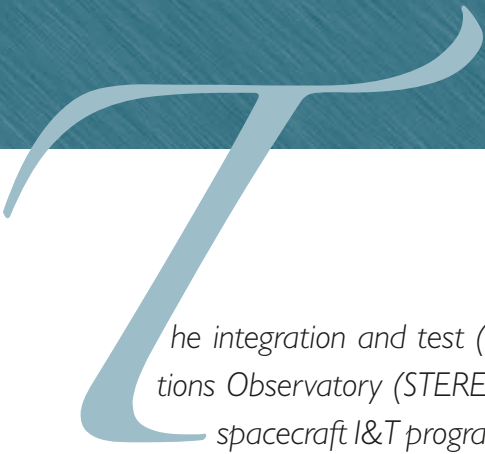


# The Challenges of Integrating the Two STEREO Spacecraft

Annette M. Dolbow and Elliot H. Rodberg



The integration and test (I&T) phase of the two Solar TErrestrial RElations Observatory (STEREO) spacecraft was in many ways typical for a spacecraft I&T program. The spacecraft went through all of the usual integration subphases. Integration began with the structure and harness, and then proceeded with integration of the power, data handling, and communications subsystems. That step was followed by integration of guidance and control components and instruments, and, finally, system-level testing. At that point, the spacecraft were complete. Environmental testing and the launch campaign completed the I&T process. However, I&T of two large, nearly identical spacecraft, each with multiple instruments and many moving parts, brought with it many special challenges. There were many areas of concern, including logistics and scheduling, subsystem support, test personnel scheduling, contamination control, and the sheer magnitude of the ground support equipment, both mechanical and electrical, required to support spacecraft testing. Even little details—like telling the spacecraft, their data, and their respective ground support equipment apart—were challenges to be overcome. Many lessons were learned on STEREO that will serve APL well on future multispacecraft programs.

## INTRODUCTION

The integration and test (I&T) phase for a spacecraft normally involves four main subphases: subsystem and instrument integration onto the spacecraft structure, system-level testing, environmental testing, and launch site operations. The individual components and instru-

ments are designed, built, and tested as stand-alone components, and then they are delivered to the spacecraft for integration, which is a combination of mechanical installation and electrical interface checkout. Once all of the components are integrated, a series of system-

level tests are performed during which the spacecraft is exercised as a complete system. The environmental testing phase is necessary to ensure that the spacecraft will survive and perform as expected through the rigors of launch and the temperature extremes of outer space. During launch site operations, final system tests are performed, and the spacecraft is prepared for launch.

For the Solar TERrestrial RELations Observatory (STEREO) program, APL was contracted by NASA to build two nearly identical spacecraft (Fig. 1) that would be launched into Earth-like orbits around the Sun and perform simultaneous solar observations. One spacecraft was designed to be placed into orbit around the Sun ahead of the Earth (Ahead or Spacecraft A), and the other was designed to be placed into orbit behind the Earth (Behind or Spacecraft B). In addition, they were launched together on top of a Delta II launch vehicle from Cape Canaveral Air Force Station, Florida.

### SUBSYSTEM INTEGRATION AND TESTING

For STEREO, two approaches were used for integrating the spacecraft. Initially, on Spacecraft A, multiple integrations were attempted by multiple engineers simultaneously. The sharing of test equipment coupled with the fact that there was still only one test conductor per spacecraft to send commands and monitor telemetry led to multiple stops, starts, and reconfigurations, adding significant time to each individual integration procedure. From the beginning on Spacecraft B, a serial approach in which components were integrated one at a time was used. After a couple of months, the serial approach proved to be more effective and was used for the rest of the integration activities on both spacecraft. In terms of progressing through I&T with two spacecraft, a parallel approach was used, and there was almost always something happening on both spacecraft. Also, a lead engineer was assigned to each spacecraft to ensure that someone had the

responsibility for preparing and monitoring all activities and tracking issues for each spacecraft.

STEREO had a typical flow with regards to integration of components. The structures were delivered with the propulsion systems installed and most of the panels attached. The harnesses, having been fabricated on a wooden mock-up in APL's Building 13, were transferred one at a time to a bakeout fixture and then moved down to Building 23 for the thermal vacuum bakeout. After bakeout, the first harness, destined for Spacecraft A, began its arduous installation onto the structure. Meanwhile, the Spacecraft B harness was put in the thermal vacuum chamber for bakeout. It is no small matter, no matter how good your mock-up, to take a 138-lb octopus of wires and gracefully transfer it to the form of the actual spacecraft bus. It took great care and ingenuity. After the harness was installed onto the structure, it was electrically verified through a comprehensive continuity and isolation test.

The next task was to integrate the umbilical ground support equipment (UGSE) rack (Fig. 2). This rack (one for each spacecraft) was the main piece of GSE that provided power and communications. It was used from the first power-up at the beginning of electrical I&T all the way through launch. The UGSE rack contained two power supplies: one for powering the entire spacecraft and all of its components and another for charging the flight battery while on the launch pad. Also included in the rack were meters to monitor spacecraft bus voltage, spacecraft bus current, battery voltage, and battery current. An integrated oscilloscope and in-house-designed and -fabricated interface panels were installed as well.

A main component of the UGSE is the command and telemetry interface. Spacecraft generally have base-band command and telemetry interfaces that can be used throughout most of the ground testing, as opposed



**Figure 1.** Both STEREO observatories in the APL high-bay facility.



**Figure 2.** Spacecraft B UGSE rack (center) with other GSE racks on either side.

to running strictly through the RF subsystem. Operating via the baseband interface is particularly crucial in the early phases of I&T, before the RF components have been installed, and on the launch pad, where the RF components cannot be used. The UGSE rack was accompanied by a PC running LabVIEW for control of the rack and a set of Sun workstations running an APL-tailored version of EPOCH 2000 for control and monitoring of the spacecraft. Testing was automated by writing many command scripts using the EPOCH 2000 STOL (Spacecraft Test and Operations Language) scripting language.

The first subsystem integrated could be either power or command and data handling (C&DH). On STEREO, the first component integrated was the power distribution unit (PDU). The PDU is the box that controls power to the rest of the spacecraft subsystems. By integrating the PDU before the integrated electronics module (IEM) or the C&DH subsystem, the power subsystem GSE, which was operated strictly with hex commands, and some alternate cabling had to be used to integrate and test the PDU. Using the PDU GSE at the spacecraft was a little awkward, but with the help of the power subsystem engineers as test conductors, in the end it was successful.

Once the PDU was integrated, the IEM, which contains the main computer that runs the spacecraft and is the core of the C&DH subsystem, was integrated. Once this box was installed, the umbilical rack could be used to communicate with the spacecraft, and the EPOCH 2000 control system could be used for commanding by using standard command mnemonics and telemetry displays.

The next box to be integrated was the power system electronics (PSE). The battery simulator was connected to fully test this box. Last, the solar array junction box (SAJB) and the solar array simulator (SAS) were integrated to complete the power subsystem. At this point, there were three means of powering the spacecraft: the umbilical rack power supply; the battery simulator, which was routed into the harness via the actual battery interface connectors; and the SAS, which allowed the spacecraft to be operated as though being powered by the solar arrays. SAS power was fed through the SAJB, controlled by the PSE, and provided to the PDU, which distributed the power to the rest of the spacecraft bus.

After the power subsystem was complete on Spacecraft A, the same set of component integrations was performed on Spacecraft B. On Spacecraft A, the RF subsystem was integrated next. There are numerous other ancillary components, as well as guidance and control components, the propulsion subsystem, the pyro interfaces, and the thermal subsystem, that complete the spacecraft bus. In addition, there is a flight battery and the actual solar arrays, which are integrated later.

## INSTRUMENT INTEGRATION

When the spacecraft buses were mostly complete, the instruments were delivered and integrated. On STEREO, there were four suites of instruments:

- STEREO/WAVES (S/WAVES)
- PLASma and SupraThermal Ion Composition (PLASTIC)
- *In situ* Measurements of PArticles and Coronal mass ejection Transients (IMPACT)
- Sun–Earth Connection Coronal and Heliospheric Investigation (SECCHI)

In terms of their impact on I&T, the suites came with varying degrees of complexity. S/WAVES consisted of an electronics box and three deployable antennas. This particular instrument was extremely sensitive to electrostatic discharge, and special conductive black gloves were required when working in the vicinity of any of its components. The antennas are 6 m when deployed and were housed in a single box mounted on the bottom of the spacecraft. No antennas were actually deployed during spacecraft-level testing, but the circuits were tested with a test actuator, and there was a first motion test of one of the antennas with a safety cover in place. For this test, the real actuator was fired, but with the safety cover in place, the antenna just barely moved in its housing. Even with this limited deployment, re-stowing the stacer-type antenna for flight took the better part of a day.

The PLASTIC instrument was seemingly the least complex. It was simply a box with electronics and detectors all in one unit. It used the IMPACT suite's instrument data processing unit for its data processing services. It had nothing that deployed. It did, however, have a high-voltage service, extremely fragile foils, intricate thermal blankets, and the need for radioactive sources for testing. All of these things were costly in terms of schedule, and the instruments had to be removed and reinstalled once on one spacecraft and twice on the other.

The IMPACT suite contained the most modules, a total of seven on each spacecraft, including a 12-m boom that was deployed once during testing just prior to electromagnetic compatibility (EMC) testing. The sensors and detectors in this suite were spread around the spacecraft, a configuration that made integration very tedious. They required specific spacecraft orientations for some of their tests, total darkness for others, and radioactive sources for others. In addition, the thermal blanketing for this suite was particularly intricate.

Finally, the SECCHI suite of optics contained the primary science instruments for the STEREO spacecraft. These instruments on both spacecraft would be the means of creating 3D images of the Sun and its coronal mass ejections. The SECCHI instrument suite was complex from every aspect. Multiple telescopes were developed by multiple teams. Mechanically integrating this suite into the center cylinder of the STEREO spacecraft was a complicated task. The harnessing and thermal blanketing were similarly complex. However, the number one issue of concern, which affected the schedule every step of the way, was contamination

control because optics are highly susceptible to particulate and molecular contamination. In addition to these integration issues, testing of the instrument suite required reorienting the spacecraft numerous times. SECCHI had an electronics box inside the spacecraft, four telescopes mounted in the center cylinder of the spacecraft and heliospheric imager, a camera that was mounted on a side panel of the spacecraft. All of the optics needed to be aligned with the spacecraft attitude control system and co-aligned with each other, which was a time-consuming activity. Very large pieces of external GSE and total darkness for certain tests were two additional constraints that affected the test schedule.

Once all of the instruments were integrated onto each spacecraft, they were referred to as observatories, as specified by the STEREO program office, rather than as spacecraft. Also at this point, the observatories were ready for system-level testing.

### SYSTEM-LEVEL TESTING

With all of these requirements and constraints, coming up with a comprehensive performance test (CPT) for the entire spacecraft that flowed, could be run in a reasonable amount of time, and could be run in parallel with CPT on the other spacecraft, was indeed a challenge. Many hours of planning and replanning were involved in the round-the-clock test plan. The performance test took 5–6 days to execute.

Other system-level testing that was required to qualify the flight hardware and software included phasing tests, mission simulations, fault-protection tests, and RF compatibility tests. The phasing tests included polarity testing of the star tracker hardware and software, polarity testing of each reaction wheel, phasing tests of the digital Sun sensors, and phasing tests of the propulsion-system thrusters. One full end-to-end launch sequence test was performed on STEREO B. It was initiated by manual removal of the separation switch caps that simulated separation from the launch vehicle for the bottom spacecraft. Removing the caps initiated the execution of the automated sequence that powered on the RF transmitter, power amplifier, and attitude control components, and then fired pyros to deploy both solar array wings. This sequence was simulated several times on both spacecraft over the course of I&T, but the full end-to-end test was performed just once.

### ENVIRONMENTAL TESTING

Once the spacecraft were integrated and proven fully functional, and their performance had been verified, the next step was environmental testing. The STEREO program used the following environmental test flow: vibration testing at APL (Fig. 3), a magnetic swing test, and then shipment to Goddard Space Flight Center (GSFC)

for acoustics, thermal balance, thermal vacuum, EMC (Fig. 4), mass properties, and spin balance (Fig. 5) testing.

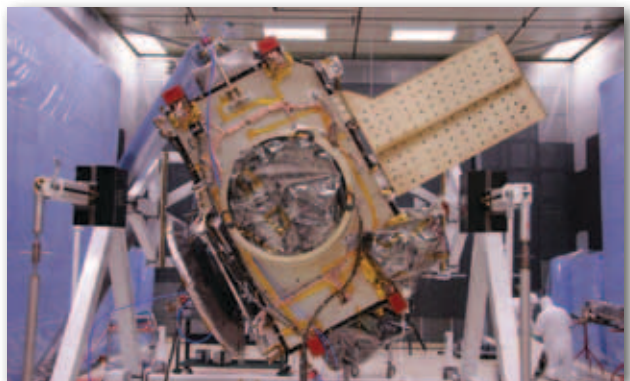
In addition to these major mechanical tests, there were other tests during which the solar arrays were deployed, separation testing was performed, booms were deployed, and software was loaded and tested. Much of the testing at GSFC was mechanical in nature, with system electrical testing performed at each step, both before and after a mechanical test, to verify that all of the spacecraft systems functioned properly.

### LAUNCH SITE TESTING

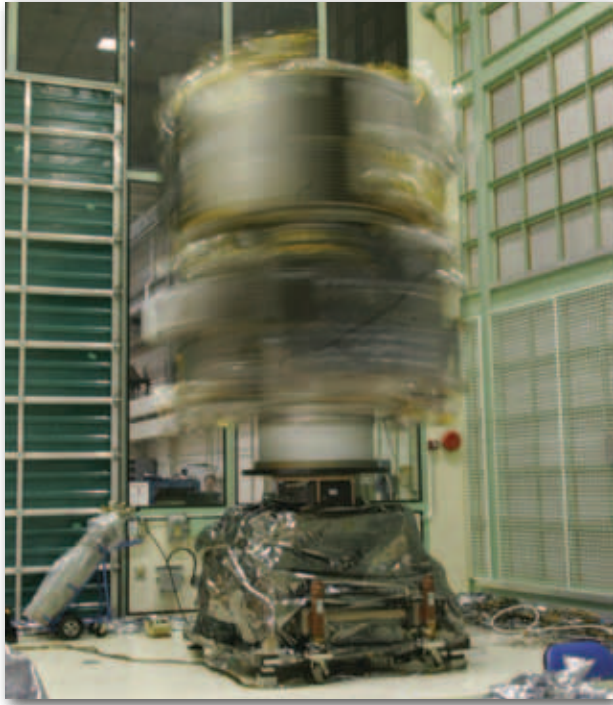
STEREO's launch campaign was a typical field-test sequence. There were several instrument reinstallations



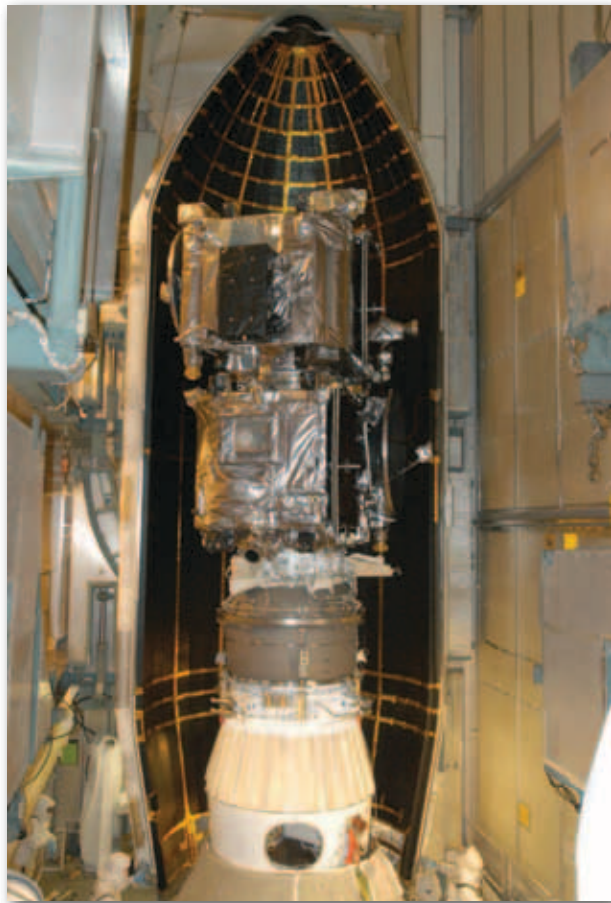
**Figure 3.** Stacked STEREO observatories on the APL vibration table.



**Figure 4.** One of the STEREO spacecraft in the GSFC EMC chamber.



**Figure 5.** Stacked observatories spinning at GSFC.



**Figure 6.** Spacecraft A on top of Spacecraft B on top of the Boeing Delta II launch vehicle with half of the launch vehicle fairing in place behind the spacecraft stack.

along with flight battery and solar array installations. Many system-level tests were repeated, including the CPT, the automated fault-protection testing, attitude sensor phasing tests, Deep Space Network RF compatibility tests, and mission operations simulations. When the spacecraft were completed and tested, they were moved to the Hazardous Processing Facility for propellant loading. At this point, things got a little more exciting. First, while one of the spacecraft was being rolled across the tarmac to the Hazardous Processing Facility, it began to rain, and the spacecraft nearly got wet. Next, while the hydrazine propellant loading operation was beginning, there was a small leak. The investigation and resolution were handled very quickly by the on-site engineering team, but NASA management decided to allow for a more detailed investigation into the situation, which precipitated the first launch delay. When the investigation was completed, the propellant loading operation was begun anew and successfully completed. Propellant loading was followed by weighing, stacking, and the stacked spin balance test and then by moving the spacecraft onto the Boeing rocket's third stage (Fig. 6). There were delays caused by concern with the integrity of several launch vehicle components. They were all resolved, and STEREO successfully launched at 0052 UTC on 26 October 2006 (Fig. 7).



**Figure 7.** STEREO launch at Cape Canaveral Air Force Station in Florida.

## INTEGRATION ISSUES

### Space and Cable Management

Daily operations planning was logistically complex. Two spacecraft of this size, splayed open for integration and surrounded by work platforms, take up a lot of space (Fig. 8). Considering the number of people, the cabling, the additional test equipment, and the safety boundaries required, the cleanroom in Building 23 at APL was just barely big enough. It was challenging to mechanically integrate all of the spacecraft components and instruments on both spacecraft within this space.

Every time the mechanical configuration changed, the electrical configuration changed as well. Usually, the electrical configuration changes involved removing the full set of spacecraft interface cables, moving the cables out of the way, rerouting the cables around the test facility, and remating the full set of spacecraft interface cables. The amount of cabling necessary to fully integrate and test two deep-space observatories was staggering (Fig. 9). There were 30 test cables per spacecraft. Each cable had two segments: one for inside the thermal vacuum chamber and one for outside the thermal vacuum chamber. The total length of each cable was 150 ft, specifically to ensure that the cables were long enough for each test operation where the spacecraft was in a test chamber or cleanroom and the racks of test equipment were in another room or high-bay area. Moving and routing this amount of cabling while attempting to keep it orderly was challenging and more time-consuming than expected.

### Moving and Shipping

Moving two spacecraft and all of the accompanying equipment was a complicated task. When the spacecraft were moved from the cleanroom to the vibration laboratory, it took a week to break down, move, set up, and check out the equipment. With this move, as well as those from test site to test site around GSFC and later to Astrotech Space Operations in Titusville, Florida, a whole battery of GSE checkout tests were required after moving and prior to connecting to the spacecraft for test. The two full-scale moves to GSFC and then to Astrotech required four tractor trailer trucks full of mechanical GSE (MGSE) and electrical GSE, and all of the tables, chairs, printers, PCs, bookcases, and file cabinets. The observatories traveled on their own flat-bed truck inside individual shipping containers (Fig. 10), and the two Ransome tables were also shipped separately on a sixth truck. Nearly the entire team was involved in the packing, sorting, labeling, moving, unpacking, and setting up process.

### Planning and Scheduling

It took countless hours of planning to schedule all of the testing as efficiently as possible. First, the actual



**Figure 8.** Spacecraft A (foreground) and Spacecraft B (background) with panels splayed open during component integration in the APL cleanroom.



**Figure 9.** Cabling for one spacecraft outside the GSFC thermal vacuum test chamber.



**Figure 10.** Preparing the spacecraft for transport (outside APL Building 23) to GSFC.

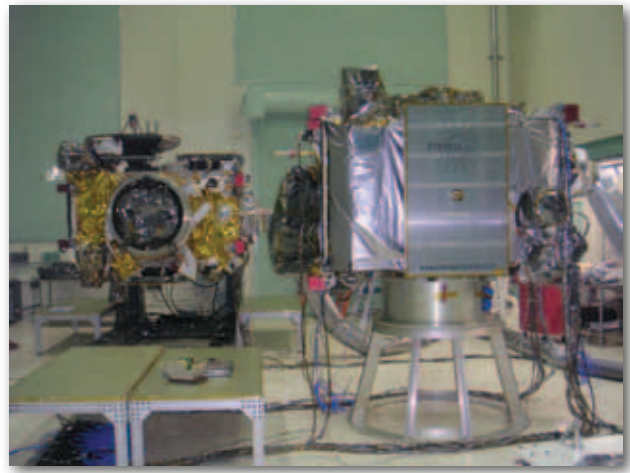
test activities were scheduled, followed by arrangements for mechanical, electrical, contamination, thermal blanketing, and instrument setup and configuration. Many of these activities conflicted with each other, so lots of planning was required to schedule them efficiently. With one spacecraft, scheduling can get tricky, but with two, the task was quite complicated. A detailed daily schedule was developed to manage the tasks, the equipment, and the staff.

In addition to the activities, there were also the people to consider. On STEREO, the core I&T team had 22 people. Ten of them were test conductors who worked shifts that allowed operations to run around the clock on both spacecraft for tests such as CPTs, thermal vacuum testing, and launch day testing. They were the people who would power up the spacecraft each day and execute the planned tests. Often they were operating the spacecraft at the direction of the subsystem or instrument leads who participated in tests that exercised their unit, instrument, or software. In many instances, there was only one subsystem or instrument engineer. Because of this constraint, scheduling testing of the same subsystem or instrument on both spacecraft simultaneously was not possible. However, scheduling the tests serially, given the time involved in some of the more performance-oriented testing, was also a challenge. Great effort was taken to interleave tests and people in such a way that the test engineers were available when needed and were able to get enough rest, and the testing was accomplished in the shortest possible time.

### Mechanical Handling and MGSE

Mechanical I&T operations focused on building up the spacecraft structure followed by integrating spacecraft components and instruments. Much of the mechanical effort, after successful spacecraft buildup, was occupied with managing the large amount of MGSE. Included in this effort were all of the spacecraft lifts required by the program to place the spacecraft into the correct configuration for each test. The mechanical team based its spacecraft-handling planning on the use of pre-existing MGSE from past APL programs. Because of this, for each of the various spacecraft test configurations, a unique piece of MGSE was required.

For each spacecraft, there were five unique spacecraft stands (Fig. 11 shows two of the five stands), but to support testing of two spacecraft in parallel, 10 spacecraft stands were needed. These work stands occupied considerable I&T floor space. Exacerbating this issue was the time needed to move each spacecraft from one MGSE stand to another. Lift operations took an average of 3–4 h. From the initial spacecraft power down, de-cable, spacecraft mechanical preparations, lift operations, mechanical operations, re-cable, and power up, the STEREO program lost valuable testing time. During



**Figure 11.** Spacecraft A on an elephant stand (foreground) and Spacecraft B rotated forward on a Ransome table (background).

system-level testing, great efforts were taken by the mechanical and electrical I&T teams to plan out the order of testing, as well as room layouts, to achieve the most efficient test flow.

### Documentation

Paperwork and data management are always more time-consuming than first anticipated. To comply with all of the Space Department's new Performance Assurance System requirements and NASA requirements, while still operating with the plans and procedures the I&T group was used to using, a large amount of paperwork was generated. For many activities, there was a plan, a procedure, an activity sheet, and a summary sheet of data and results. Activity sheets contained a list of approved steps that were to be executed on a given spacecraft. Sometimes they would include multiple procedures being run and the transitions between them. Other times, they would simply have a single step to run one specific procedure. The activity sheets always required signatures before the procedures were run and again once the procedures were completed. Sometimes these were written in advance to cover major activities like CPTs and launch day. Other times, they were written up quickly for a new task that had been identified. Any time there was an unexpected event or a problem, an anomaly report was generated that also required a number of signatures for closure. At the time of launch, there were a total of 1188 anomaly reports and 840 activity sheets. One of the problems encountered in using all of these methods of tracking the job at hand, concurrently, was that it created lots of places for signatures by the same set of people. Often a person would sign in one place and not another. Keeping track of the closure status of all this paperwork became a significant issue as launch approached.

In addition to procedures, plans, and problem reports, there was a large amount of data to track and analyze, and most importantly, we needed to keep track of which spacecraft the data came from. With so many tests and activities happening, often at the same time, sometimes separated by days or weeks, and sometimes happening on only one spacecraft, it was a complicated task to ensure that all activities intended to be done on each spacecraft were in fact done, documented, and eventually approved. The I&T team developed a master activity sheet log in spreadsheet form that catalogued all test activities and their statuses. This log was accompanied by logbooks for each spacecraft to hold completed activity sheets as well as a third book to hold original copies (with no writing) of each activity sheet. As a result of this forethought and dedication to the process, there were no issues with confusing one spacecraft's data with the other's, which was a significant accomplishment.

The large number of red tag and green tag items was another area of unusual concern. Red tag items are the things that may be present on an instrument or the spacecraft in general that should under no circumstances fly with the spacecraft at launch. It is extremely important to keep track of such things as covers, safe plugs, and restraining pins so that they are not left in place to hinder operations on orbit. Green tag items are the things that must be attached to the spacecraft in order for things to work. During the course of I&T, there are many tests during which the red and green tag items needed to be installed or removed. Keeping track of these configuration requirements was imperative for the safety of the hardware, the people working with the hardware, and the proper operation of the spacecraft. The list was painfully large, and it seemed to ebb and flow through various stages of the program. Things were added and removed from the list on a regular basis. It was a struggle from the beginning of I&T to devise a method of keeping track of these items. Several lists and databases were generated. Eventually, a spreadsheet checklist was created that was used throughout environmental testing at GSFC. A lengthy procedure was written to handle the final removals and installations of all of these items on the launch pad. As with many other STEREO tasks, this one turned out to be harder and more time-consuming than expected.

### Contamination Control

Another area in which STEREO was complicated was contamination control. When there are optics on a spacecraft, there are going to be stringent contamination-control requirements. This requirement, in itself, was not unusual. The fact that there were two of everything doubled the effort. Configuration changes, and the way they were carried out and the times that they were scheduled, affected contamination control as well. Often,

something needed to be bagged while something right next to it needed to be opened up. Some of our configurations made it difficult for cleaning or bagging to take place in the off hours, often making it an activity that had to be planned into the daily and weekly schedules. To increase control over each instrument's environment, individual bags were made as a first layer. A larger spacecraft bag could then be crane-lifted delicately over everything, when necessary. The fact that the spacecraft were large made contamination a pseudo-mechanical operation in many cases. When major testing was taking place, holes were cut in the bags to provide access to test connectors and allow for battery-cooling ducts (Fig. 12), and then they were re-taped again and again. At one point, when a hurricane was headed toward the Astrotech test facility, a third bag was added to each spacecraft for extra protection. An unusual amount of planning time and schedule time went to contamination control, but the result is that all of the optics can see clearly on orbit.

### LESSONS LEARNED

During STEREO I&T, many things were done very well. The fact that the two spacecraft were nearly the



**Figure 12.** Contamination preparations for acoustical testing at GSFC.



same, but not identical, was constantly considered from the beginning of integration. The procedures and data for each spacecraft were stored separately and were easily identifiable. In addition, having a lead for each spacecraft whose job it was to keep specific track of only one spacecraft was an important assignment that significantly helped keep the testing moving forward efficiently.

STEREO would have greatly benefited from a more accurate MGSE/I&T plan that contained all spacecraft and instrument orientation requirements. Two adjustable spacecraft support stands would have allowed the spacecraft to be placed in many, if not all, of the orientations needed and allowed all necessary access and clearances for testing. A piece of MGSE such as this would have saved the program significant amounts of time and labor by eliminating the need for numerous spacecraft moves that required not only mechanical effort but also electrical effort to power down, de-cable, re-cable, and power up, both before and after the move.

As with the MGSE required to work a dual-spacecraft mission, the overall space required for I&T for a dual-spacecraft mission needs to be twice that for a single-spacecraft mission. I&T configurations for each spacecraft should be fully thought out during the planning phases of the program to allow for proper allocation of I&T space. Detailed room layouts showing the locations of MGSE/electrical GSE while they are being used and stored should be generated as part of I&T planning.

Procedures that were too broad in their scope also caused some issues. The integration procedures for boxes covered the entire life of the box: incoming inspection, bench test, mechanical installation, all levels of testing in between, and even potential removal from the spacecraft. In theory, this would be a good way to keep track of each box and everything that was done to it. In practice, this made it hard to close out procedures in a timely way. Generating cleaner, less all-encompassing procedures that can be finalized and closed out as each step is completed is definitely a better approach to use in the future.

One item that allowed real flexibility with planning the order of integration was delivery of a fully functional version of flight software at the very beginning of spacecraft I&T. One of the best things to have in an I&T effort is the ability to replan. Having a full complement of flight software from the start goes a long way toward ensuring this flexibility. Also, fault-protection autonomy rules were developed, tested, and run on the spacecraft very early in the I&T phase. An enormous number of these rules and macros, or predetermined sequences built into the spacecraft's computer processor along with the various telemetry triggers that set them in motion, were developed

specifically for STEREO. Getting an early start on testing them kept the autonomy effort from becoming a problem late in the test program, as has happened on several previous programs. The same thing can be said of mission operations testing and mission simulations. Early preparation and testing led to smooth tests and a well-trained operations team. As it turns out, being able to start these efforts early and test them over and over throughout I&T can be partly attributed to having fully functional software installed. Often on a project, as launch approaches, these types of system-level tests are the things that have not been completed and need to be squeezed into an already tight schedule. STEREO did a remarkable job of scheduling this testing early and often so that there were no late surprises with our system design.

## CONCLUSIONS

Designing, building, and testing the two STEREO solar observatories were interesting and challenging tasks. Although they were nearly identical, the spacecraft had several necessary distinguishing characteristics. During electrical integration, many challenges were overcome as the components and instruments were delivered and installed. The effort to coordinate all of the system-level testing and required support personnel was a daily challenge that involved many interacting disciplines, including mechanical, electrical, thermal, RF, power, science instrumentation, and contamination control.

As challenging a project as STEREO was, it was equally rewarding. Many people worked many hours to make it a success, and as the spacecraft were lifted onto the rocket for their final preparations before launch (Fig. 13), there was much pride in a job well done.



**Figure 13.** Lifting both STEREO observatories to the top of the launch tower.

**ACKNOWLEDGMENTS:** The STEREO I&T effort was a complicated task supported by many people who were critical to its success. Key among them were James M. Roberts, who led the integration team for many years, and R. Alan Reiter, who was a spacecraft lead. Stuart Hill and his mechanical team were an invaluable asset throughout the STEREO I&T program. A large debt is also owed to the whole STEREO team, including the test conductors and technicians, who spent many hours, including nights and weekends, working to make STEREO a success.

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