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SOLAR THERMAL VACUUM TESTS OF MAGELLAN SPACECRAFT*

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ABSTRACT

The Magellan solar/thermal/vacuum test involved a number of unique requirements and approaches. Because of the need to operate in orbit around Venus, the solar intensity requirement ranged up to 2.3 "suns" or Earth-equivalent solar constants. Extensive modifications to the solar simulator portion of the test facility were required to achieve this solar intensity. Venus albedo and infrared emission were simulated using temperature-controlled movable louver panels to allow the spacecraft to a view either a selectable-temperature black heat source with closed louvers, or the chamber coldwall behind open louvers. The spacecraft was mounted on an insulated hydraulically-actuated turntable/tilt-beam gimbal fixture to accommodate several positions relative to the solar beam and albedo simulator. Innovative methods were used to tilt both the gimbal fixture and the solar simulator mirror to maximize spacecraft illumination coverage in the solar beam.

The test conditions included widely varying solar intensities, multiple sun angles to the spacecraft, alternate (redundant) hardware configurations, steady-state and transient cases, and cruise and orbital power profiles. "Margin" testing was also performed, wherein supplemental heaters were mounted to internal thermal blankets to verify spacecraft performance at higher-than-expected temperatures. The test was highly successful, uncovering some spacecraft anomalies and verifying the thermal design. The test support equipment experienced some anomalous behavior and a significant failure during the test. Analytical temperature predictions compared favorably with test results with a few notable exceptions.

INTRODUCTION

The Magellan spacecraft is a three axis stabilized, fine pointing, fully redundant radar carrier using stellar inertial references and reaction wheel torquing. The overall dimensions of the spacecraft are 6.3m by 9.1m. The spacecraft was provided by Martin Marietta under contract to the Jet Propulsion Laboratory.

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The 3.7-meter diameter parabolic high gain antenna (HGA) dominates the forward end of the spacecraft, used for radar data taking at S-Band and for playback to Earth at X-band. Medium gain and low gain links are also provided.

The radar electronics, telecommunications equipment, batteries and attitude control system are housed in the forward equipment module adjacent to the antenna. The command and data system, power system and attitude control electronics are located in the decagonal Voyager bus structure.

The power system is a direct energy transfer type which provides 28 Vdc and 2.4 kHz inverted power using 2 each 3 by 3 meter solar panels and two NiCad batteries. The solar panels (not used in STV test) are partially populated with optical solar reflectors to reduce panel temperatures. The command and data system is a multi-processor design which is a modification to the Galileo spare unit. The propulsion system includes a solid rocket motor for Venus orbit insertion (not used in STV test) and a mono-propellant system (dry for STV test) for midcourse corrections, thrust vector control and reaction wheel desaturation. The spacecraft test configuration is shown in Figure 1.

The Magellan mission launched a single spacecraft to Venus in May 1989. The mission design includes the use of a Type IV Earth-Venus transfer trajectory. This results in the spacecraft traversing a heliocentric angle of slightly greater than 540° during cruise. This particular trajectory was selected because of the timing of its availability, its relatively low Earth escape energy requirement and its moderate approach velocity at Venus, which made the mission possible with the Space Shuttle Atlantis and the Inertial Upper Stage (IUS).

Magellan will be placed in a near polar elliptical orbit with a periapsis altitude of 250 km. The spacecraft will map 25 km swaths from the North Pole to 74° South latitude. The orbit period of 3.15 hours will result in an East West displacement of each successive swath, due to Venus rotation, of about 18 km, thus assuring continuity of the coverage. Coverage of the planet above 74° South latitude is achieved in one Venus rotation of 243 Earth days.

Mapping begins over the North Pole, continues through periapsis, and lasts for 37.2 minutes. During mapping and data recording, the spacecraft points the HGA to the left, looking in the direction of orbital motion. The look-angle (the angle between the local vertical and the HGA boresight direction) is varied with altitude in the elliptical orbit, to optimize the radar performance. After each mapping pass, the spacecraft turns and points the HGA at Earth for playback of the recorded mapping data.

The playback is accomplished in two intervals separated by a star calibration (STARCALS) near apoapsis. During the STARCAL, the spacecraft gyros are recalibrated with reference to the star scanner to assure that the HGA pointing during the next mapping swath will meet the radar pointing requirements.[1]

Several of these mission scenarios were simulated in the STV test. This paper contains a description of the test objectives, the facility and configuration (including the modifications required to accommodate the spacecraft), the timeline, the test execution and the test results, concluding with some lessons learned.

TEST OBJECTIVES

The objectives of the Magellan Solar Thermal Vacuum (STV) Test were as follows:

1. a. Provide data for the validation of the Magellan thermal math models.

   b. Verify thermal subsystem performance.

2. Demonstrate integrated system performance at cold and hot ("margin") temperature levels.

In addition to the formal objectives, the following special requirements were to be implemented:

1. Provide an appropriate thermal environment for characterization of spacecraft systems such as radar performance testing, articulation mechanism functional testing, and radio performance testing.

2. Provide for shunted power adjustments to validate shunt radiator thermal design and workmanship and provide testing to satisfy protoflight testing criteria.

No system-level thermal cycling tests were explicitly required. However, the cycling which occurred as a result of varying test conditions, margin testing and mapping orbital simulations provided system-level workmanship confidence to supplement component- and subsystem-level thermal cycling tests.

TEST FACILITY[2,3,4]

The test facility was located in the Space Simulation Laboratory, Martin Marietta Astronautics Group, near Denver, Colorado. The Magellan test used the 8.8m dia X 19.8m high (29'X65') chamber configuration, the solar simulator modified to produce 2.3 suns intensity, and portions of the thermal environment simulator to form the albedo simulator.

TEST CONFIGURATION

The Magellan (MGN) spacecraft is a protoflight vehicle and therefore actual flight hardware was used in the test configuration, with the following exceptions:

1. No solar array panels. Simulated by temperature-controlled aluminum structure supporting the sun sensor units.

2. The hydrazine tank was dry with pad pressure to maximize response rates.

3. Test batteries installed (identical to flight batteries).

Magellan's size and the requirement to illuminate both its long axis and its transverse axis with the solar beam introduced the need to tilt both the gimbal and the solar mirror. The gimbal tilt was constant throughout the test and was accomplished by constructing an adapter with the required tilt. The adapter picked up three of the four mounting hardpoints in the chamber floor and accommodated the gimbal's four mounting legs. Stress and dynamic analysis verified the capability of the tilted gimbal structure to withstand the off-nominal loading. The gimbal tilt and spacecraft position envelopes are shown in Figure 2.

The solar mirror tilt was accomplished by installing longer suspension turnbuckles in the secondary support structure. Since the mirror was supported primarily by a single-axis beam which could be rotated, turnbuckle adjustments could be used to tilt the mirror. The solar mirror tilt was not constant during the test, requiring a -2° mechanical tilt (-4° solar incidence angle) for cases 1 and 2 where sun directly along the MGN +Z axis was required, and +2° (mechanical) for the remaining cases when sun perpendicular to the +Z axis was required. The mirror could not be repositioned while under vacuum, thereby necessitating a return to ambient conditions between cases 2 and 3. Figure 3 shows the unusual resulting geometries for the various test cases. The net result of the gimbal and mirror tilts was a nearly complete illumination of the entire spacecraft, with only a small crescentshaped portion of the HGA plus two Rocket Engine Modules (REM) and a sun sensor outside the beam in cases 1 and 2, and only the extreme tip of the HGA outside the beam in cases 4-13.

Venus albedo (reflected sunlight) is as high as 78%. When combined with a 2-"sun" solar intensity, over 1.5 "suns" of additional sunlight can be expected in the Magellan mission. This energy could not be applied to the test configuration in the solar spectrum since only one sun source was available. An albedo simulator was therefore constructed to provide additional energy to the spacecraft. The albedo simulator used 18 existing temperature-controlled 1.8m X 1.8m louver panels, each with eight louver blades, mounted in a new frame to provide a known infrared (IR) heat source. The louvers could be opened to allow the spacecraft to view liquid-nitrogen-cooled shrouds, or closed and heated to simulate Venus albedo and planetary IR emissions. The location was chosen as representative since Venus albedo can be incident from virtually any angle in the actual mission. The albedo simulator was also available for emergency safing (warming of the chamber environment) in case of a long-term solar simulator failure. The albedo simulator is depicted in Figure 4.

Redundant guard heaters were used to null heat loss to the gimbal and cable bundle. Heaters were also used to simulate the presence of the solar panels, which were omitted due to their prohibitive size, for sun sensor and solar array drive motor conductive environments. Cabling was routed through the insulated aft end of the spacecraft, and was insulated and guard-heated. Guard heaters totalled 630 Watts in seven zones (1260 Watts for both redundant sets).

An additional set of test heaters was installed within the spacecraft to provide artificial heating for higher-than-expected temperature testing of the complete spacecraft. This testing was referred to as "margin" testing since its purpose was to evaluate system performance at elevated temperatures, thereby demonstrating "margin" above expected levels. The non-redundant margin heaters were attached to large interior insulation blankets such that blanket emittance was not compromised, and were controlled with dedicated thermocouples including an autonomous overtemperature kill capability. A total of 5500 Watts were provided in eight zones.

Test instrumentation consisted of 372 type E thermocouples placed to provide information for component temperature requirements compliance, thermostat function, external heat flux level, and thermal math model correlation. Each thermocouple was bonded to its substrate material. Additionally, 84 flight temperature sensors (platinum resistors) were available for comparison to and supplementation of the test thermocouples. A further 26 flight sensors became available when the spacecraft's radar was active. The data were displayed, printed, and plotted realtime and were stored on magnetic tape for post-test processing.

TIMELINE

The test timeline was established after consideration of a number of factors, primarily driven by the desire to maximize the variety of conditions and to envelope the extreme conditions. Since the spacecraft is designed to operate under continuous motion while mapping Venus, consideration was given to duplicating this motion on the gimbal structure while operating the radar in synchronization. However, because of constraints due to physical envelope in the chamber, and in an attempt to minimize unnecessary test complexity, a series of fixed attitudes was chosen instead. The criteria used to select the test cases were as follows:

1. Include at lease one situation where two successive cases are identical with the exception of a substantial change in solar intensity (used to determine sensitivity to solar absorptivity).

2. Provide several "pure" transients to correlate thermal capacitance of the spacecraft; "pure" transients are those where a minimum of step changes are made to the environment or the spacecraft power state (preferably only one).

3. Provide six days vacuum before radar power-up as requested by Hughes Aircraft (HAC), the radar contractor.

4. Include at lease one transient eclipse case.

5. Place the sun on the spacecraft faces containing the most thermally sensitive equipment.

6. Provide for integrated system performance testing at hot and cold conditions.

7. Provide for special component performance testing of tape recorders, radios, star scanner, and shunt radiators.

Thirteen planned test cases resulted from these criteria and the test objectives. Figure 3 depicts the various spacecraft attitudes for each of the 13 test cases. Each case is described in the following paragraphs:

Case 1 The intent of this case was to simulate the cold thermal design point for the majority of the spacecraft heaters and thermostats. Since the HGA effectively shadows most of the spacecraft, a near-Earth (1.0 solar constant) HGA-to-sun attitude presents the coldest possible cruise conditions for most components and therefore, the cold thermal design case. In order to establish the acceptability of heater sizes and thermostat setpoints, it was important to achieve thermal stabilization under these cold conditions.

During this case the albedo simulator was in its cold configuration, with louvers open and heaters inactive. The chamber solar mirror position for this case was at -2° tilt to provide a true HGA-to-sun attitude due to the off-center positioning of the gimbal. Initially, all thermal components were enabled such that heater activity occurred on the primary string. After stabilization, the primary string was disabled such that heater activity occurred on the secondary string. Since the secondary string of heaters operates at a lower temperature setpoint than the primary string, the disabling of the primary string, combined with a duty cycle evaluation, could be used to infer heater design margin. A maximum duty cycle of 80% on the secondary string was required. The power state of the spacecraft during the stabilization was the nominal cruise state on "A" side components.

Since this case represented the cold case for many components, it also provided appropriate conditions for verification of integrated system performance at minimum expected temperatures. During cases 1 and 2, identification of any required thermal design changes was a high priority. This was necessary so that any changes could be implemented during chamber return to ambient after case 2.

Case 2 The intent of this case was to provide a steady state hot case for the HGA area. This case verified that solar focusing by the parabolic HGA onto the subreflector was thermally acceptable. In attitude, in albedo simulator configuration, and in power state, case 2 was identical to the stabilization portion of case 1. Primary heaters were enabled to minimize warmup time in anticipation of return to ambient conditions. The solar intensity, however, was increased to 2.3 suns to provide maximum heating to the HGA. Due to relatively low mass/area ratios in the HGA componentry, stabilization would be reached sooner than in the remainder of the spacecraft, so this case was a transient case (meaning lack of stabilization at equilibrium for the majority of the components).

At this point, the chamber was returned to ambient conditions, the lid removed and solar mirror reconfigured to +2° mechanical tilt for the remainder of the test. Inspection of the spacecraft was performed. The spacecraft was also repositioned as discussed in case 3. The lid was replaced and the chamber returned to vacuum conditions. This time-point started the 6-day clock while the radar was to remain powered off. All thermal components were enabled for the remainder of the solar thermal vacuum testing.

Case 3 The intent of this case was to simulate worst-case solar exposure to the bay 3 and 4 area. This condition is prevalent during the playback portion of some mapping orbits. The reason for the 20° off-point from true +Y-to-sun was to avoid pointing the star scanner boresight directly at the sun. Full near-Venus solar intensity of 2.3 suns (1.94 suns expected plus 20% margin) was selected. The albedo simulator was in its hot configuration with louvers closed and heaters active (temperature controlled to -59°C) to simulate Venus albedo (239 mW/cm^2, 199 expected +20% margin) considering appropriate wavelength conversions.

The vehicle power state was: radar turned completely off, radios in playback mode as if radar data were being transmitted and tape recorders in standby mode. Case 3 was a steady state case, where stabilization was required for math model correlation purposes. Time was allocated after stabilization for system performance evaluation, during which time the battery reconditioning circuits were tested.

At this point, the spacecraft was repositioned to point the +X face towards the sun. The repositioning was performed under vacuum conditions and involved a 20° pitch-down rotation and a 90° roll. During the repositioning, the sun was dowsed to prevent the possibility of excessive solar loading on the low gain antenna as it passed through the concentrated beam above the solar snout. The albedo simulator remained active (louvers closed, -59°C).

Case 4 The intent of this case was to begin a series of solar exposures to the radar area for math model correlation purposes. The solar intensity was set at 1.0 equivalent sun, the albedo simulator was active with its louvers closed and its temperature set to -59°C. This was a stabilization case for correlation purposes and to establish a known initial condition for later transient exposure. System performance evaluation time was not allocated here as it would invalidate the equilibrium condition established.

Case 5 This case was intended to provide a "pure" transient condition for math model correlation purposes. The case was identical to case 4 except for a step increase of solar intensity from 1.0 to 1.6 suns. This case established thermal control subsystem response to infer sensitivity to surface solar absorptivity.

Case 6 The intent of case 6 was to establish a known equilibrium condition with the radar powered in standby mode, in order to reach approximate mapping temperatures prior to the first mapping sequence in case 7. The radar could now be powered up because six days had elapsed since pump down. Therefore, this case was essentially a continuation of case 5, except for radar power up.

Case 7 This case represented a hot mapping transient orbit at Venus. An orbital component power profile was simulated with the radar cycling from map to standby to map, tape recorders cycling from record to playback to record, and radios cycling on and off in mapping mode. Repetitive orbital simulations of 3.15 hours each, back-to-back, were conducted until a pseudo-steady state condition was established. The vehicle attitude did not change; the sun was constantly positioned normal to the +X side of the spacecraft. The solar intensity remained at 1.6 suns and the albedo simulator remained active (louvers closed, heated to -59°C).

Case 8 This case was intended to drive +X side components above flight allowable levels by activating supplemental test heaters. The case was identical to case 7, except the power to the internal supplemental margin heaters was increased until the first component in each of eight zones reached approximately its previous test level less 5°C at the hottest point in the orbital cycle. At this point, system performance was evaluated at elevated temperatures. The goal was that a minimum of four simulated orbits (12.6 hours) be spent at elevated temperatures.

Case 9 This case simulated an eclipse event. It was intended primarily for math model correlation purposes as the duration exceeded flight requirements. The environment was modified by dowsing the solar simulator and powering the albedo simulator off (louvers open) at the cold point in the cyclic orbital simulation. The power state was maintained in playback mode for a constant dissipation over the length of the eclipse. Spacecraft power was supplied by the on-board batteries. In order to maximize information for math model correlation, the length of the eclipse was not preset. The eclipse was terminated when the battery depth-of-discharge (DOD) reached 80%.

At this point, the spacecraft was repositioned to point the -X face towards the sun. The repositioning was performed under vacuum conditions and involved a 180° roll. During the repositioning, the albedo simulator was active (louvers closed, -59°C) and the sun was dowsed.

Case 10 This case was equivalent to case 6 in that it was a preparatory equilibrium case for the mapping case to follow. The environment was identical to case 6 except for the attitude change to -X-to-sun and a solar intensity reduction to 1.0 sun. The power state was identical except that "B" side components were powered rather than "A" side for case 6. Finally, the radar was powered to standby. Spacecraft batteries experienced recharging early in this case as a result of the case 9 discharging.

Case 11 This case was functionally similar to case 7, with repetitive 3.15 hour back-to-back orbital simulations. The attitude (-X-to-sun), sun intensity (1.0) and powered components ("B" side) were the operative differences between cases 11 and 7, all other aspects being identical. Again, as in case 7, repetitive orbital simulations were planned until pseudo-steady state conditions were achieved.

Case 12 This case was similar to case 8, representing another margin test, this time to force the -X components beyond flight allowable levels. The same margin heaters were used, with the same philosophy as case 8, to achieve elevated temperatures. Environmentally and electrically, it was to be a continuation of case 11, except the margin heaters were activated. System performance was again evaluated as elevated temperatures were achieved. The goal was that a minimum of four simulated orbits (12.6 hours) be spent at elevated temperatures.

Case 13 The last case was functionally similar to case 9 in simulating another eclipse. The environment was modified as in case 9 (dowse sun, albedo simulator off), a constant playback mode was selected, batteries supplied spacecraft power, and duration was determined by battery DOD.

Following case 13, the chamber was returned to ambient conditions and the spacecraft was inspected and found to be in excellent condition.

TEST EXECUTION

The test was executed nearly according to plan. Pumpdown was initiated at 1900 GMT, 8 July 1988. Case 1 began at 08:35 GMT, 9 July 1988. Stabilization was reached at 12:30 GMT, 11 July at which time primary heaters were deactivated, allowing secondary heaters to control. Primary heaters were reactivated at 01:50, 12 July. At 05:51, 12 July, all solar illumination was lost when a lamp exploded, damaging a second lamp in the process and shutting down the solar simulator. The albedo simulator was immediately closed and warmed to safe the spacecraft while repairs were undertaken. Solar was restored at 10:35, 12 July, and testing resumed with no detrimental effects on the spacecraft. At 02:12, 13 July, case 2 began with a step increase in solar intensity to 2.3 suns. Case 2 completed with HGA stabilization at 06:45, 13 July. Repressurization was complete at 00:52, 14 July.

Spacecraft inspection revealed several areas where closeout tape had become debonded. These areas were reworked. The sun sensors were removed since their extreme thermal environments had been experienced. A loose thermocouple wire was discovered to be interfering with louver operation (detected in test data in case 1) and was rebonded. The mirror tilt was adjusted and the spacecraft was repositioned for case 3.

The second pumpdown began 09:00 GMT, 15 July. Case 3 began 01:26, 16 July, and was completed without anomaly at 18:18, 17 July. The spacecraft was repositioned under vacuum and case 4 began at 20:00, 17 July. At 13:50, 18 July, the gimbal tilt was detected to be 4.3° too large and was corrected, while efforts began to understand the cause of the error. During this case the sunside spacecraft/gimbal adapter guard heaters ceased to operate as solar illumination warmed the normally heated spacecraft-gimbal interface. Temperatures did not rise substantially over the control setpoints, so near zero heat transfer was nearly maintained. Case 4 was completed and case 5 initiated at 20:14, 19 July, with a step change of solar intensity from 1.0 to 1.6 suns.

During case 5, the adapter temperature increased with the higher illumination, and the spacecraft began receiving conducted heat from this source. Although not desirable, the additional heat could be accounted for in post-test analysis and correlation. Also during this case, the sunlit rocket engine modules (REM) unexpectedly reached flight allowable temperatures. Case 5 ended at 13:10, 21 July, and case 6 immediately began with radar power-on. Case 6 stabilization was reached at 22:52, 22 July.

Case 7 began repetitive mapping orbits for the first time in prelaunch testing. A minor water leak in the solar dowser cooling was detected and the water circuit was shut off (unnecessary unless dowser is closed). The gimbal tilt beam slipped again, this time 11°, at 13:51, 23 July, and the hydraulic fluid level was observed to be low. Replenishment of fluid cured the mysterious gimbal movements. During case 7, unexpected noise in radar data was detected. Case 7 was completed at 15:43, 24 July, after 13 consecutive successful orbits.

At 15:59, case 8 began with the turnon of the margin heaters while mapping continued. The heaters were adjusted over the next seven orbits to maximize the number of components reaching their previous (component or subsystem) test temperatures less 5°C. The first of four stabilized orbits was begun with orbit number 21 at 15:44, 25 July. The 24th orbit and case 8 were completed at 04:24, 26 July.

Case 9, the first intentional eclipse case, began at 04:34 with solar system shutdown. Eighty percent (80%) DOD on batteries was reached at 07:22 signaling the end of case 9. Spacecraft repositioning for the remaining cases was then accomplished.

At this point a significant deviation from the pretest plan was made: since the spacecraft was still at elevated temperatures from case 8 margin testing, it was decided to perform the case 12 margin testing out of sequence for schedule considerations. Case 12 began at 07:44, 26 July. Case 12 was completed nominally at 09:45, 27 July, and about 13 hours of radio subsystem characterization testing was accomplished before the start of case 10 at 22:55, 27 July. Case 10 was completed without anomaly at 18:30, 29 July, and case 11 began immediately. During case 11, the radar noise was correlated to propulsion line heater activity. Stabilization was reached at 17:51, 30 July, after six mapping orbits and the second eclipse (case 13) was initiated with termination at 80% DOD at 20:25, 30 July. Upon completion of the 13 thermal cases essentially on schedule, star scanner, radar and radio characterization testing was undertaken. Repressurization was begun at 18:04, 31 July, and ambient conditions were reached at 00:18, 1 August 1988.

RESULTS

The test met all thermal objectives and requirements. The spacecraft overall thermal balance was as expected, falling within about 5°C of predictions in all cases, with several local exceptions:

1. The HGA temperatures were 10° to 20°C low compared to predictions, discounting the area of the HGA which was not fully illuminated. This error was attributed to the need to instrument large curved areas with thermocouples which can only measure local temperatures. Since math models predict average temperatures over the large area, substantial errors can be expected without detailed local modeling of the actual thermocouple position. No action was taken since temperatures remained within allowable limits.

2. A portion of the radio experienced colder-than-expected temperatures (about 9°C low). This was attributed to an undersized heater and a faulty thermostat placement controlling the heater; a heater size increase and thermostat relocation later corrected the problem.

3. The heater for one of the tape recorders was slightly undersized. No action was taken as test conditions were deemed significantly colder than expected flight conditions. Flight temperatures have remained nominal.

4. The radar baseplate temperature gradients were larger than expected, requiring that the heater setpoints be adjusted up 6°C to ensure all parts of the radar remain within allowable temperature limits.

5. A sun sensor thermostat appeared to "dither" or cycle rapidly with a small deadband. Later analysis proved this indication to be faulty, caused by relative locations of heater, thermostats, and thermocouple on a low-conductivity thin plate.

6. The propulsion lines were about 15°C warmer than expected. This discrepancy was later traced to a difference in temperature sensor location between preliminary design and as-built position, plus an area error in math modeling.

7. The Rocket Engine Modules exceeded expected values by as much as 20°C. Later analysis identified the probable cause as solar entrapment in the engine catalyst bed thermal standoff. A hardware modification was made to

shield the area from sunlight, but no retest was performed due to lack of available test hardware. Flight experience has shown that the anomaly was not corrected by the modification, and the REMs continue to operate above expected temperatures.

8. The electronics bus temperature gradients were about 4°C larger than expected. The math model was corrected.

9. The white paint on four solar array holddown structures did not adhere. They were cleaned and repainted after STV test.

10. An S-Band transmitter failed immediately after STV test; chip capacitors were diagnosed as having been overstressed during earlier component testing and were replaced.

11. The radar noise/heater cycling anomaly was later determined to be a propulsion line heater damaged in installation and shorted to structure. It was replaced posttest.

Figure 5 shows representative test data compared with math model results. In this figure the electronics bus is "unrolled" and bay numbers are indicated on the abscissa.

CONCLUSIONS

The Magellan STV test was an unqualified success, demonstrating thermal subsystem performance, evaluating system integrated performance at extreme temperatures, and providing necessary data for math model validation. It was also successful in uncovering several workmanship, analytical and design errors whose effects would have ranged from minor to substantial in flight. It was not successful in identifying one major design flaw (REM), primarily because the test was designed to evaluate the integrated system, not necessarily previously tested subsystems. The REMs had been tested as a subsystem, but not under solar simulation.

The STV test also employed innovative solutions to minimize costs under stringent physical constraints in the test facility.

Among the lessons learned from the Magellan test include:

1. System-level thermal balance testing should be required for new hardware designs. Solar simulation should also be a requirement whenever feasible.

2. Careful attention should be paid to conductive and radiative interfaces with facilities to minimize effects which could compromise test results.

3. Thermal design modifications should be verified by test to ensure successful problem resolution.

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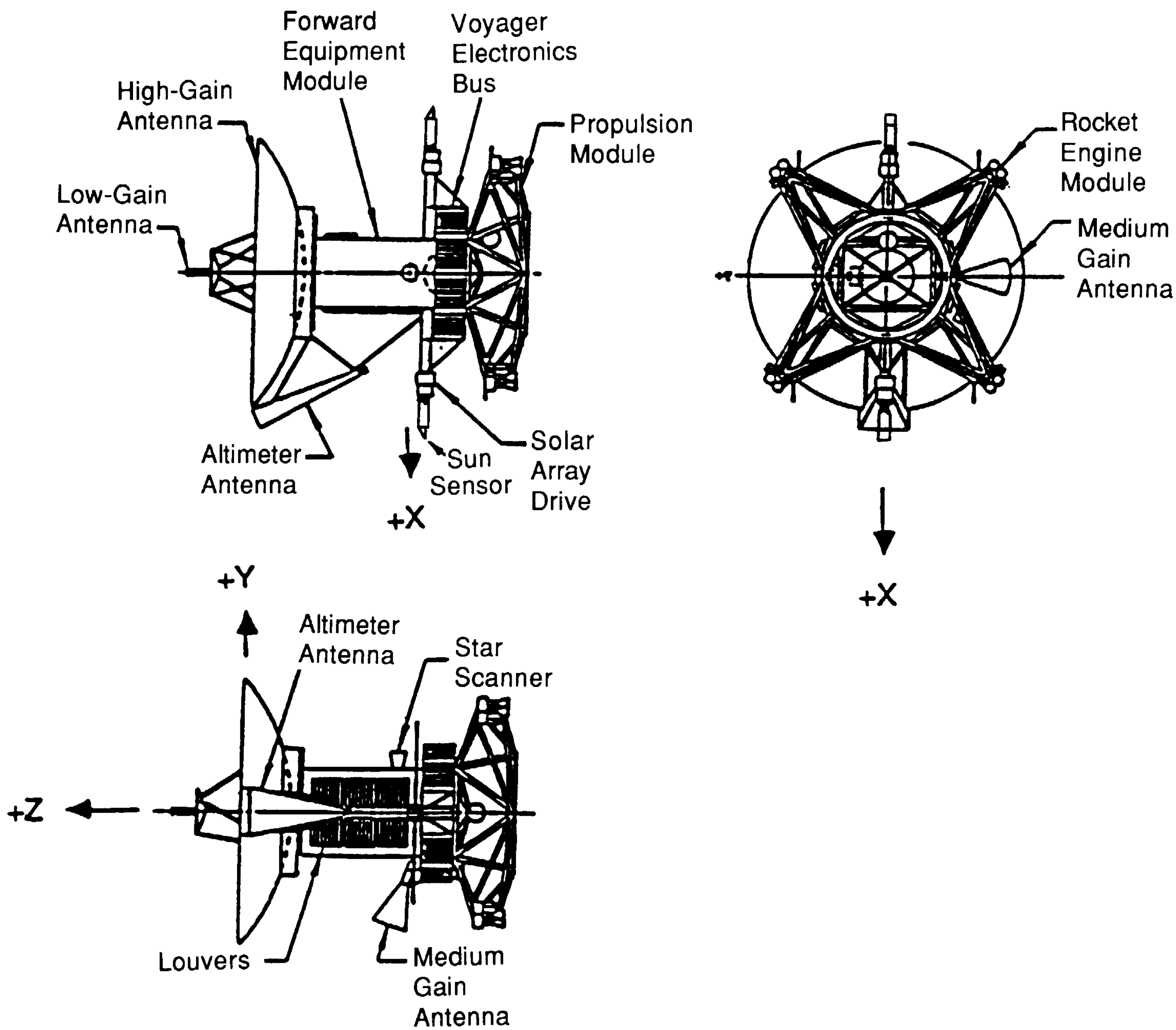

Figure 1. Magellan Test Configuration

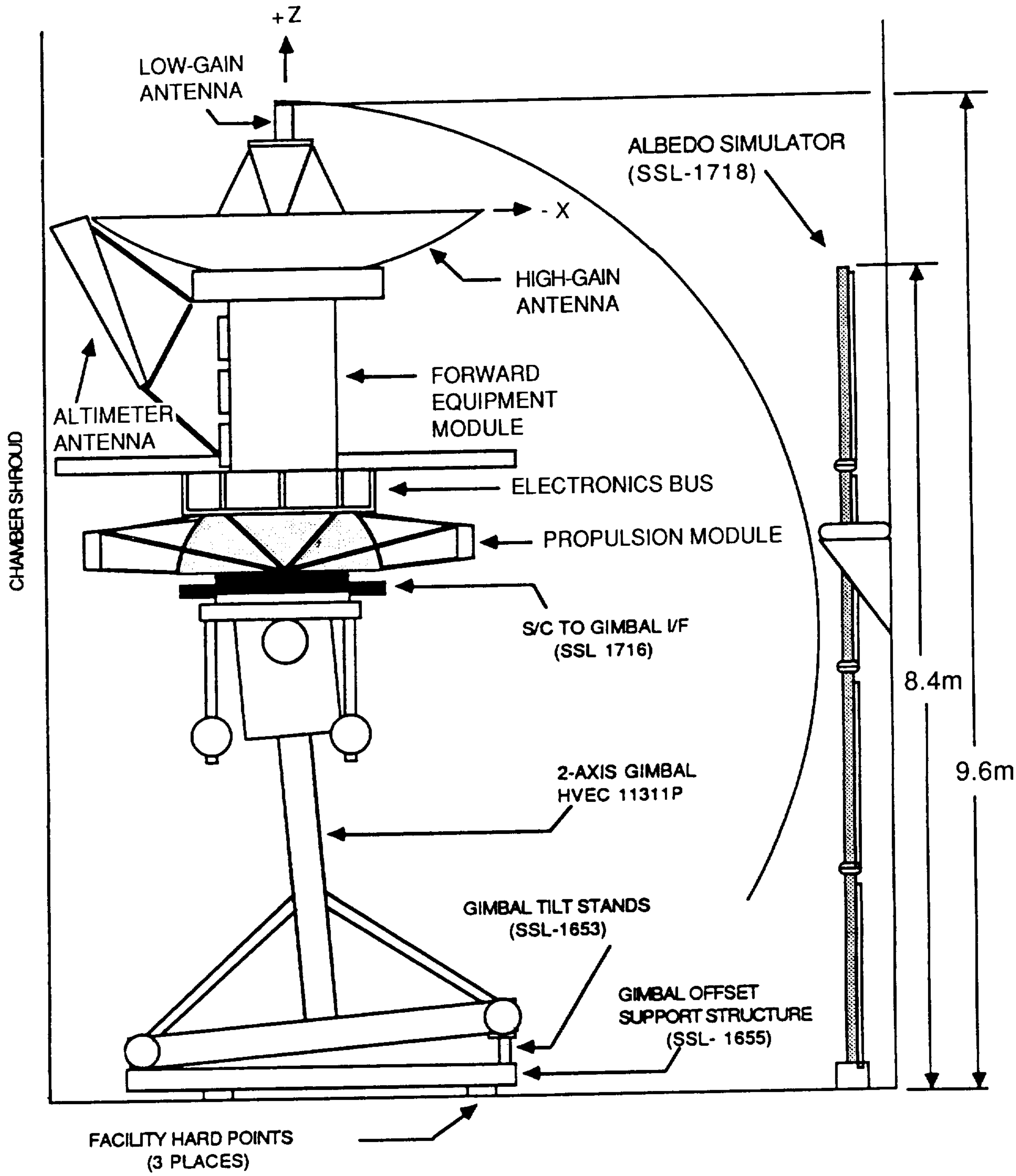

Figure 2. Magellan Installed on Gimbal Fixture

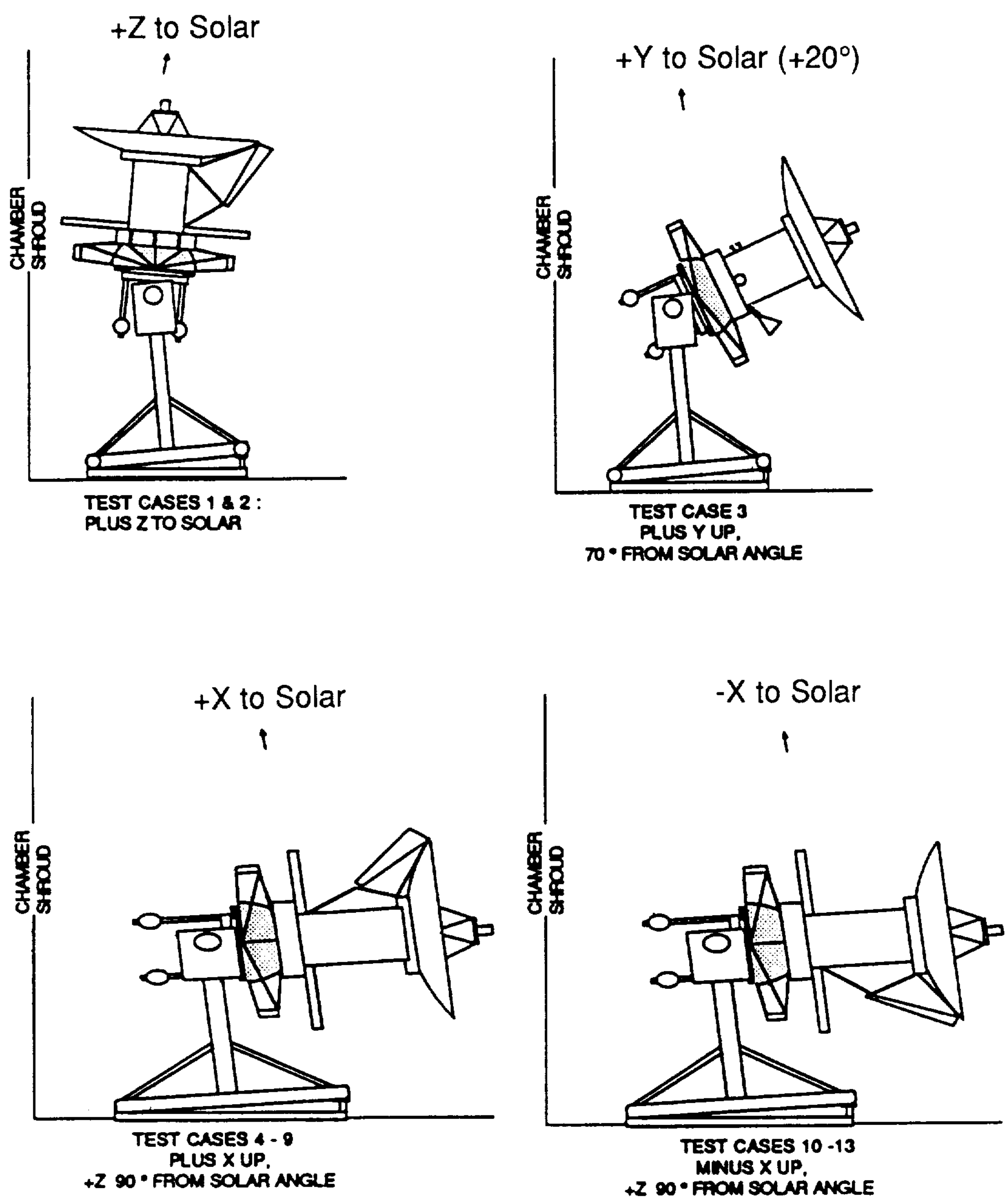

Figure 3. Spacecraft Test Attitudes

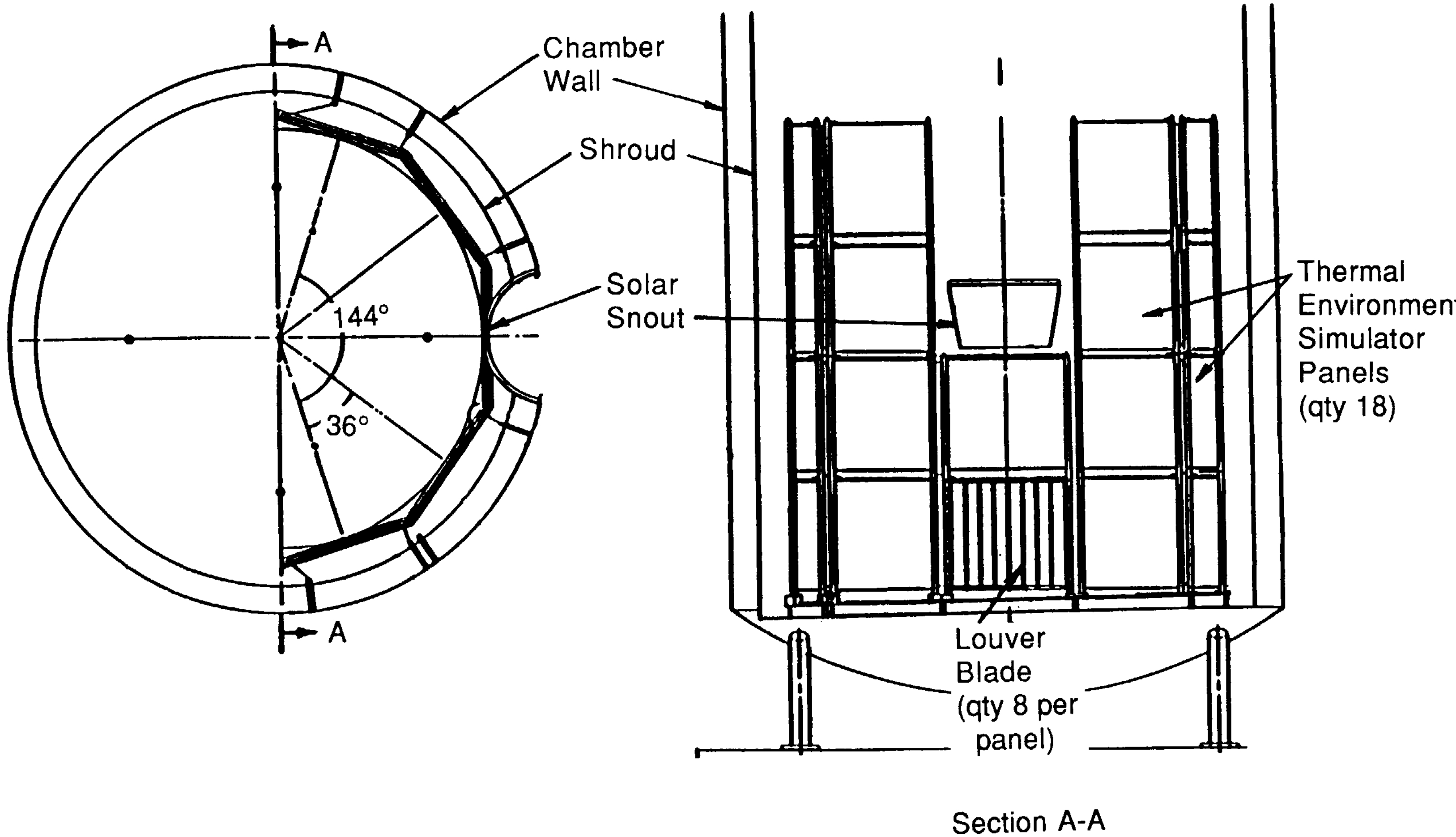

Figure 4. Albedo Simulator

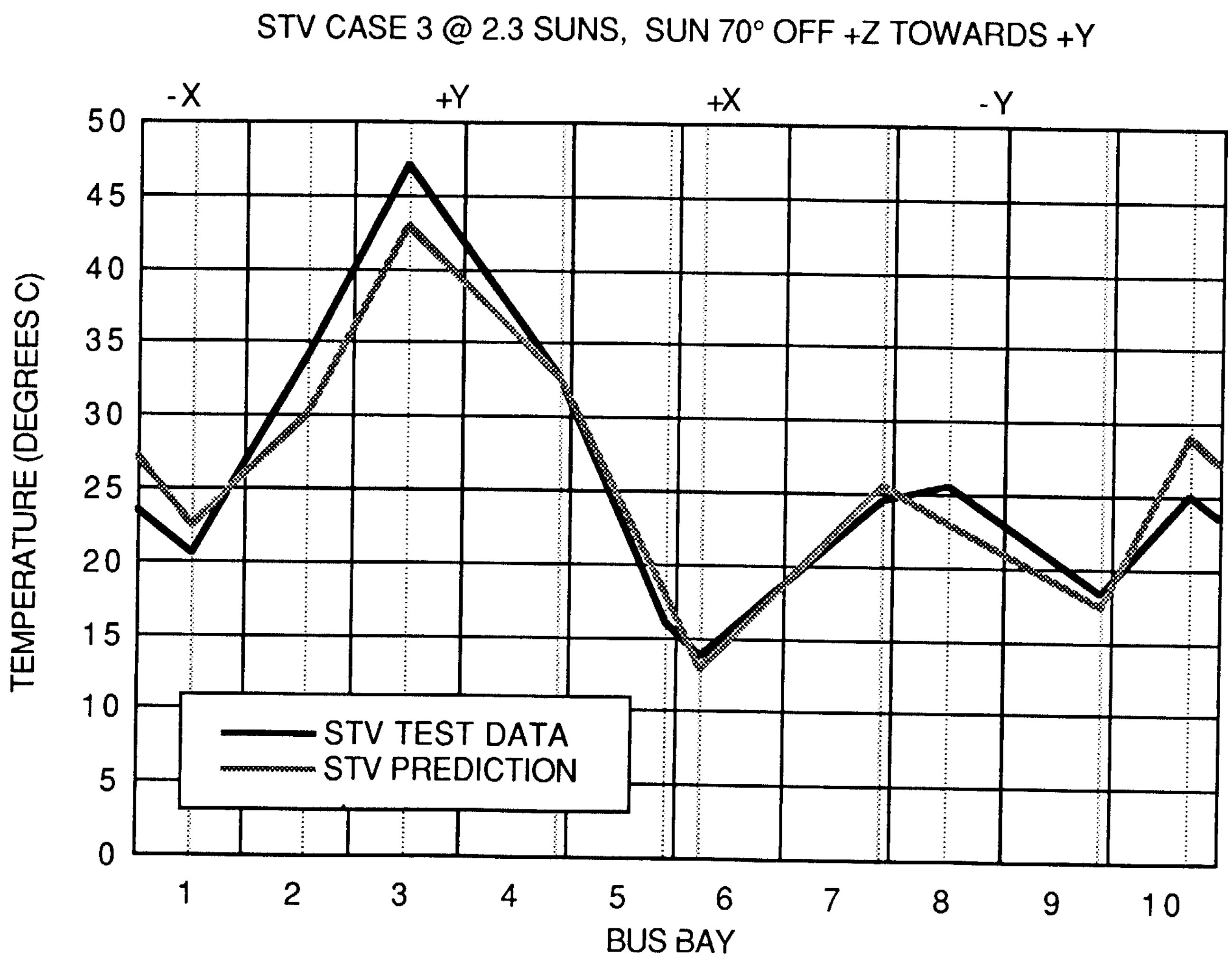

Figure 5. Electronics Bus Test Temperatures vs Math Model Predictions