were not detailed enough to catch subtle design problems. For example, the mirror transport mechanism (MTM) was a good mechanical design but complex enough that proper assembly was not immediately apparent. If the assembly were not perfect, the mechanism would not work properly. Parts were assembled at ambient temperature and cooled to near absolute zero; components cool at different rates and to different lengths.

Solution: Have experts perform a thorough technology assessment early in the program. Then you can find out early which parts of the program need more emphasis and more work; you can point out potential problem areas which are technology drivers. Reviews should be held at each level of maturity of design, so that problems can be caught early, before the hardware is cut. Peer reviews should be conducted in small groups in a small conference room where the diagrams can be put on a conference table for people to review together. The reviewers are thus more likely to discuss the diagrams and to mark problem spots and indicate solutions. When the review is held in a large conference room with a large group and the diagrams projected on a screen, the atmosphere is less conducive to criticism, discussion, and changes.

4. Comprehensive system level approach to system design

Problem: The responsibility for the various electronic subsystems of FIRAS was divided among different branches and divisions. Some FIRAS circuits required modification late in the program. For example, the MTM is extremely complex. We didn't find out how noisy it was until it was installed on the spacecraft; we then had to modify the electronics design of the shielding and grounding to make it work properly. This including piggybacking a box onto the drive electronics box to eliminate noise and to ensure that the MTM would recover from any scan upsets. Before modification the mechanism would occasionally go to the end of its course for a while, where it drew excessive power. Once the problems were corrected, it performed flawlessly.

Solution: Early in the evolution of the electronic system design, the instrument team needs to have an expert on grounding, noise immunity, electronics components and interfaces, etc., to coordinate the overall system design. This skilled individual should have overall responsibility for all the electronics.

5. Engineering model

Problem: The engineering model was deleted from the program because of time and cost. An engineering model could provide some flight spare components as well as an instrument for testing fixes on the ground before trying to correct an on-orbit problem. The FIRAS team ended up making changes to flight hardware.

Solution: There is no easy solution here. An engineering model of FIRAS would have been more expensive and time-consuming than the modifications made to the flight hardware. However, for an instrument as complex as FIRAS, I believe an engineering model would have been good insurance.

6. Documentation

Problem: With the pressing schedule, the

FIRAS team received hardware without its documentation. The same people who supplied the hardware had to prepare the documentation. To maintain the schedule, testing had to proceed without all supporting documentation.

Solution: Insist that without complete documentation, the hardware is not considered to be delivered.

7. Test requirements and schedule

Problem: In the FIRAS test program, tests were sometimes shortened or deferred to a higher level of integration to maintain the schedule. FIRAS paid a price for trying to maintain the schedule. The problem of the Xcal (external calibrator) not staying in the horn was not discovered until FIRAS was in the flight dewar. The MTM drive electronics required modification on the spacecraft, and then a special electronics box had to be mounted on the drive box (see #4). The lesson here is that the risks of a success-oriented schedule are very real.

Solution: There is no easy solution here either. We're doing Monday morning quarterbacking. The success-oriented schedule had many successes, but going back into the dewar was a big hit (costing us more time in the long run). At times, a more flexible schedule would have helped.

The FIRAS team could have fought harder for additional time at certain critical points in the program.

8. Software support

Problem: FIRAS was severely constrained by having to use the developing mission software system for its instrument integration and testing. The software was periodically modified as it was being developed as a ground support system for the mission. The integration and test team had to use the same software; when the version of the VAX operating system was changed right before a test, the software would not work properly for the integration and test team. The integration and test effort was necessary for launch, but the team felt they were being used as guinea pigs for the new software, rather than having software developed to support their efforts. They had no control; they couldn't prevent the software from being modified as they were preparing to conduct a test.

Solution: Instrument integration and testing needs independent, dedicated software support.

9. Programmed pauses

Problem: A number of times in the FIRAS program, the FIRAS team fell behind schedule. We were trying to prepare for the next item on the schedule while also bringing test procedures, test reports, etc., up to date. We would get into a new test without having a chance to completely evaluate the results of the previous test. It was easier at times to run a test again, rather than to go back and try to process old data.

Solution: At times in a test program, it may be necessary to stop everything and get up to date. This may save time in the long run.

10. Common language

Problem: We tested FIRAS using one version of STOL, a program for commanding the instrument from a computer. The spacecraft has a slightly different version of STOL. The POCC (payload operations control center) has a significantly different version of STOL.

Solution: Use the same test language from the start.

11. Procedure changes

Problem: It was a rare event for a FIRAS test procedure not to go through several iterations.We made considerable extra work for ourselves in developing and reviewing new procedures for early orbit operations and the FIRAS mission.

Solution: Develop procedures from the start with inputs to cover all phases of the program. This would require a lot of coordination in the beginning, with procedures reviewed by subsystem, engineering, science, and operations personnel. However, the overall program would be more efficient and more appropriate.

12. Personnel work hours

Problem: The COBE work has been exciting and demanding. However, a work schedule that runs through holidays, nights, and weekends for extended periods is usually not good for the individual. Health and efficiency may be affected. There should be a way to maintain a steady work pace that allows the individual to keep up with responsibilities outside of work.

Solution: There is no easy solution here. Mandatory time off would mean that the project would take longer and be more expensive. At Goddard, projects are where the action is. One could say that if you can't stand the heat, get out of the kitchen. Some people want to work lots of extra hours. However, since thIs is now a "kinder and gentler nation," project work could be made available for individuals content with working more normal work weeks.

Conclusions

People at Goddard received a lot of training with the COBE project. Goddard benefitted as a whole; it learned that it could handle a large project in-house.

The FIRAS team was to a large extent captive to the overall push to complete COBE. COBE put an extraordinary demand on personnel, money, and facility resources. Better planning might have allowed for more efficient resource utilization. As the magnitude of the job became evident, it would have been helpful to conserve personnel resources by reducing night, weekend, and holiday work. Additional facility (and money) resources would have been required, but there would have been a better overall balance in resource utilization.

In the end, everything came together. We are very excited about how well FIRAS and the other instruments are working. It is hard to argue with success. Thus COBE may reinforce our dependence on extraordinary personal efforts by our people. Any volunteers for COBE 2?