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SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

Flight Motor Set 360L009 (STS-36) Final Report

Volume I – System Overview
September 1990

Prepared for:

National Aeronautics and Space Administration
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Marshall Space Flight Center, Alabama 35812

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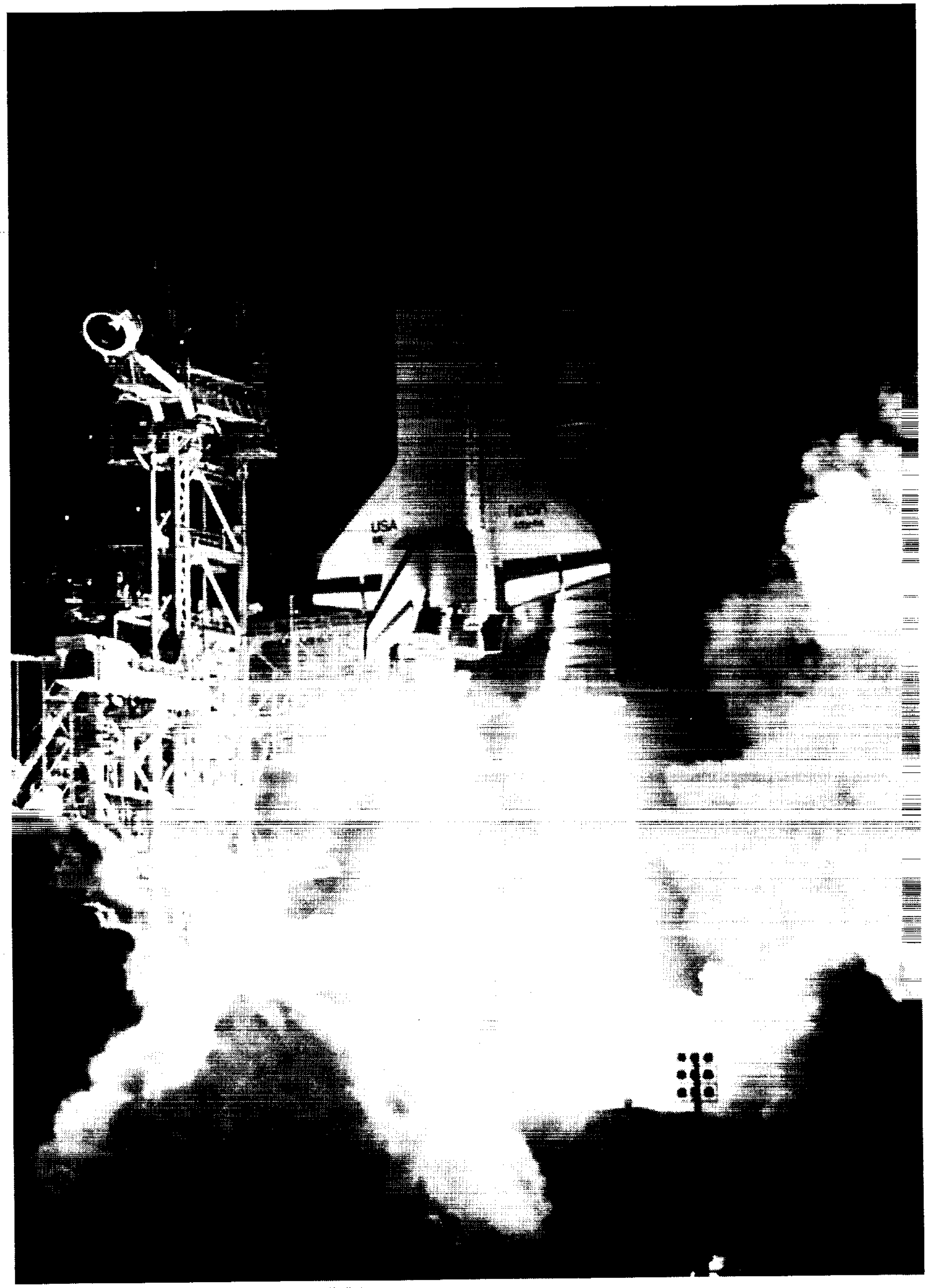

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STS-36 (Atlantis), assisted by Thiokol Flight Motor Set 360L009, was successfully launched at 4:34 a.m. CST on 24 April 1990. Atlantis carried a DoD payload.

ABSTRACT

Flight Motor Set 360L009, as part of NASA Space Shuttle Mission STS-36, a Department of Defense mission, was launched at approximately 1:50 a.m. CST (090:059:07:50:22.000 GMT) on 28 February 1990 after two launch attempts. One launch on 24-25 February was scrubbed following the failure of a ground-based Range Safety computer and one on 25 February was scrubbed due to cloud cover at the return to launch landing site. As with all previous redesigned solid rocket motor launches, overall motor performance was excellent. There were no debris concerns from either motor.

Nearly all ballistic contract end item specification parameters were verified, with the exception of ignition interval, pressure rise rate, and ignition thrust imbalance. These could not be verified due to the elimination of developmental flight instrumentation on 360L004 (STS-30R) and subsequent, but the low sample rate data that were available showed nominal propulsion performance. All ballistic and mass property parameters that could be assessed, closely matched the predicted values and were well within the required contract end item specification levels.

All field joint heaters and igniter joint heaters performed without anomalies.

Evaluation of the ground environment instrumentation measurements again verified thermal model analysis data and showed agreement with predicted environmental effects. No launch commit criteria violations occurred.

Postflight inspection again verified nominal performance of the insulation, phenolics, metal parts, and seals. Postflight evaluation indicated that both nozzles performed as expected during flight. All combustion gas was contained by insulation in the field and case-to-nozzle joints.

Recommendations were made concerning improved thermal modeling and measurements. The rationale for these recommendations and complete result details are contained in this report.

TWR-17548

Flight Motor Set 360L009 (STS-36) Final Report System Overview

Volume I
27 Apr 1990

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TABLES

ACRONYMS

A/D . . . . analog/digital
ADCAR . . . . . . Automatic Data Collection and Retrieval
AT . . . . action time
CCP . . . . carbon cloth phenolic
CEI . . . . contract end item
CF . . . . capture feature
cg . . . . center of gravity
CN . . . . change notice
CST . . . . central standard time
DFI . . . . development flight instrumentation
DR . . . . discrepancy report
EPDM . . . . . . ethylene-propylene-diene monomer (insulation)
ET . . . . external tank
FBMBT . . . . . . flex bearing mean bulk temperature
FEP . . . . front end processor
FEWG . . . . . . flight evaluation working group
FMEA . . . . failure mode effects analysis
FSEC . . . . Florida Solar Energy Center
FSM . . . . Fuel Supply Module
GCP . . . . glass cloth phenolic
GEI . . . . ground environment instrumentation
GFE . . . . government-furnished equipment
GMT . . . . Greenwich mean time
GN_2 . . . . gaseous nitrogen
GOx . . . . gaseous oxygen
GSE . . . . ground support equipment
HOSC . . . . Huntsville Operations Support Center
IFA . . . . in-flight anomaly
IPR . . . . interim problem report
IPT . . . . igniter pressure transducer
IR . . . . infrared
I_{sp} . . . . specific impulse
IVBC . . . . integrated vehicle baseline configuration
JPS . . . . joint protection system
KSC . . . . Kennedy Space Center
LH . . . . left hand
LRU . . . . line replaceable unit
LSC . . . . linear-shaped charge
MBT . . . . mean bulk temperature
MEOP . . . . . . maximum expected operating pressure
MLP . . . . mobile launch platform
ms . . . . millisecond
MSFC . . . . Marshall Space Flight Center
NSI . . . . NASA standard initiator
NSTS . . . . National Space and Transportation System
OBR . . . . outer boot ring

ACRONYMS (cont)

OD	outside diameter
OFI	operational flight instrumentation
OPT	operational pressure transducer
PEEP	postflight engineering evaluation plan
PMBT	propellant mean bulk temperature
PR	problem report
PRCB	program requirements control board
RH	right hand
RSRM	redesigned solid rocket motor
RSRML	redesigned shuttle rocket motor lightweight
RSS	range safety system
S&A	safe and arm (device)
SCN	Specification change notice
SF	safety factor
SII	SRM ignition initiators
SRB	solid rocket booster
SRM	solid rocket motor
SSME	space shuttle main engine
STI	shuttle thermal imager
TPS	thermal protection system
USBI	United Space Boosters, Inc.
VAB	vehicle assembly building

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INTRODUCTION

Solid rocket booster (SRB) ignition command for Flight Motor Set 360L009 was given at 1:50 a.m. CST (090:059:07:50:22.000 GMT) on 28 Feb 1990 at Kennedy Space Center (KSC), Florida. This flight was the thirty-fourth space shuttle mission, designated STS-36, and the ninth redesigned solid rocket motor (RSRM) flight. The individual motor identification numbers were 360L009A left hand (LH) and 360L009B right hand (RH), indicating that the cases were both lightweights. Additional case configuration details are addressed in Volume I, Section 4.2 of this report.

Volume I of this report contains the Thiokol Flight Evaluation Working Group (FEWG) inputs submitted to United Space Boosters, Inc. (USBI) for incorporation into the shuttle prime contractors' FEWG report (Document MSFC-RPR-1581). An executive summary of the entire RSRM flight set performance and a one-to-one correlation of conclusions by objectives and contract end item (CEI) paragraphs are also included in this report. The detailed component volumes of this report and the approximate timelines from launch date to volume release are listed in Table 1-1. TWR-60065 is a flow report which starts from receipt of 360L009 hardware at KSC, documents aft booster buildup and RSRM stacking, and includes processing milestones and highlights, stacking configuration, and significant discrepancy reports (DR), problem reports (PR), etc.

The subsections of this report volume that were submitted to USBI as part of the FEWG report are so designated with the FEWG report paragraph number.

Table 1-1. Component Volume Release Schedule

Volume	Description/ Component	Interim Release	Final Release
I	Systems Overview	NA	60 working days after launch
II	Case/Seals	NA	60 days after washout of last segment at Clearfield, UT
III	Internal Insulation	60 days after last joint demate at KSC	60 days after washout of last segment at Clearfield, UT
IV	TPS/JPS/Heaters/ Systems Tunnel	NA	60 days after hydrolase is complete at KSC
V	Nozzle	NA	60 days after nozzle phenolic sectioning is complete
VI	Igniter	NA	60 days after washout of last igniter chamber at H-7, Clearfield, UT
VII	Performance/Mass Properties	NA	60 days after launch

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OBJECTIVES

The Thiokol RSRM ninth-flight objectives were intended to satisfy the requirements of CPW1-3600A as listed in parenthesis below. A one-to-one correlation of conclusions by objectives and CEI paragraphs is included in Volume I, Section 3.2 of this report.

Qualification Objectives

A. The ignition interval shall be between 202 and 262 milliseconds (ms) with a 40 ms environmental delay after ignition command to the SRM ignition initiators (SII) in the safe and arm (S&A) device up to a point at which the headend chamber pressure has built up to 563.5 psia (3.2.1.1.1.1).

B. The maximum rate of pressure buildup shall be 115.9 psi for any 10 ms interval (3.2.1.1.1.2).

C. Verify that the thrust-time performance falls within the requirements of the nominal thrust-time curve (3.2.1.1.2.1 Table 1).

D. Certify that the measured motor performance parameters, when corrected to a 60°F propellant mean bulk temperature (PMBT), fall within the nominal value, tolerance and limits for individual flight motors (3.2.1.1.2.2 Table II).

E. With a maximum PMBT difference of 1.4°F between the two RSRMs on a shuttle vehicle, the differential thrust between the two RSRMs shall not be greater than the values given in Table III at any time during the periods shown. These differentials are applicable over the PMBT range of +40 to +90°F (3.2.1.1.2.3).

F. Certify that the thrust-time curve complies with impulse requirements (3.2.1.1.2.4).

G. Certify that specified temperatures are maintained in the case-to-nozzle joint region during the countdown LCC time period (3.2.1.2.1.f).

H. The case segment mating joints shall contain a pin retention device (3.2.1.3.g).

I. Certify the performance of the igniter heater so it maintains the igniter gasket rubber seals between 64°F and 130°F (3.2.1.5.3).

J. Verify that the S&A devices perform as required using the specified power supply (3.2.1.6.1.2).

K. Verify that the operational flight instrumentation (OFI) is capable of launch readiness checkout after the ground system has been connected on the launch pad (3.2.1.6.2).

L. Certify the proper operation of the operational pressure transducer (OPT) during flight (3.2.1.6.2.1).

M. The ground environment instrumentation (GEI) shall monitor the temperature of the SRBs while on the ground at the pad. It is not required to function during flight. These instruments will be monitored on the ground through cables with liftoff breakaway connectors (3.2.1.6.2.3).

N. When exposed to the thermal environments of 3.2.7.2, the system tunnel floorplates and cables will be maintained at a temperature at or below that specified in ICD 3-44002 (3.2.1.10.1).

O. Certify the performance of the field joint heater and sensor assembly so that it maintains the case field joint at 75°F minimum. Field joints shall not exceed 130°F (3.2.1.11.a).

P. Certify that each field joint heater assembly meets all performance requirements (3.2.1.11.1.2).

Q. Demonstrate isolation of subsystem anomalies if required on ninth flight (360L009) hardware (3.2.3.3).

R. Demonstrate the RSRM capability of vertical disassembly if required (3.2.5.1).

S. The RSRM and its components will be adequately protected, by passive means, against natural environments during transportation and handling (3.2.8.c).

T. Demonstrate the remove-and-replace capability of the functional line replaceable unit (3.4.1).

Objectives by Inspection

A. Inspect all RSRM seals for performance (3.2.1.2).

B. Inspect the seals for satisfactory operation within the specified temperature range that results from natural and induced environments (3.2.1.2.1.b).

C. Inspect the factory joint insulation for accommodation to structural deflections and erosion (3.2.1.2.2.a).

D. Inspect the factory joint insulation for operation within the specified temperature range (3.2.1.2.2.b).

E. Verify that at least one virgin ply of insulation exists over the factory joint at the end of motor operation (3.2.1.2.2.d).

F. Verify that no leakage occurred through the insulation (3.2.1.2.2.e).

G. Verify that the flex bearing seals operates within the specified temperature range (3.2.1.2.3.b).

H. Verify that the flex bearing maintained a positive gas seal between its internal components (3.2.1.2.3.d).

I. Verify that the ignitions system seals operates within the specified temperature range (3.2.1.2.4.b).

J. Verify that the nozzle internal seals and exit cone field joint seals operate within the specified temperature range (3.2.1.2.5.b).

K. Inspect the risers for damage or cracks that would degrade the pressure holding capability of the case (3.2.1.3.c).

L. Inspect the flex bearing for damage due to water impact (3.2.1.4.6).

M. Verify that the environmental protection plug will withstand space shuttle main engine (SSME) shutdown, if incurred (3.2.1.4.7.b).

N. Verify the performance of the nozzle liner (3.2.1.4.13).

O. Inspect the ignition system seals for evidence of hot gas leakage (3.2.1.5.a).

P. Inspect the igniter for evidence of debris formation or damage (3.2.1.5.2).

Q. Inspect the seals for visible degradation from motor combustion gas (3.2.1.8.1.1.d).

R. Verify by inspection that the insulation met all performance requirements (3.2.1.8.1.1.e).

S. Inspect insulation material for shedding of fibrous or particulate matter (3.2.1.8.1.1.f).

T. Inspect the joint insulation for evidence of slag accumulation (3.2.1.8.1.1.g).

U. Inspect the thermal protection system (TPS) to ensure that there was no environmental damage to the RSRM components (3.2.1.8.2).

V. Inspect for thermal damage to the igniter chamber and the adapter metal parts (3.2.1.8.3).

W. Verify that the case components are reusable (3.2.1.9.a).

X. Verify that the nozzle metal parts are reusable (3.2.1.9.b).

Y. Verify through flight demonstration and a postflight inspection that the flex bearing is reusable (3.2.1.9.c).

Z. Verify that the igniter components are reusable (3.2.1.9.d).

AA. Verify by inspection that the S&A is reusable (3.2.1.9.e).

AB. Verify by inspection that the OPTs are reusable (3.2.1.9.f).

AC. Inspect the case factory joint external seal for moisture (3.2.1.12).

AD. Inspect the hardware for damage or anomalies as identified by the failure mode effects analysis (FMEA) (3.2.3).

AE. Determine the adequacy of the design safety factors, relief provisions, fracture control, and safe life and/or fail-safe characteristics (3.2.3.1).

AF. Determine the adequacy of subsystem redundancy and fail-safe requirements (3.2.3.2).

AG. Inspect the identification numbers of each reusable RSRM part and material for traceability (3.3.1.5).

AH. Verify the structural safety factor of the case-to-insulation bond (3.3.6.1.1.2.a).

AI. Verify by inspection the remaining insulation thickness of the case insulation (3.3.6.1.2.2, 3.3.6.1.2.3, 3.3.6.1.2.4, 3.3.6.1.2.6).

AJ. Verify by inspection the remaining nozzle ablative thicknesses (3.3.6.1.2.7).

AK. Verify the nozzle safety factors (3.3.6.1.2.8).

AL. Inspect metal parts for presence of stress corrosion (3.3.8.2.b).

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RESULTS SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

3.1 RESULTS SUMMARY

This section contains an executive summary of the key results from the flight data evaluation and postflight inspection. Additional information and details can be found in the referenced report sections or in the separate component volumes of this report.

3.1.1 In-Flight Anomalies

Two in-flight anomalies (IFA) relating to RSRM Flight Motor Set 360L009 were identified and are summarized below.

MSFC IFA No.	Problem Title/ Description	Corrective Action Closure
STS-36-M-1	Igniter chamber-to-forward dome boss interface surface metal pitting and igniter inner gasket retainer damage due to putty blowhole found on 360L009B (RH).	No corrective action required. A change of gasket retainer material from cadmium plated steel to stainless steel and/or an igniter joint redesign is being considered.
STS-36-M-2	Separation on inside diameter (ID) of the igniter adapter plug secondary O-ring (0.7 in. long by 0.045 in. deep).	For Flights 10 through 12, check flushness of plug head to igniter adapter with 0.003 in. shim. If shim goes under plug head, replace plug and O-ring and perform a leak check. Change planning to add witness by joints and seals Design Engineering with Quality buyoff. For long-term action, see Section 4.1.

3.1.2 Mass Properties

All solid rocket motor (SRM) weight values were well within the CEI specification limits, as has been the case on all previous RSRM motor sets. Complete mass property values are included in Volume I, Section 4.3 and Volume VII of this report.

3.1.3 Propulsion Performance (Ballistics)

3.1.3.1 Propellant Burn Rates/Specific Impulse. The delivered burn rate (at 67°F and 625 psia) for Flight Motor Set 360L009 was 0.370 ips for the LH motor, (0.002 ips higher than predicted) and 0.370 ips for the RH motor (0.002 ips higher than predicted). The reconstructed vacuum specific impulse (I_{sp}) values were 267.4 lbf-sec/lbm for the LH motor and 266.7 lbf-sec/lbm for the RH motor at 67°F, which was within 0.67 percent of the predicted value of 268.5 lbf-sec/lbm. The low specific impulse values are believed to be due to pressure measurement system data loss.

3.1.3.2 CEI Specification Values. All impulse values, time parameters, and pressure thrust levels (all corrected to 60°F) again showed excellent agreement with the motor nominal performance requirements. Actual value variations from the allowable CEI specification limits were all significantly less than the allowable 3σ variation. Thrust imbalance was also well within the specification limits for the required time periods.

Nearly all ballistic parameters were verified, with the exception of ignition interval, pressure rise rate, and ignition thrust-time imbalance. These parameters could not be addressed due to elimination of development flight instrumentation (DFI) on STS-30R (360L004) and subsequent. A complete evaluation of all ballistic parameters is included in Volume I, Section 4.4 of this report.

3.1.4 S&A Device

The S&A device safe-to-arm rotation times were all within the minimum 2-sec requirement during prelaunch functional tests and the actual launch. The S&A is discussed in Volume I, Section 4.10.4 of this report.

3.1.5 Ascent Loads and Structural Dynamics

This paragraph is reserved pending availability of DFI on future missions.

3.1.6 External TPS/Joint Heater Evaluation

Postflight assessment results stated all TPS components to be in very good to excellent condition, with typical flight heat effects and erosion. National Space and Transportation System (NSTS) debris criteria for all missing TPS was not violated.

All six field joint heaters performed adequately and as expected throughout the required operating periods. Prior to launch, a contingency field joint LCC redline was approved, which reduced the LCC from 85° to 69°F as a precaution in the event that both the primary and secondary heaters failed on a given field joint. A detailed TPS and heater evaluation is included in Volume I, Section 4.8 of this report.

3.1.7 Aero/Thermal Evaluation

3.1.7.1 On-Pad Local Environments/Thermal Model Verification. The ambient temperatures ranged from 45° to 83°F. The normal temperature range for the month of February is 54° to 67°F. Wind speeds were higher than the historical conditions. Wind direction was from the north to northeast during the LCC timeframe.

No extreme outward cooling effects from external tank (ET) cryogenic loading were noted.

3.1.7.2 LCC/Infrared Readings. No LCC thermal violations were noted. The igniter heaters were activated at L-18 hours for all six launch countdowns and deactivated at T-9 minutes for the last three launch countdowns. The igniter heaters were activated for a total time of 75 hours and 47 minutes over the six launch countdowns, which is the longest time the heaters have been operated for any flight to date. The first three countdowns were scrubbed before ET loading so the heaters were deactivated at the time of scrub. The igniter heater operation maintained the temperatures between 92° and 97°F during the LCC timeframe. The SRB aft skirt purge operation was activated at or after L-13 hours 20 minutes during the first and final three launch countdowns. The second and third launch countdowns were scrubbed before activation of the aft skirt purge. All case-to-nozzle joint and flex bearing aft end ring temperatures were between 78° and 88°F during the LCC timeframe.

Because there were essentially three full countdowns with the ET loaded, a great amount of data was obtained from the various thermal imagers. Stationary shuttle thermal imager (STI) measurements throughout the walkdowns and countdowns remained consistently 2° to 4°F below the GEI. The portable STI scanner was more erratic, ranging from about 7°F low to matching the GEI exactly. The infrared (IR) gun was even more erratic, ranging from 8°F low to matching the GEI exactly.

A complete aero/thermal evaluation is included in Volume I, Section 4.8 of this report.

3.1.8 Instrumentation

All 108 GEI measurements performed properly throughout the prelaunch phase, except for several case acreage sensors which read different from surrounding sensors (Tables 4.10-2 and 4.10-3). All GEI is disconnected by breakaway umbilicals at SRB ignition and are not operative during flight. All OPTs functioned properly during flight and successfully passed the prelaunch calibration checks. A complete discussion of GEI and all instrumentation is included in Volume I, Section 4.10 of this report.

3.1.9 Postflight Hardware Assessment

3.1.9.1 Insulation. Postflight evaluation again verified excellent insulation performance, showing that the insulation effectively contained the motor combustion gas in the two case-to-nozzle joints and six field joints. Three of the fourteen weatherseals on this flight set exhibited aft edge unbonds. No forward edge unbonds were seen on any seal. No gas paths through the case-to-nozzle joint polysulfide adhesive or any other anomalous joint conditions were identified. The internal insulation in all six of the case field joints also performed as designed, with no anomalous conditions. There were no recordable (over 0.1 in.) clevis edge separations. No evidence of hot gas penetration through any of the acreage insulation or severe erosion patterns were identified. Complete insulation performance evaluations are included in Volume I, Section 4.11.1 and Volume III of this report.

3.1.9.2 Case. The case field joint surface conditions were as expected. Field joint fretting on this flight ranged from light to heavy. All joints had some fretting. The left center and aft field joints had the worst fretting (0.008 to 0.011 in. deep); the right center field joint had a 0.009 in. deep fret. New fretting was interspersed between the old fret repairs.

Complete case evaluation results are included in Volume I, Section 4.11.2 and Volume II of this report.

3.1.9.3 Seals. All internal seals performed well, with no heat effects, erosion, or hot gas leakage evident. No motor pressure reached the field or case-to-nozzle joint seal. Evaluation of the field joints indicated that the internal seals performed as expected during flight. A raised area on the forward face outboard cushion of the primary seal at the 173-deg location was found on the LH outer gasket. Approximate dimensions were 0.005 in. in diameter by 0.002 in. high. Two areas of medium corrosion were found on the igniter through hole of the LH forward dome boss at the 285- and 324-deg locations. Complete seals performance evaluations are included in Volume I, Section 4.11.3 and Volume II of this report.

3.1.9.4 Nozzle/Thrust Vector Control Performance. Postflight evaluation indicated that both nozzles performed as expected during flight, with typical smooth and uniform erosion profiles. Complete evaluations are included in Volume I, Section 4.11.4 and Volume V of this report.

3.2 CONCLUSIONS

Listed below are the conclusions as they relate specifically to the objectives and the CEI paragraphs. Also included with the conclusion is the report section (in parenthesis) where additional information can be found.

Objective	CEI Paragraph	Conclusions
Certify that the thrust-time performance falls within the requirements of the nominal thrust-time curve.	3.2.1.1.2.1 (see nominal thrust-time curve)	Certified. The thrust-time performance was within the nominal thrust-time curve. (Figure 4.4.1.)

Objective	CEI Paragraph	Conclusions
Certify that the measured motor performance parameters, when corrected to a 60°F PMBT, fall within the nominal value, tolerance and limits for individual flight motors.	3.2.1.1.2.2 The delivered performance values for each individual motor when corrected to a 60°F PMBT shall not exceed the limits specified...	Partially Certified. All measurable motor performance values were well within the specification requirements. (Tables 4.4-2 and 4.4-3.) The ignition interval and rise rates could not be measured due to DFI elimination.
Certify that the thrust-time curve complies with impulse requirements.	3.2.1.1.2.4 Impulse Gates Time (sec) / Total Impulse (10E6lb-sec) 20 / 63.1 Minimum 60 / 172.9 -1%+3% Action Time (AT) 293.8 Minimum	Certified. The nominal thrust-time curve values are listed below. Time (sec) / Value LH / RH 20 / 65.03 / 64.91 60 / 173.50 / 173.16 AT / 295.76 / 294.93 (Table 4.4-1)
Certify that specified temperatures are maintained in the case-to-nozzle joint region.	3.2.1.2.1.f Case-to-nozzle joint O-rings shall be maintained within the temperature range as specified in ICD 2-0A002. (75°-115°F)	Certified. Temperature ranges in the case-to-nozzle joint region are listed below. RH 82°-88°F LH 78°-85°F (Table 4.8-2)
Certify that the ignition interval is between 202 and 262 ms with a 40 ms environmental delay after ignition command.	3.2.1.1.1.1 The ignition interval shall be between 202 and 262 ms with a 40 ms environmental delay after ignition command to the SII in the S&A device up to a point at which the head-end chamber pressure has built up to 563.5 psia.	Unable to Certify. Due to DFI elimination (high sample rate pressure transducer).
Certify that the pressure rise rate meets specification requirements.	3.2.1.1.1.2 The maximum rate of pressure buildup shall be 115.9 psi for any 10 ms interval.	Unable to Certify. Due to DFI elimination (high sample rate pressure transducers).

Objective	CEI Paragraph	Conclusions
Certify that the motor thrust differential meets specification requirements.	3.2.1.1.2.3 With a maximum PMBT difference of 1.4°F between the two RSRMs on a shuttle vehicle, the differential thrust between the two RSRMs shall not be greater than the values given in Table III at any time during the periods shown. These differentials are applicable over PMBT range of +40° to +90°F.	Partially Certified. Ignition transient is unavailable due to DFI elimination, but steady state, transition, and tailoff were within the imbalance limits (Table 4.4-2).
Certify the performance of the igniter heater so it maintains the igniter gasket rubber seals between 64° and 130°F.	3.2.1.5.3 The igniter heater shall maintain the igniter gasket rubber seals between 64° and 130°F.	Certified. The igniter heater maintained the igniter sensors between 91° and 96°F (RH) and 92° and 97°F (LH) during the prelaunch period. Sensor temperatures between 66° and 123°F ensure O-ring temperatures between 64° and 130°F. (Table 4.8-2)
Certify that the S&A devices perform as required using the specified power supply.	3.2.1.6.1.2 Power Supply. The S&A device shall meet all performance requirements... in accordance with ICD 3-44005.	Certified. The rotation and arming times of both S&A devices were within the required limits. (Volume I, Section 4.10).
Certify that the OFI is capable of launch readiness checkout after the ground system has been connected on the launch pad.	3.2.1.6.2 Instrumentation. The OFI shall be capable of launch readiness checkout after ground system connection on the launch pad.	Certified. The 0% and 75% calibration checks of the OFI verified launch readiness after ground system connection on the launch pad. (Volume I, Section 4.10).
Certify proper operation of the OPT during flight.	3.2.1.6.2.1 The OPT shall monitor the chamber pressure of the RSRMs over the range from 0 to 1050 ±15 psi. They shall operate in accordance with ICD 3-44005...	Certified. The OPTs properly monitored the chamber pressure and operated in accordance with ICD 3-44005. Recorded pressure data and values are discussed in Volume I, Section 4.4

Objective	CEI Paragraph	Conclusions
Certify that the systems tunnel properly: 1) attaches to the case, 2) accommodates the government-furnished equipment (GFE) and linear-shaped charge (LSC), and 3) provides OFI, GEI and heater cables.	3.2.1.10.1 When exposed to the thermal environments of 3.2.7.2, the tunnel floor-plates and tunnel cables will be maintained at a temperature at or below that specified in ICD 3-44002.	Certified. Postflight evaluation showed no evidence of heat damage to the systems tunnel or adjacent cork, cables and seams (Table 4.8.1). Proper case attachment and accommodation of the GFE, LSC, and cabling was also verified. Detailed systems tunnel evaluation in Volume IV of this report.
Certify the performance of the field joint heater and the sensor assembly so it maintains the case field joint at 75°F minimum. Field joints shall not exceed 130°F.	3.2.1.11.a The case field joint external heater and sensor assembly shall maintain the case field joint O-ring seals between 75° and 130°F at launch...	Certified. The joint heaters maintained all field joint sensors between 91° and 107°F during the prelaunch period. Sensor temperatures between 85° and 122°F ensure O-ring temperatures of between 75° and 130°F. (Table 4.8.2)
Certify that each field joint heater assembly meets all performance requirements.	3.2.1.11.1.2 Power Supply. Each field joint external heater assembly shall meet all performance requirements... as defined in ICD 3-44005.	Certified. The field joint external heaters met all the performance requirements (Volume I, Section 4.8.3)
Demonstrate isolation of subsystem anomalies if required on ninth flight (360L009) hardware.	3.2.3.3 Isolation of anomalies of time-critical functions shall be provided such that a faulty subsystem element can be deactivated without disrupting its own or other subsystems.	No subsystem anomalies of time-critical functions were detected on Flight Motor Set 360L009.

Objective	CEI Paragraph	Conclusions
Demonstrate RSRM capability of assembly/disassembly in both the vertical and horizontal positions.	3.2.5.1 The RSRM shall be capable of assembly/disassembly in both the vertical and horizontal position. The RSRM shall be capable of vertical assembly in a manner to meet the alignment criteria of USBI-10183-0022 without a requirement for optical equipment.	RSRM vertical assembly in accordance with USBI-10183-0022 was demonstrated in the vehicle assembly building (VAB) prior to pad rollout. No vertical disassembly was required. Postflight horizontal disassembly was accomplished at Hangar AF (KSC) facilities.
Demonstrate that the RSRM and its components are protected against environments during transportation and handling.	3.2.8.c The RSRM and its components.. are adequately protected, by passive means, against natural environments during transportation and handling.	Transportation criteria for the RSRM and its components was not violated during shipping (TWR-19311).
Demonstrate remove-and-replace capability to the functional line replaceable unit (LRU).	3.4.1 The maintenance concept shall be to "remove and replace" ...in a manner which will... prevent deterioration of inherent design levels of reliability and operating safety at minimum practical costs.	Both S&A gaskets on Flight Motor Set 360L009 were removed and replaced with gaskets that had been inspected to the proper criteria (72 hour minimum compression inspection).
Certify by inspection all RSRM seals performance.	3.2.1.2 Redundant, verifiable seals shall be provided for each pressure vessel leak path. Both the primary and secondary seals shall provide independent sealing capability through the entire ignition transient and motor burn without evidence of blowby or erosion.	<u>Certified</u>. No motor pressure reached any of the field or case-to-nozzle joint seals. (Volume I, Section 4.11.3)

Objective	CEI Paragraph	Conclusions
Inspect the factory joint insulation for accommodation to structural deflections and erosion.	3.2.1.2.2.a Sealing shall accommodate any structural deflections or erosion which may occur.	The factory joint insulation remained sealed and accommodated all deflection and erosion. (Volume I, Section 4.11.1)
Certify that at least one virgin ply of insulation over factory joint at end of motor operation.	3.2.1.2.2.d The insulation shall provide one or more virgin ply coverage at end of motor operation. The design shall perform the seal function throughout SRM operation.	Certified. Preliminary inspections indicate adequate factory joint insulation ply coverage. (Volume I, Section 4.11.1) Detailed insulation inspection results in Volume III of this report.
Certify that the field and case-to-nozzle joint seals, factory joint insulation, flex bearing seals, ignition system seals, and nozzle internal seals operate within the specified temperature range resulting from the natural and induced environments.	3.2.1.2.1.b Field and Case-to-Nozzle Joint Seals... 3.2.1.2.2.b Factory Joint Insulation... 3.2.1.2.3.b Flex Bearing Seals... 3.2.1.2.4.b Ignition System Seals... 3.2.1.2.5.b Nozzle Internal Seals... ...shall be capable of operating within a temperature range resulting from all natural and induced environments ...all manufacturing processes, and any motor induced environments.	Certified. All field joint and case-to-nozzle joint seals, ignition system seals, and internal nozzle seals operated within all induced environments and showed no evidence of heat effects, erosion, or blowby. (Volume I, Section 4.11.3.) Evaluation indicates no anomalies with the factory joint insulation (Volume I, Section 4.11.1), or the flex bearing internal seals. (Detailed flex bearing evaluation in Volume V of this report).
Certify that no leakage occurred through the insulation.	3.2.1.2.2.e The insulation used as a primary seal shall be adequate to preclude leaking through the insulation.	Certified. Preliminary inspections showed no evidence of leakage through the factory joint insulation. (Volume I, Section 4.11.1) Detailed postflight evaluations are completed at the H-7 (Clearfield, UT) facility. Detailed results in Volume III of this report.

Objective	CEI Paragraph	Conclusions
Verify by inspection that no gas leaks occurred between the flex bearing internal components.	3.2.1.2.3.d The flex bearing shall maintain a positive gas seal between its internal components.	Partially Verified. Preliminary inspection indicates that the flex bearing maintained positive seal within its internal components. Detailed inspection to be completed during flex bearing acceptance testing.
Inspect the risers for damage or cracks that would degrade the pressure-holding capability of the case.	3.2.1.3.c The case shall contain risers for attaching the ET/SRB aft attach ring as defined in ICD 3-44004. The risers shall be part of the pressurized section of the case and shall not degrade the integrity of the case.	No damage or adverse effects to the ET attach risers was noted during post-test inspection. Preliminary case inspection results are included in Volume I, Section 4.11.2, and final case evaluation is in Volume II of this report.
Inspect the case segment mating joints for the pin retention device.	3.2.1.3.g The case segment mating joints shall contain a pin retention device.	The pin retention device on all joints performed as designed. (Volume I, Section 4.11.2). Detailed results in Volume II of this report.
Inspect the flex bearing for damage due to water impact.	3.2.1.4.6 The nozzle assembly shall incorporate a nozzle snubbing device suitable for preventing flex bearing damage resulting from water impact and shall not adversely affect the nozzle assembly vectoring capability.	Preliminary inspections indicate no anomalous conditions to the 360L009A or 360L009B flex bearing.
Inspect the nozzle for the presence of the environmental protection plug.	3.2.1.4.7.a The nozzle assembly shall contain a covering and/or plug to protect the RSRM.... during storage after assembly.	Both nozzle assemblies contained an environmental protection plug which burst into multiple pieces upon motor ignition.

Objective	CEI Paragraph	Conclusions
Certify that the environmental protection plug will withstand SSME shutdown, if incurred.	3.2.1.4.7.b The nozzle assembly shall contain a covering and/or plug to protect the RSRM... in the event of an on-pad SSME shutdown prior to SRB ignition.	Not Required to Certify. No SSME shutdown was required during the actual launch sequence.
Certify the performance of the nozzle liner.	3.2.1.4.13 The nozzle flame front liners shall prevent the formation of: a. Pockets greater than 0.250 in. deep (as measured from the adjacent non-pocketed areas), b. Wedgeouts occurring during motor operations that result in negative liner performance margins of safety as specified in Para 3.3.6.1.2.8. c. Prefire anomalies except as allowed by TWR-16340.	Certified. No nozzle flame front liner erosion pockets greater than 0.25 in. were noted. All wedgeouts observed occurred postburn and do not effect liner performance. No prefire anomalies were found. (Volume I, Section 4.11.4)
Inspect the ignition system seals for evidence of hot gas leakage.	3.2.1.5.a The ignition system shall preclude hot gas leakage during and subsequent to motor ignition.	All ignition system seals, gaskets, and sealing surfaces showed no evidence of heat effects, erosion, or blowby. (Volume I, Section 4.11.3)
Inspect the igniter for evidence of debris formation or damage.	3.2.1.5.2 ...the igniter hardware and materials shall not form any debris...	Preliminary indications show no evidence of any igniter debris formation. Complete evaluation in Volume VI of this report.
Certify that the GEI can monitor the temperature of the SRBs while on the ground at the pad.	3.2.1.6.2.3 The GEI shall monitor the temperature of the SRBs while on the ground....	Certified. Extensive monitoring of the GEI was done during the countdown to access the SRM thermal environment and LCC. Detailed results are discussed in Volume I, Section 4.8.

Objective	CEI Paragraph	Conclusions
Inspect the seals for visible degradation from motor combustion gas.	3.2.1.8.1.1.d Insulation shall protect primary and secondary seals from visible degradation from motor combustion gas.	All motor combustion gas was contained by the insulation J-leg on the six field joints and the polysulfide adhesive on the two case-to-nozzle joints. No seals showed evidence of motor combustion gas degradation. (Volume I, Section 4.11.1)
Certify by inspection that the insulation met all performance requirements.	3.2.1.8.1.1.e The insulation shall... meet all performance requirements under worst manufacturing tolerances and geometry changes during and after assembly and throughout motor operation.	Certified. Preliminary inspection indicates that the insulation met all performance requirements. (Volume I, Section 4.11.1). Detailed inspection results are in Volume III of this report.
Inspect insulation material for shedding of fibrous or particulate matter.	3.2.1.8.1.1.f Insulation materials shall not shed fibrous or particulate matter during assembly which could prevent sealing.	No shedding of fibrous or particulate matter during assembly was detected. (Volume I, Section 4.11.1 and Volume III of this report).
Inspect the joint insulation for evidence of slag accumulation.	3.2.1.8.1.1.g The joint insulation shall withstand slag accumulation during motor operation.	No evidence of insulation damage due to slag accumulation was observed. (Volume I, Section 4.11.1 and Volume III)
Inspect the TPS to ensure that there was no environmental damage to the RSRM components.	3.2.1.8.2 TPS shall ensure that the mechanical properties of the RSRM components are not degraded when exposed to the environments...	Postflight inspection revealed excellent TPS condition with no violation of any NSTS debris criteria. No thermal degradation of any RSRM component was noted (Volume I, Section 4.8.3)

Objective	CEI Paragraph	Conclusions
Inspect for thermal damage to the igniter chamber and the adapter metal parts.	3.2.1.8.3 The igniter insulation shall provide thermal protection for the main igniter chamber and adapter metal parts to ensure that RSRM operation does not degrade their functional integrity or make them unsuitable for refurbishment.	Preliminary investigation revealed no thermal damage to the igniter due lack of insulation functionality. (Igniter details in Volume VI of this report)
Certify that the case components are reusable.	3.2.1.9.a Reusability of... Case - Cylindrical segments, stiffener segments, attach segments, forward and aft segments (domes), stiffener rings, clevis joint pins.	<u>Cannot be Completely Certified (at this time)</u>. All case component previous use history is included in Volume I, Section 4.2. No damage was noted to any cylindrical segments, attach segments, forward and aft domes, clevis joint pins, or the stiffener rings and segments on 360L009B (RH) or 360L009A (LH). Reuse criteria is not established until after refurbishment. (Detailed case component inspection results in Volume II of this report.)
Certify that the nozzle metal parts are reusable.	3.2.1.9.b Reusability of... Nozzle metal parts-boss attach bolts.	<u>Cannot be Completely Certified (at this time)</u>. All nozzle metal part previous use history is included in Volume I, Section 4.2. Preliminary observations showed no damage or corrosion to any nozzle reusable metal parts. (Volume I, Section 4.11.4) Any nozzle metal parts that are determined not to be reusable are discussed in Volume V of this report.)

Objective	CEI Paragraph	Conclusions
Certify through flight demonstration and a post-flight inspection that the flex bearing is reusable.	3.2.1.9.c Reusability of... Flex bearing system - Reinforced shims and end rings, elastomer materials.	Cannot be Completely Certified (at this time). The flex bearing previous use history is included in Volume I, Section 4.2. No apparent anomalies were observed with the 360L009A (LH) or 360L009B (RH) flex bearing. (Volume I, Section 4.11.4). Final reuse criteria cannot be determined until after flex bearing acceptance testing.
Certify that the igniter components are reusable	3.2.1.9.d Reusability of... igniter-chamber, adapter, igniter port, special bolts.	Cannot be Completely Certified (at this time). All igniter component previous use history is included in Volume I, Section 4.2. Preliminary postflight inspection revealed nothing that would adversely affect reuse of any igniter part. Detailed inspection results in Volume VI of this report.
Certify by inspection that the S&A is reusable.	3.2.1.9.e Reusability of... S&A Device	Cannot be Completely Certified (at this time). The S&A previous use history is included in Volume I, Section 4.2. Preliminary postflight inspection revealed nothing that would adversely affect reuse of any S&A part. Detailed inspection results in Volume VI of this report.

Objective	CEI Paragraph	Conclusions
Certify by inspection that the OPTs are reusable.	3.2.1.9.f Reusability of... transducers	Cannot be Completely Certified (at this time). The OPT previous-use history is included in Volume I, Section 4.2. All pressure data and preliminary postflight inspection indicate no issues that would adversely effect OPT reuse. Final OPT reuse criteria is established after refurbishment and calibration by the metrology lab.
Inspect the case factory joint external seal for moisture.	3.2.1.12 The factory joint external seal shall prevent the prelaunch intrusion of rain into the factory joints from the time of assembly of the segment until launch... The factory joint seal shall remain intact through flight and, as a goal, through recovery.	The external weather seal protected the case adequately from assembly until launch. Three of the fourteen factory joint weatherseals showed signs of aft edge unbonds. Detailed weatherseal evaluation in Volume III of this report.
Inspect the hardware for damage or anomalies as identified by the FMEAs.	3.2.3 The design shall minimize the probability of failure taking into consideration the potential failure modes identified and defined by FMEA.	No hardware damage or anomalies identified by FMEAs were found. Specific inspection results are in the individual component volumes of this report.

Objective	CEI Paragraph	Conclusions
Determine the adequacy of the design safety factors, relief provisions, fracture control, and safe life and/or fail-safe characteristics.	3.2.3.1 The primary structure, thermal protection, and pressure vessel sub-systems shall be designed to preclude failure by use of adequate design safety factors, relief provisions, fracture control, and safe life and/or fail-safe characteristics.	Postflight inspections verified adequate design safety factors, relief provisions, fracture control, and safe life and/or fail-safe characteristics for the primary structure, thermal protection, and pressure vessel subsystems as documented in this volume and the component volumes of this report.
Determine the adequacy of subsystem redundancy and fail-safe requirements.	3.2.3.2 The redundancy requirements for sub-systems... shall be established on an individual subsystem basis, but shall not be less than fail-safe...	No primary subsystem failure was noted, thus subsystem redundancy and fail-safe requirements were not determined.
Inspect the identification numbers of each reusable RSRM part and material for traceability.	3.3.1.5 Traceability shall be provided by assigning a traceability identification to each RSRM part and material and providing a means of correlating each to its historical records...	Inspection numbers for traceability of each RSRM part and material is provided, and are maintained in the Automatic Data Collection And Retrieval (ADCAR) computer system. The past history of all RSRM parts used is included in Volume I, Section 4.2.
Verify the structural safety factor (SF) of the case-to-insulation bond.	3.3.6.1.1.2.a The structural SF for the case-to- insulation bonds shall be 2.0 minimum during the life of the RSRM.	Verification of a 2.0 SF cannot be done by inspection, however, flight performance verified a SF of at least 1. Case-to-insulation bond and adhesive bond SF of 2.0 are verified by analysis, documented in TWR-16961.

Objective	CEI Paragraph	Conclusions
Verify by inspection the remaining insulation thickness of the case insulation.	3.3.6.1.2.2 The case insulation shall have a minimum design SF of 1.5, assuming normal motor operation, and 1.2, assuming loss of a castable inhibitor.	Preliminary insulation thickness measurements indicate adequate thermal SFs near the igniter boss (LH-2.15,RH-2.21). A final evaluation will be made after the internal insulation thicknesses are measured at the Clearfield, UT, H-7 facility. Results and verification of SFs are included in Volume III of this report.
(Objective continued)	3.3.6.1.2.3 Case insulation adjacent to metal part field joints, case-to-nozzle joints, and extending over factory joints shall have a minimum SF of 2.0.	See above statement.
(Objective continued)	3.3.6.1.2.4 Case insulation in sandwich construction regions (aft dome and center segment aft end) shall have a minimum SF of 1.5.	See above statement.
(Objective continued)	3.3.6.1.2.6 Insulation performance shall be calculated using actual pre- and postmotor operation insulation thickness measurements.	Standard measurement techniques were used for final evaluation, as discussed in Volume III of this report.
Verify by inspection the remaining nozzle ablative thicknesses.	3.3.6.1.2.7 The minimum design safety factors for the nozzle assembly primary ablative materials shall be as listed below... (Values not included here, as detailed results are not available at this writing.)	Preliminary inspections indicate nozzle ablative thicknesses were within design SFs. (Volume I, Section 4.11.4). Detailed results are included in Volume V of this report.

Objective	CEI Paragraph	Conclusions
Verify the nozzle SFs.	3.3.6.1.2.8 The nozzle performance margins of safety shall be zero or greater...	Verification of SFs cannot be done by inspection. Nozzle margins of safety will be discussed in Volume V of this report.
Inspect metal parts for presence of stress corrosion.	3.3.8.2.b The criteria for material selection in the design to prevent stress corrosion failure of fabricated components shall be in accordance with MSFC-SPEC-522 and SE-019-094-2H.	Inspection of metal parts for the presence of stress corrosion cannot be done visually but will be accomplished during refurbishment. Any stress corrosion found will be reported in Volume II of this report.

3.3 RECOMMENDATIONS

Following is a summary of the recommendations made concerning Motor Flight Set 360L009. Additional background information can be found in the referenced sections.

3.3.1 Aero/Thermal Recommendations

(Additional information included in Volume I, Section 4.8.4)

3.3.1.1 Aft Skirt Purge Operation. During the early stages of the STS-36 purge operation, up to a 5°F circumferential temperature differential existed between the case-to-nozzle joint sensors and between the aft end ring sensors. This occurred under high flow and temperature conditions. It is recommended that a GEI sensor be placed in the inlet of the aft skirt.

3.3.1.2 GEI Accuracy. Gage range has been reduced on all joint heater sensors resulting in better data resolution. It is recommended that the data collection accuracy of all GEI be increased by reducing the gage range and increasing the digital word length. The real fidelity of the KSC ground support equipment (GSE) could then be quantified, and conceivably replaced, if determined to be inadequate.

3.3.1.3 IR Measurements. STI data continues to be much more reliable than IR gun measurements. Comparisons with GEI are within acceptable margins for STI data, but are questionable and unpredictable for IR gun data. Future efforts should be made in specifying locations for additional stationary STI cameras to assist in the eventual replacement of the outboard GEI (inboard GEI will need to be maintained since the STI cannot reach these blind regions.

Case Recommendations

3.3.2 Handling Ring/Field Joint Fretting

A problem has been observed in almost all RSRM flight sets following shipment to KSC. Fretted surfaces on the field joint tang outer diameter of the center and forward segments have occurred. The degradation which occurs to the hardware justifies immediate attention. At this time, various approaches are being investigated to eliminate metal-to-metal contact between the handling rings and tang outer diameter. Testing is currently underway to investigate grease additives in addition to special coatings that will eliminate fretting. It is recommended that implementation occur as soon as the proper fix is determined.

4

FLIGHT EVALUATION RESULTS AND DISCUSSION

4.1 RSRM IN-FLIGHT ANOMALIES (FEWG REPORT PARA 2.1.2)

Two IFAs pertaining to Flight Motor Set 360L009 were identified. The summary sheets follow. The IFA description, discussion, conclusion, corrective actions, and closeout signature of the Level II Program Requirements Control Board (PRCB) chairman are included. No IFA was considered to be a flight constraint.

4.2 RSRM CONFIGURATION SUMMARY (FEWG REPORT PARA 2.1.3.2)

4.2.1 SRM Reuse Hardware

The case segment reuse history for Flight Motors 360L009A and 360L009B are shown in Figures 4.2-1 and 4.2-2, respectively. Figures 4.2-3 through 4.2-6 show the left and right igniter and nozzle part reuse, respectively. Nozzle snubber segments were new. Stiffener ring reuse is shown in Figures 4.2-7 through 4.2-10.

4.2.2 Approved RSRM Changes and Hardware Changeouts

There were four Class I hardware changes:

ECP SRM 1907 – Insulation thickness increase on stiffener stub tip
ECP SRM 1998 – Igniter gasket inspection
ECP SRM 2297 – Leak check and vent port configuration modifications
ECP SRM 2303 – Lubricant spray formulation change

There was one critical process change

OCRs 159009 – Igniter installation, putty application – First-time implementation of change in shop planning at Thiokol

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PRCBD S044816P		PRCB DATE 03/30/90

CHANGE TITLE
360L009B IGNITER CHAMBER/FORWARD DOME BOSS INTERFACE SURFACE METAL PITTING AND IGNITER GASKET RETAINER DAMAGE (IFA STS-36-M-1)

CHANGE PROPOSAL(S) NO. AND SOURCE	DOCUMENTS AFFECTED (NO.,TITLE,PARA)
STS-36 ANOMALY TRACKING LIST FLIGHT PR. NO. STS-36-M-1	

INITIATED BY: MSFC-EP73/E.CARRASQUILLO	SUBMITTED BY: MSFC-SA51/R. MITCHELL

LEVEL II BASELINE CHANGE DIRECTION: OPR: WA MBE/LS
BOARD: DAILY

PRCBD S044816P IS ISSUED TO AUTHORIZE THE CLOSEOUT OF STS-36 ANOMALY NUMBER STS-36-M-1 PER THE ATTACHED PAGE(S).

LEVEL II IMPACTS AUTHORIZED BY THIS DIRECTION: --WEIGHT: NONE, --SCHEDULE: NONE, --COST: NONE.

EFFECTIVITY:NON FLT SPECIFIC AND STS-36

AUTHORIZATION:

L H Williams ______ 03/30/90

for CHAIRMAN, LEVEL II PRCB DATE

BARS RPT 8101 BARS NSTS FORM 4003

PCIN 044816	NATIONAL SPACE TRANSPORTATION SYSTEM DOCUMENT CONTINUATION SHEET	PAGE 2 OF 2
PRCBD S044816P		OFFICE
DOCUMENT PRCBD S044816P		DATE 03/30/90

ACTION:
MSFC-SRM (1-1) REVIEW DESIGN CHANGE TO REMOVE CADMIUM PLATING FROM THE GASK-O-SEAL. REPORT RESULTS TO PRCB 05/03/90.

ACTION DUE: 05/03/90
(NEED DATE)
CLASSIFICATION: OTHER
EFFECTIVITY: NON FLT SPECIFIC

ATTACHMENT
ARCAD S044816P
Pg. 1 OF 2

FLIGHT PROBLEM REPORT

No. STS-36-M-1

Statement of Problem:
360L009B igniter chamber/forward dome boss interface surface metal pitting and igniter inner gasket retainer damage.

Discussion:
A blowhole was found in the 360L009B igniter outer joint at 175 degrees that measured 0.3 inches circumferentially at the igniter adapter and widened to 2.5 inches circumferentially at about 4 inches below the adapter. A small area of pitting was found on the I.D. of the forward dome boss about 1-3/8 inches below the forward surface of the forward dome boss in line with the putty blowhole. The dome pitting had a maximum depth of 0.002 inches. The O.D. of the igniter chamber had pitting in the same location. The pitting depth was less than 0.001 inches. The igniter inner gasket retainer cadmium plating was also damaged at 175 degrees. The cadmium plating was missing over an area of 1.5 inches circumferentially by 0.15 inches radially.

Blowholes in the outer igniter joint putty have been observed on 13 of 18 RSRM flight motors. RSRM blowhole exit widths have ranged from 0.16 to 0.69 inches. A 0.012 inch blowhole exit width was observed on MJES 3B. A 2-D thermal analysis has been performed on the 360L009B configuration and on a "worst case" (0.10 inch exit hole) configuration.

Conclusions:
A 10x magnification inspection revealed morphology characteristics of pits (i.e. sharp edges). Erosion would have resulted in smooth edges because of the wash effect and the direction of flow on the eroded material. Hence it is concluded that the metal was not removed by erosion. The dome and igniter chamber pitting is not on sealing surfaces and is repairable per standard repair criteria. The corrosion of the dome boss and igniter chamber was caused by the hot combustion gases which contain chlorides, and was augmented by sea water exposure.

Similar cadmium plating damage on igniter inner gasket retainers has been observed on STS-26A (360L001), STS-27B (360L002), and STS-28B (360H005). A laboratory analysis of the residue on the gasket metal retainer from STS-36 revealed the presence of powdery cadmium chloride on the gasket retainer, which shows that corrosion was the mechanism that removed the cadmium and that the cadmium did not melt. The cadmium corrosion was caused by the hot combustion gases which contain chlorides. The STS-36B gasket was sectioned and hardness tests showed that the hardness of the gasket retainer (4130 steel) was unaffected. The cadmium melting point is 610° F. Since the cadmium plating did not melt, and the steel microstructure was unaffected (no cadmium attack or penetration), it is estimated that the surface of the hardware experienced a temperature between 450° F and 550° F.

The results of the 2-D thermal analysis show that even in a worst case condition the elastomer seal temperature on the igniter gaskets will not exceed 450° F. These seal temperatures cause no concern for seal performance (temperatures up to 800° F are acceptable).

ATTACHMENT
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The analysis predicts that, in the worst case, the cadmium plating will experience a temperature of 1050° F. This temperature will cause cadmium to melt, therefore the potential for melted cadmium causing D6AC steel embrittlement concern was investigated. The forward dome and the igniter chamber are both made of D6AC steel.

The chlorides (HCL) in the combustion gases combine with cadmium to form $CdCl_2$. All the cadmium in contact with hot combustion gases will convert to $CdCl_2$, hence no melted cadmium will be available to come in contact with the forward dome or the igniter chamber surfaces. Higher stresses are present in the forward dome, therefore the rest of the discussion will address the forward dome. In a remote case, should cadmium melt and come in contact with the forward dome surface, thermal analysis has shown that temperatures high enough to keep cadmium in a liquid state will last for 4 seconds maximum (after which the cadmium will solidify). This time of exposure of melted cadmium to the D6AC steel of the forward dome is too short for any embrittlement. It is concluded that the possibility of embrittlement of the forward dome by any melted cadmium (from the gasket retainer) is negligible.

Corrective Action:
No corrective action required for STS-31. An investigation is being conducted to consider a change of gasket retainer material from cadmium plated steel to stainless steel, and/or an igniter joint redesign.

Effects on Subsequent Missions:
Blowholes with resulting pitting and cadmium damage could occur on subsequent flights. This damage will not affect the joint performance and will have no impact on flight operation or flight safety.

Approved: Royce E. Mitchell 3/29/90
SRM Project Manager Date

Personnel Assigned:

THIOKOL: B. Russell/D. Fulleyn MSFC: E. Carrasquillo

Resolution:
The SRM Project recommends Level II closure of this IFA. Future failure analysis/recurrence will be tracked via Significant Problem Report (SPR) # DR4-5/191 in the MSFC PRACA system.

ORIGINAL PAGE IS OF POOR QUALITY

PCIN 044816	NSTS PROGRAM REQUIREMENTS CONTROL BOARD DIRECTIVE - LEVEL II	PAGE 1 OF 1
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CHANGE TITLE
360L009A SEPARATION ON I.D. OF THE IGNITER PRESSURE TRANSDUCER (IPT) PLUG SECONDARY O-RING (IFA STS-36-M-2)

CHANGE PROPOSAL(S) NO. AND SOURCE	DOCUMENTS AFFECTED (NO., TITLE, PARA)
STS-36 ANOMALY TRACKING LIST FLIGHT PR. NO. STS-36-M-2	

INITIATED BY: MSFC-EP73/E.CARRASQUILLO	SUBMITTED BY: MSFC-SA51/R. MITCHELL

LEVEL II BASELINE CHANGE DIRECTION   OPR: WA   MBE/LS
BOARD: DAILY

PRCBD S044816N IS ISSUED TO AUTHORIZE THE CLOSEOUT OF STS-36 ANOMALY NUMBER STS-36-M-2 PER THE ATTACHED PAGE(S). THIS DIRECTIVE LEVIES NO FORMAL PROGRAM ACTION.

LEVEL II IMPACTS AUTHORIZED BY THIS DIRECTION: --WEIGHT: NONE, --SCHEDULE: NONE, --COST: NONE.

EFFECTIVITY: STS-36

AUTHORIZATION:

David S. Simmons   03/30/90

CHAIRMAN, LEVEL II PRCB   DATE

BARS RPT 8101   BARS NSTS FORM 4003

ATTACHMENT
PRCBD S044416N
Pg 1 OF 2

FLIGHT PROBLEM REPORT

No. STS-36-M-2

Statement of Problem:
360L009A separation on I.D. of the igniter pressure transducer (IPT) plug secondary O-ring.

Discussion:
A separation was found on the I.D. of the dual seal plug secondary O-ring, (P/N 1U50228-22, ECL0032) used on the igniter adapter of 360L009A. The disassembly team reported the dimensions to be approximately half way around the I.D. circumference and approximately 0.060 inch deep. The separation was later evaluated at Thiokol and found to be 0.7 inch long by 0.045 inch deep. See attached figure. The dual seal plug groove was described as having excessive grease in the secondary groove.

Conclusions:
Testing with similar conditions found in 360L009A indicated that the grease overfilling the groove forced the O-ring between the dove tail of the IPT plug and the igniter adapter. The extruded O-ring was cut by the dove tail as the plug was tighten into the igniter adapter. This cut duplicated the damage found on the flight 9 IPT plug O-ring. Testing of the O-ring and plug from 360L009A verified that the O-ring separation damage still sealed at igniter MEOP (2159 psi) for the full time duration of motor firing.

Corrective Action:
Short Term Action:

1. For flights 10 through 12, check flushness of plug head to igniter adapter with 0.003 inch shim at the center of each flat area on the plug. If shim goes under plug head, replace the plug and O-rings and perform leak check with vacuum bell.
2. Change planning to add witness by Joints and Seals Design Engineering with Quality buy-off for grease application to O-ring and dual seal plug, installation of O-ring into plug groove and installation of plug into igniter adapter. Starting with flight 13 and continuing until the procedure is understood and is proceeding correctly with modified planning.

Long Term Action:

1. Change planning to add Quality buy-off to insure that a thin film of grease (wet look with no clumps or excessive grease) is applied to the O-ring.
2. Change planning to add a thin coat of grease to the secondary groove and then wipe clean with a lint free cloth just prior to installing the O-ring into the groove, also add Quality buy-off in log to verify grease application.
3. Change planning to add a thin coat of grease to the spot face on the igniter adapter, also add Quality buy-off in log to verify grease application.
4. Change planning to check for flushness of plug head to igniter adapter using 0.003 inch shim at the center of each flat area on the plug. Replace plug and O-rings if shim goes under plug head.
5. Take similar actions for dove tail grooves on igniter OPTs and special bolt planning logs.

ATTACHMENT
PRCBD S044816N
Pg. 2 OF 2

Effects on Subsequent Missions:
Flights 10 through 12 could have similar separations on the I.D. of the O-ring. These separations are not on the sealing foot print and will not effect sealability. This condition has no impact on flight operation or flight safety.

KW
Approved: Royce E. Mitchell 3/29/90
RSRM Project Manager Date

Personnel Assigned:

THIOKOL: B. Russell/G. Nelson MSFC: E. Carrasquillo

Resolution:

The RSRM Project recommends Level II closure of this IFA. Future failure analysis/recurrence will be tracked via Significant Problem Report (SPR) # DR4-5/193 in the MSFC PRACA system.

ORIGINAL PAGE IS
OF POOR QUALITY

Component	S/N		Previous Use	360L009 Total Pressurizations	Inventory Leader Total Pressurizations
Forward Dome P/N 1U51473-04	S/N 0000049		New	3	13
Cylinder P/N 1U50131-13	S/N 0000080R4		STS-2B, STS-9B, SRM-21B, RSRM-1B	12	17
Capture Cylinder, Standard Weight P/N 1U52983-02	S/N 0000019		New	3	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000030R3		STS-8A, SRM-21A, RSRM-1A	8	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000018R1	fretting	RSRM-1A	5	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000120R1	fretting	RSRM-1A	7	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000023R1	fretting	RSRM-2A	5	7
Attach, Lightweight P/N 1U50716-08	S/N 0000021R2	fretting	DM-7, RSRM-2A	7	20
Stiffener, Lightweight P/N 1U50715-05	S/N 0000051R1		RSRM-2A	5	11
Stiffener, Lightweight P/N 1U50715-05	S/N 0000053R1		RSRM-2A	7	11
Aft Dome P/N 1U50129-11	S/N 0000031R2		SRM-21B, RSRM-2A	8	18

Denotes inventory leader status

Conclusion: There are no inventory leader components in this assembly. Fretting has occurred where indicated; all frets on sealing surfaces have been repaired and all raised metal has been removed

Figure 4.2-1. Case Segment Reuse History (LH) 360L009A

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Component	S/N	Previous Use	360L009 Total Pressurizations	Inventory Leader Total Pressurizations
Forward Dome P/N 1U51473-04	S/N 0000048	New	5	13
Cylinder P/N 1U50131-13	S/N 0000037R4	GTM-3, STS-3A, SRM-10B, SRM-20A	10	17
Capture Cylinder, Standard Weight P/N 1U52983-02	S/N 0000008R1	RSRM-2A	5	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000098R2	SRM-22A, QM-7	5	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000017R1 (fretting)	RSRM-1B	5	7
Cylinder, Lightweight P/N 1U50717-05	S/N 0000119R1 (fretting)	RSRM-1B	7	13
Capture Cylinder, Lightweight P/N 1U52982-03	S/N 0000012R1	RSRM-1B	5	7
Attach, Lightweight P/N 1U50716-08	S/N 0000016R2	SRM-20B, TEM-1	5	20
Stiffener, Lightweight P/N 1U50715-05	S/N 0000040R3	SRM-24B, QM-6, QM-8	$\boxed{11}$	11
Stiffener, Lightweight P/N 1U50715-05	S/N 0000038R3	SRSM-23B, DM-9, RSRM-2B	8	11
Aft Dome P/N 1U50129-11	S/N 0000051	New	3	18

Denotes inventory leader status

Conclusion: There is one inventory leader component in this assembly. Fretting has occurred where indicated; all frets on sealing surfaces have been repaired and all raised metal has been removed

Figure 4.2-2. Case Segment Reuse History (RH) 360L009B

A027027a

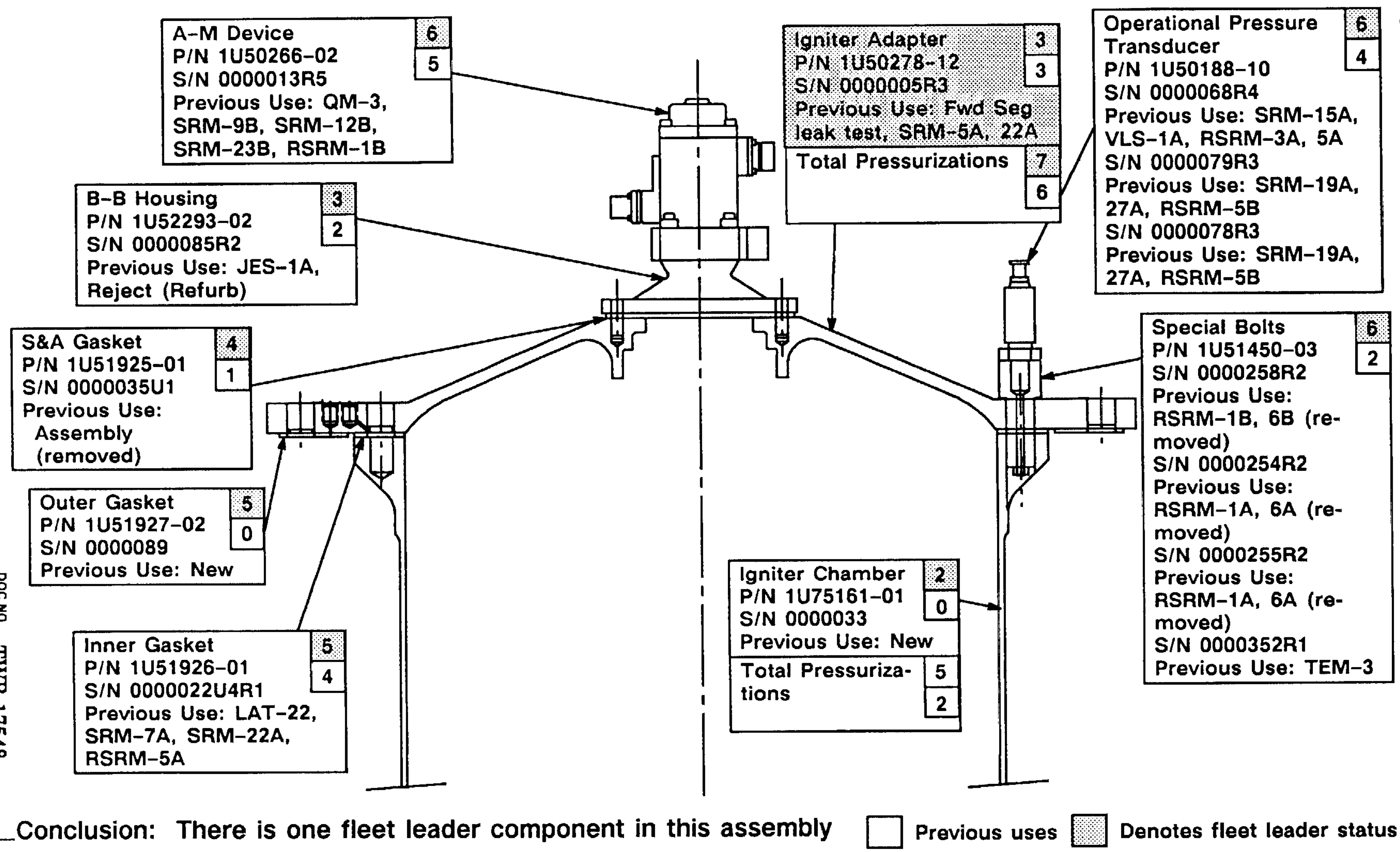


Figure 4.2-3. Case Segment Reuse History (LH) 360L009A Igniter

A027032a

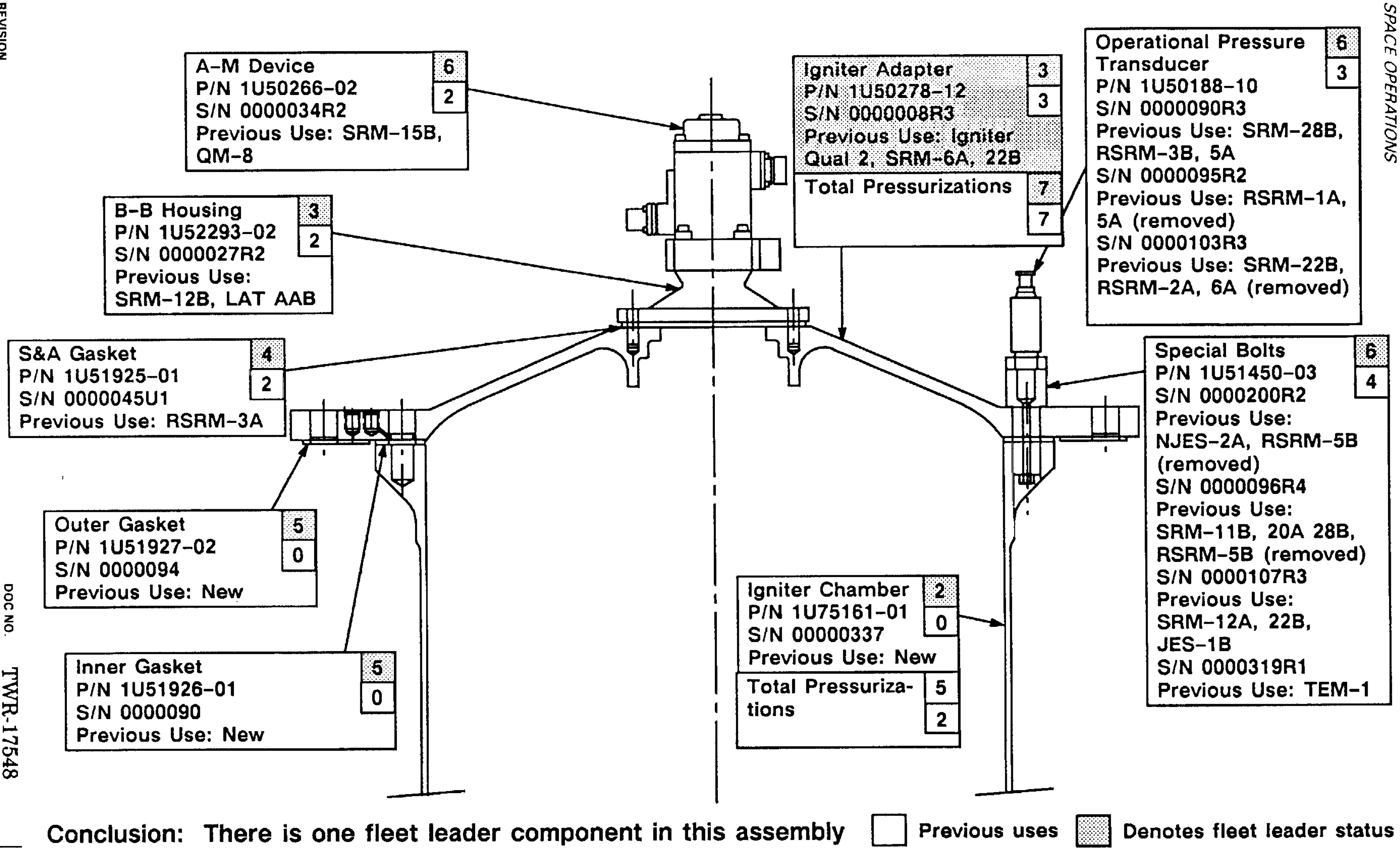
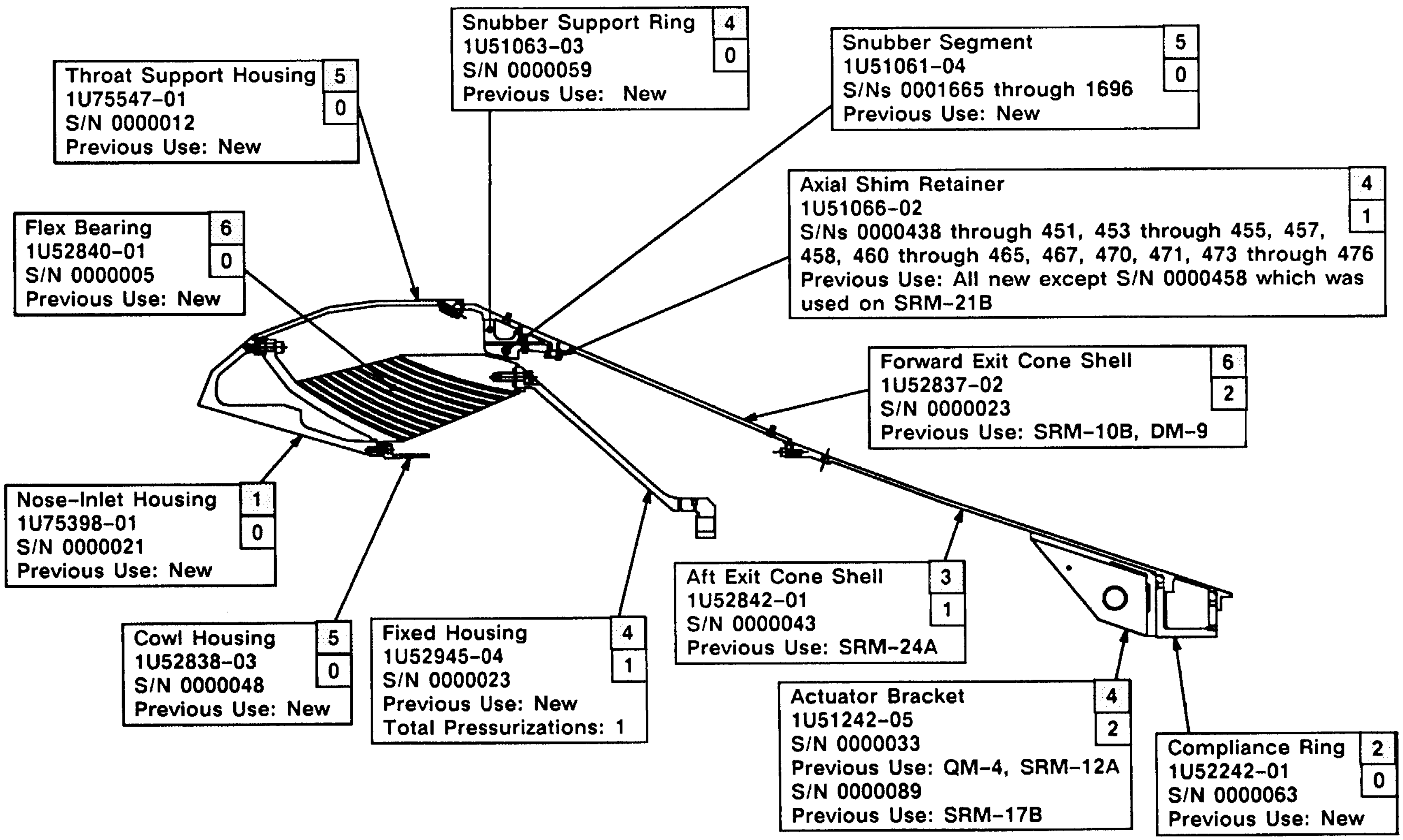


Figure 4.2-4. Case Segment Reuse History (RH) 360L009B Igniter

A027033a



Conclusion: There are no fleet leader components in this assembly

Previous uses — Denotes inventory leader status

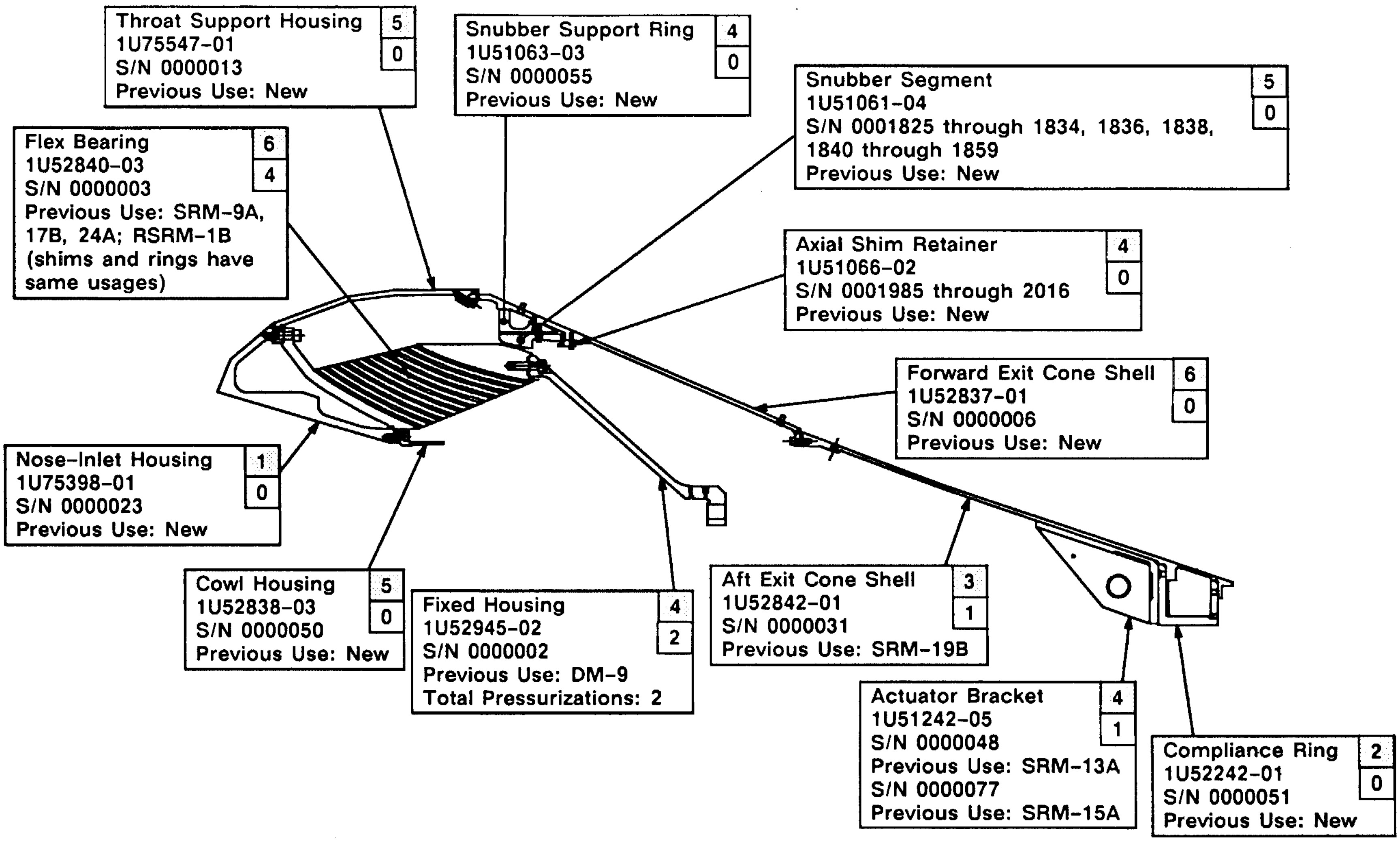
Figure 4.2-5. Case Segment Reuse History (LH) 360L009A Nozzle

A027034a

Part No.	Serial No.	Previous Use	Inventory
Leader			
Flex Bearing, Aft End Ring			
1U52833-01	0000003	New	6
Flex Bearing, Forward End Ring			
1U52834-01	0000005	New	6
Flex Bearing, Shims			
1U50097-01	0000012	SRM-5B, 12A	6
1U50097-02	0000056	New	6
1U50097-03	0000042	New	6
1U50097-04	0000054	New	6
1U50097-05	0000012	SRM-5B, 12A	6
1U50097-06	0000033	New	6
1U50097-07	0000035	New	6
1U50097-08	0000044	New	6
1U50097-09	0000012	SRM-5B, 12A	6
1U50097-10	0000012	SRM-5B, 12A	6

Figure 4.2-5. Case Segment Reuse History (LH) 360L009A Nozzle (cont)

A027035a



Conclusion: There are no fleet leader components in this assembly

Previous uses   Denotes inventory leader status

Figure 4.2-6. Case Segment Reuse History (RH) 360L009B Nozzle

A027036a

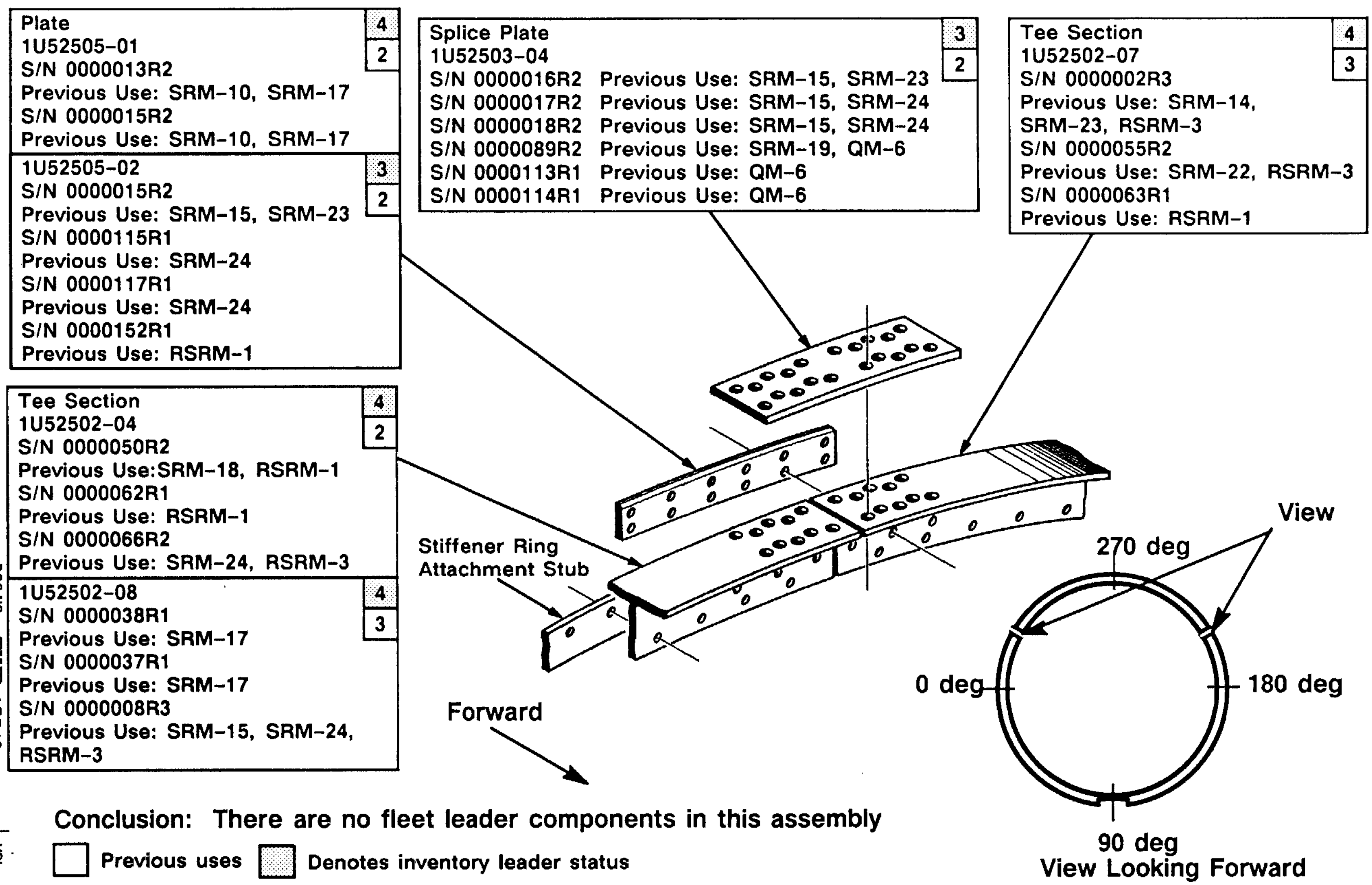
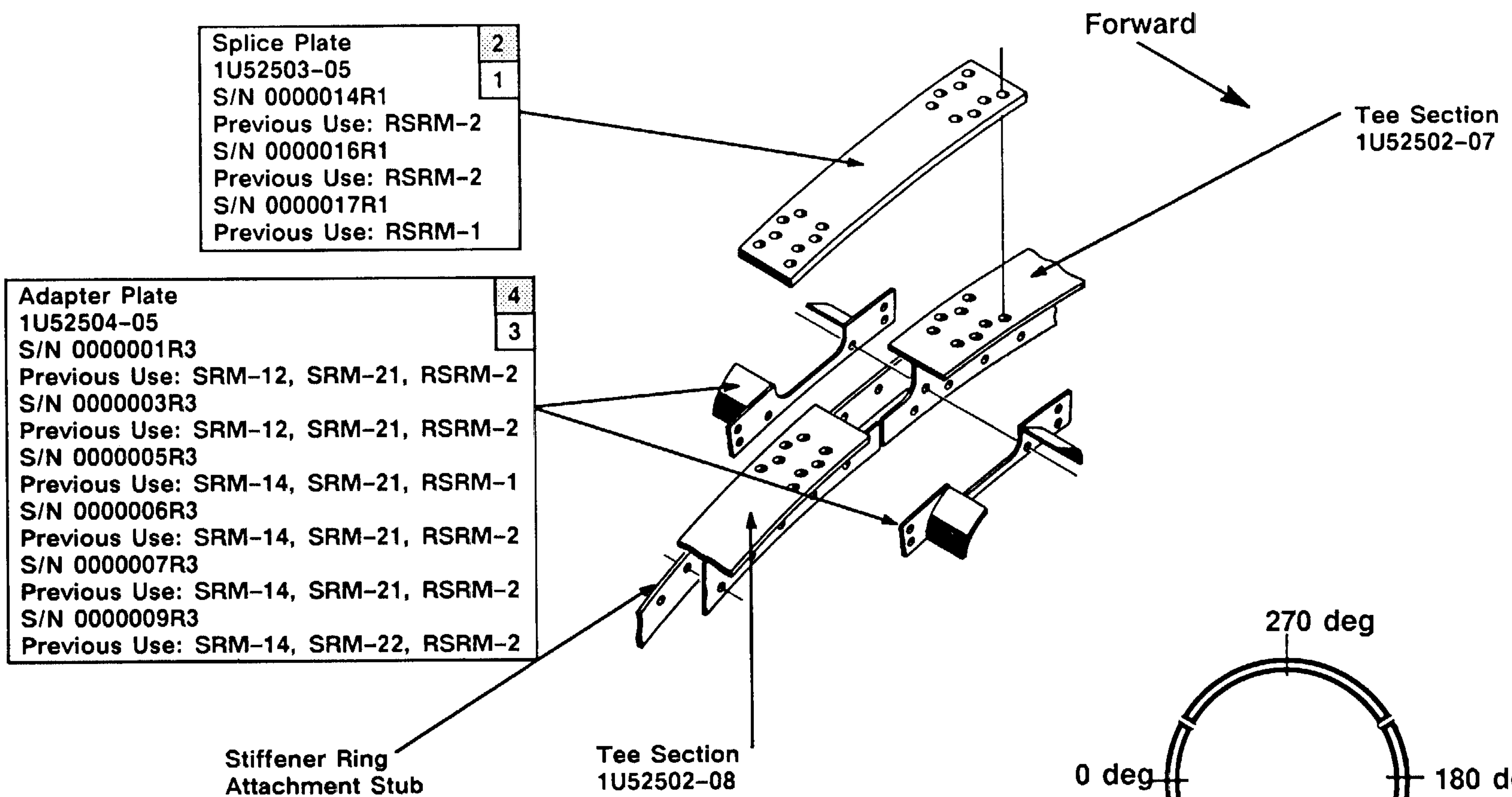
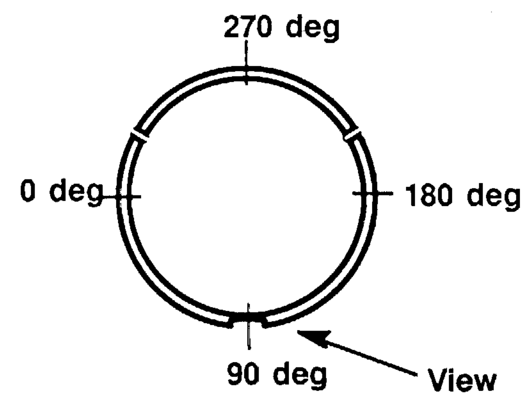


Figure 4.2-7. Case Segment Reuse History (LH) 360L009A Stiffener Rings at Normal Joints

A027028a





Conclusion: There are no fleet leader components in this assembly

☐ Previous uses

▩ Denotes inventory leader status

Figure 4.2-8. Case Segment Reuse History (LH) 360L009A Stiffener Rings at Systems Tunnel Joint

A027029a

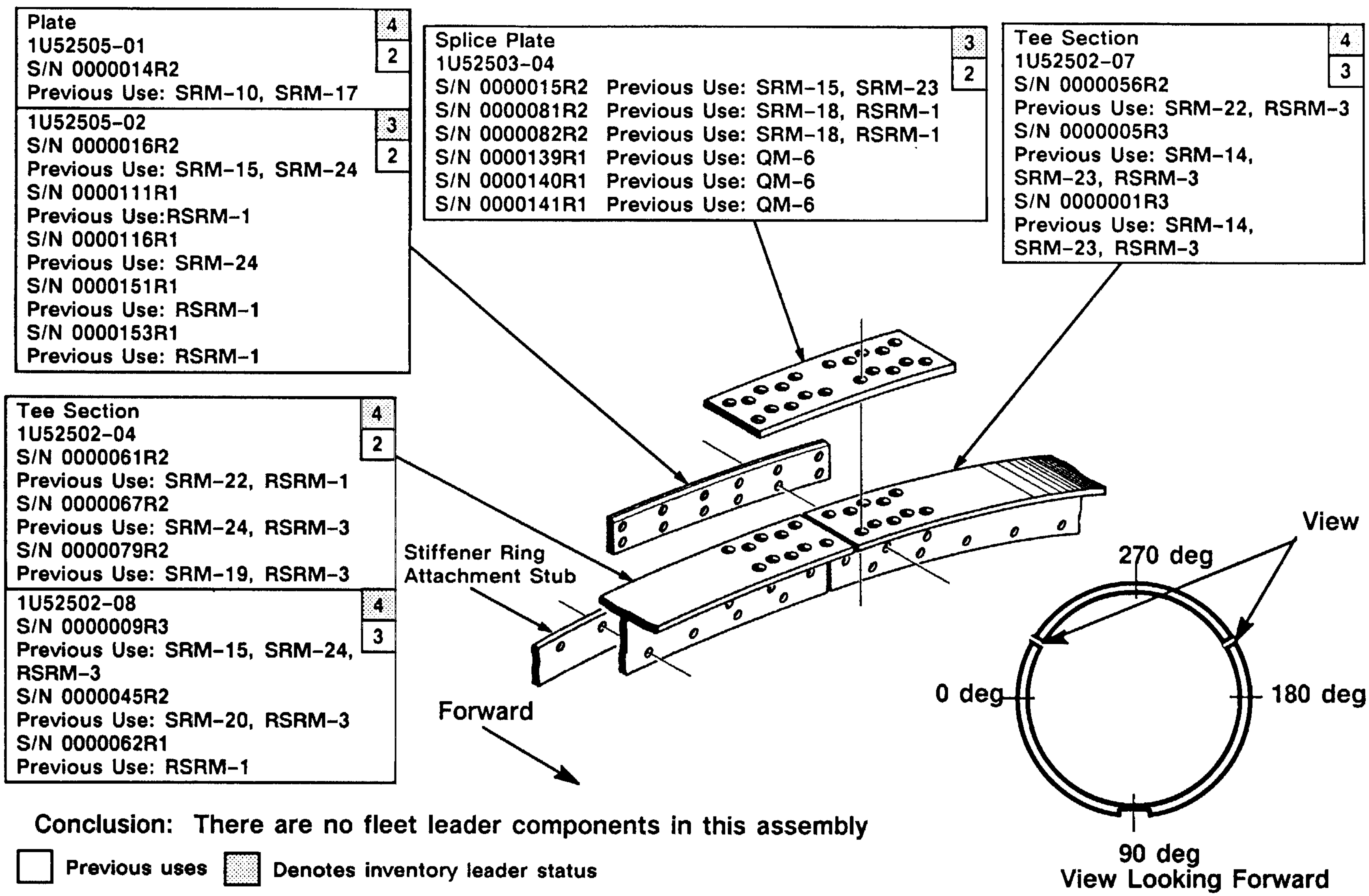
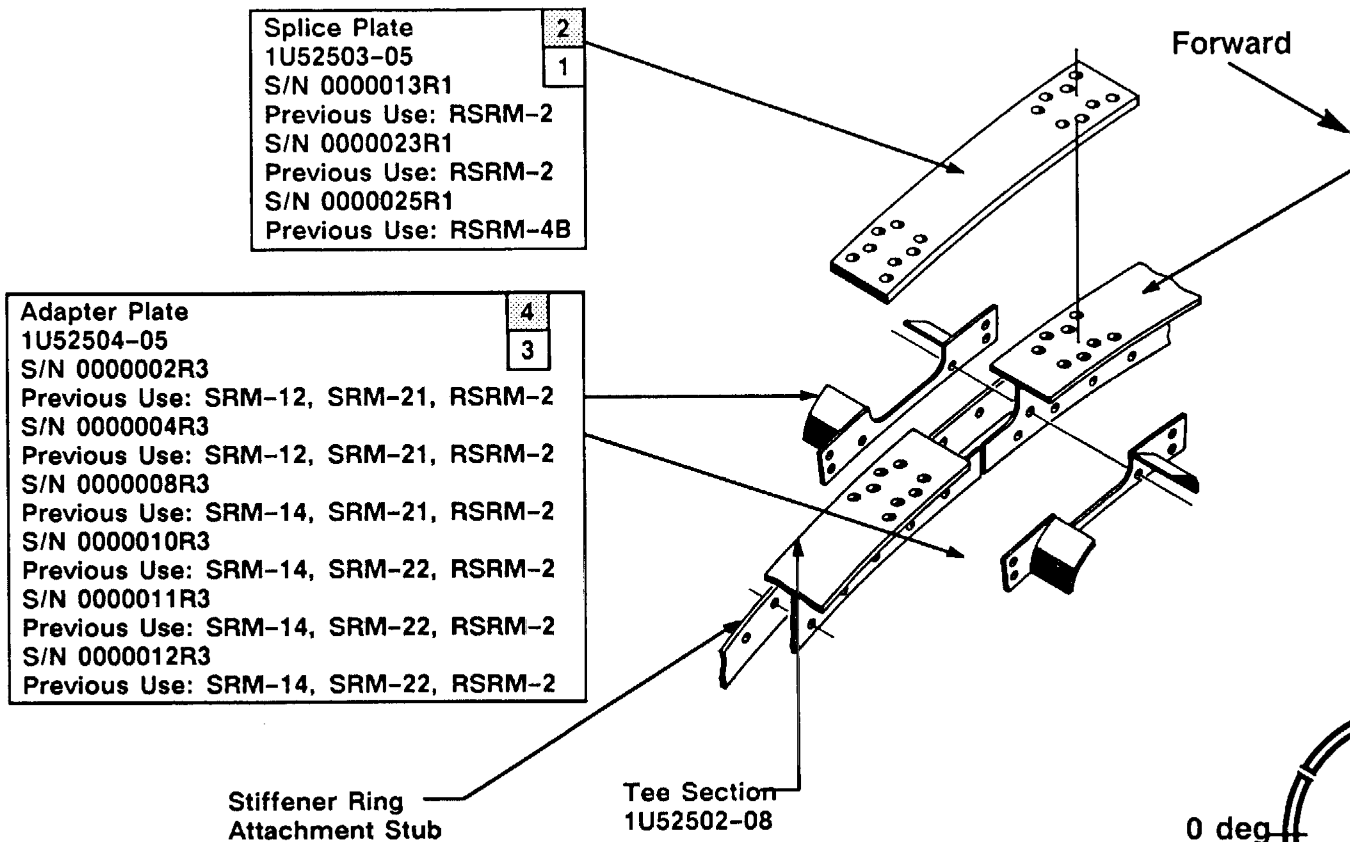
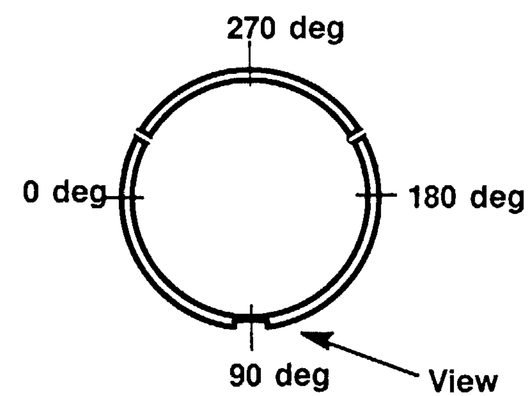


Figure 4.2-9. Case Segment Reuse HIstory (RH) 360L009B Stiffener Rings at Normal Joints

A027030a





Conclusion: There are no fleet leader components in this assembly

- Previous uses
- Denotes inventory leader status

Figure 4.2-10. Case Segment Reuse History (RH) 360L009B Stiffener Rings at Systems Tunnel Joint

A027031a

4.3 SRB MASS PROPERTIES (FEWG REPORT PARA 2.2.0)

4.3.1 Sequential Mass Properties

Tables 4.3-1 and 4.3-2 provide 360L009 (STS-36) LH and RH reconstructed sequential mass properties, respectively. Those mass properties sequential times reported after separation reflect delta times from actual separation.

4.3.2 Predicted Data Versus Postflight Reconstructed Data

Table 4.3-3 compares the LH lightweight redesigned shuttle rocket motor (RSRML) predicted sequential weight and center of gravity (cg) data with the postflight reconstructed data. Table 4.3-4 compares the RH RSRML predicted sequential weight and cg data with the postflight reconstructed data. Actual 360L009 (STS-36) mass properties may be obtained from Mass Properties History Logs. Some of the mass properties data used has been taken from average actual data presented in the Mass Properties Quarterly Status Report. Postflight reconstructed data reflects ballistics mass flow data from the 12.5 sample per second measured pressure traces and a predicted slag weight of 2,000 lb.

4.3.3 CEI Specification Requirements

Tables 4.3-5 and 4.3-6 present CEI Specification requirements, predicted, and actual weight comparisons. Mass properties data for both RSRMs complies with the CEI Specification requirements (CPW1-3600A, Addendum G, Part I).

4.4 RSRM PROPULSION PERFORMANCE (FEWG REPORT PARA 2.3.0)

4.4.1 High-Performance Motor (HPM) RSRM Performance Comparisons

The reconstructed thrust-time traces of Flight Motor Set 360L009 (STS-36) at standard conditions were averaged with the HPM/RSRM population and compared to the CEI Specification limits. The results are shown in Figure 4.4-1.

4.4.2 SRM Propulsion Performance Comparisons

An investigation team has been formed to look into the apparent low I_{sp} on both motors. The team is comprised of members from NASA, Thiokol, and Rockwell. The findings of the team indicated:

Table 4.3-1. Sequential Mass Properties for 360L009A (LH)

Event/Time	Weight (lb)	Center of Gravity			Moment of Inertia		
		Longitude	Latitude	Vertical	Pitch	Roll	Yaw
Prelaunch/0.00	1,255,293.3	1171.170	0.059	0.006	42408.326	878.960	42409.203
Lift-Off/0.23	1,254,599.0	1171.302	0.059	0.006	42365.194	877.640	42366.071
Intermediate Burn/20.00	1,012,815.9	1208.237	0.074	0.008	30670.635	760.451	30671.510
Intermediate Burn/40.00	791,360.4	1231.692	0.094	0.010	21637.244	625.427	21638.112
Max Q/54.00	661,255.7	1229.292	0.111	0.012	17955.463	548.079	17956.325
Intermediate Burn/60.00	606,519.4	1226.779	0.121	0.013	16550.710	511.659	16551.569
Intermediate Burn/80.00	414,610.0	1215.107	0.175	0.018	11877.550	377.749	11878.398
Max G/87.00	350,563.3	1214.336	0.207	0.022	10493.624	327.175	10494.467
Intermediate Burn/100.00	245,229.8	1227.594	0.293	0.031	8495.594	238.473	8496.430
Web Burn/110.88	172,259.6	1268.838	0.415	0.044	7239.456	171.573	7240.284
End of Action Time (AT)/122.39	144,006.3	1316.195	0.495	0.053	6555.460	146.290	6556.283
Separation/125.47	143,361.1	1317.931	0.498	0.053	6524.752	145.813	6525.578
Max Reentry Q/320.47	142,963.6	1317.893	0.499	0.052	6504.948	145.461	6505.775
Nose Cap Deployment/350.47	142,911.5	1317.874	0.499	0.052	6502.188	145.415	6503.015
Drogue Chute Deployment/351.07	142,910.4	1317.874	0.499	0.052	6502.132	145.414	6502.959
Frustum Release/372.17	142,873.7	1317.861	0.499	0.052	6500.179	145.382	6501.005
Main Chute Line Stretch/373.47	142,871.5	1317.860	0.499	0.052	6500.057	145.380	6500.884
Main Chute 1st Disreefing/383.57	142,853.9	1317.855	0.499	0.052	6499.118	145.364	6499.945
Main Chute 2nd Disreefing/389.47	142,843.7	1317.851	0.499	0.052	6498.568	145.355	6499.395
Nozzle Jettisoned/390.17	140,614.2	1307.649	0.497	0.052	6299.344	140.766	6300.149
Splashdown/415.47	140,570.2	1307.631	0.497	0.052	6296.968	140.727	6297.775

90537-7.1

Table 4.3-2. Sequential Mass Properties for 360L009B (RH)

Event/Time	Weight (lb)	Center of Gravity			Moment of Inertia		
		Longitude	Latitude	Vertical	Pitch	Roll	Yaw
Prelaunch/0.00	1,254,958.4	1171.147	0.059	0.006	42363.881	878.780	42364.759
Lift-Off/0.23	1,254,417.8	1171.259	0.059	0.006	42326.105	877.521	42326.983
Intermediate Burn/20.00	1,012,289.0	1208.168	0.073	0.008	30637.168	760.079	30638.044
Intermediate Burn/40.00	790,679.0	1231.475	0.094	0.010	21615.616	624.982	21616.485
Max Q/54.00	660,558.9	1228.982	0.111	0.012	17939.563	547.658	17940.426
Intermediate Burn/60.00	605,846.3	1226.425	0.121	0.013	16533.928	511.056	16534.787
Intermediate Burn/80.00	414,498.4	1214.661	0.175	0.018	11876.598	377.682	11877.446
Max G/87.00	350,483.4	1213.828	0.206	0.022	10493.770	327.133	10494.613
Intermediate Burn/100.00	245,480.9	1226.820	0.292	0.031	8502.831	238.721	8503.666
Web Burn/110.66	174,101.4	1266.078	0.410	0.044	7279.634	173.318	7280.462
End of AT/122.59	143,946.4	1315.228	0.494	0.053	6561.538	146.284	6562.362
Separation/125.47	143,380.9	1316.652	0.497	0.053	6537.219	145.853	6538.046
Max Reentry Q/320.47	143,021.0	1316.589	0.497	0.052	6516.177	145.533	6517.004
Nose Cap Deployment/350.47	142,968.9	1316.569	0.498	0.052	6513.415	145.487	6514.242
Drogue Chute Deployment/351.07	142,967.8	1316.569	0.498	0.052	6513.359	145.486	6514.186
Frustum Release/372.17	142,931.2	1316.556	0.498	0.052	6511.403	145.454	6512.231
Main Chute Line Stretch/373.47	142,928.9	1316.555	0.498	0.052	6511.283	145.452	6512.111
Main Chute 1st Disreefing/383.57	142,911.3	1316.549	0.498	0.052	6510.344	145.436	6511.172
Main Chute 2nd Disreefing/389.47	142,910.1	1316.546	0.498	0.052	6509.794	145.427	6510.622
Nozzle Jettisoned/390.17	140,671.7	1306.326	0.497	0.052	6309.813	140.839	6310.617
Splashdown/415.47	140,627.7	1306.308	0.497	0.052	6307.435	140.800	6308.241

90537-7.2

Table 4.3-3. Sequential Mass Properties Predicted Versus Actual Comparisons for 360L009A (LH)

	Weight (lb)				Longitudinal Center of Gravity (in.)			
Event	Predicted*	Actual	Delta	Error (%)	Predicted*	Actual	Delta	Error (%)
Pre-Ignition	1,255,293	1,255,293	0	0.00	1,171.170	1,171.170	0.000	0.00
Lift-Off	1,254,658	1,254,599	-59	0.00	1,171.296	1,171.302	+0.006	0.00
Action Time	144,225	144,006	-219	0.15	1,315.534	1,316.195	+0.661	0.05
Separation**	143,491	143,361	-130	0.09	1,317.522	1,317.931	+0.409	0.03
Nose Cap Deployment	142,908	142,911	+3	0.00	1,317.881	1,317.874	-0.007	0.00
Drogue Chute Deployment	142,907	142,910	+3	0.00	1,317.881	1,317.874	-0.007	0.00
Main Chute Line Stretch	142,868	142,871	+3	0.00	1,317.868	1,317.860	-0.008	0.00
Main Chute 1st Disreefing	142,851	142,854	+3	0.00	1,317,862	1,317.855	-0.007	0.00
Main Chute 2nd Disreefing	142,841	142,844	+3	0.00	1,317.858	1,317.851	-0.007	0.00
Nozzle Jettison	140,613	140,614	+1	0.00	1,307.650	1,307.649	-0.001	0.00
Splashdown	140,570	140,570	0	0.00	1,307.631	1,307.631	0.000	0.00

*Based on Mass Properties History Log Space Shuttle 360L009-LH, 12 Oct 1989 (TWR-17350A)
**The separation longitudinal cg of 1,317.931 is 66% of the vehicle length

90537-7.3

Table 4.3-4. Sequential Mass Properties Predicted Versus Actual Comparisons for 360L009B (RH)

	Weight (lb)				Longitudinal Center of Gravity (in.)			
Event	Predicted*	Actual	Delta	Error (%)	Predicted*	Actual	Delta	Error (%)
Pre-Ignition	1,254,958	1,254,958	0	0.00	1,171.147	1,171.147	0.000	0.00
Lift-Off	1,254,324	1,254,418	+94	0.01	1,171.274	1,171.259	-0.015	0.00
Action Time	144,284	143,946	-338	0.23	1,314.246	1,315.228	+0.982	0.07
Separation**	143,550	143,381	-169	0.12	1,316.225	1,316.652	+0.427	0.03
Nose Cap Deployment	142,968	142,969	+1	0.00	1,316.579	1,316.569	-0.010	0.00
Drogue Chute Deployment	142,967	142,968	+1	0.00	1,316.578	1,316.569	-0.009	0.00
Main Chute Line Stretch	142,928	142,929	+1	0.00	1,316.565	1,316.555	-0.010	0.00
Main Chute 1st Disreefing	142,910	142,911	+1	0.00	1,316.559	1,316.549	-0.010	0.00
Main Chute 2nd Disreefing	142,900	142,901	+1	0.00	1,316.555	1,316.546	-0.009	0.00
Nozzle Jettison	140,671	140,672	+1	0.00	1,306.327	1,306.326	-0.001	0.00
Splashdown	140,628	140,628	0	0.00	1,306.308	1,306.308	0.000	0.00

*Based on Mass Properties History Log Space Shuttle 360L009-RH, 12 Oct 1989 (TWR-17351)
**The separation longitudinal cg of 1,316.652 is 66% of the vehicle length

90537-7.4

Table 4.3-5. Predicted Versus Actual Weight (lb) Comparisons for 360L009 (LH)

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	Error (%)	Notes
Inerts							
Prefire, Controlled		151,076	149,187	149,187	0	0.00	1
Propellant	1,104,714		1,106,106	1,106,106	0	0.00	1
Usable			1,105,247	1,105,468	+221	0.02	2
To Lift-Off			535	594	+59	9.93	
Lift-Off to Action			1,104,712	1,104,874	+162	0.01	2
Unusable			859	638	-221	34.64	
Action to Separation			669	579	-90	15.54	
After Separation			90	59	-131	222.03	
Slag			2,000	2,000	0	0.00	2

Notes:
1. Requirement per CPW1-3600A, Addendum G, Part I, (RSRM CEI specification).
2. Slag included in usable propellant, lift-off to action.
3. Based on 12 Oct 1989, Mass Properties History Log Space Shuttle 360L009-LH (TWR-17350A).

90537-7.5

Table 4.3-6. Predicted Versus Actual Weight (lb) Comparisons for 360L009 (RH)

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	Error (%)	Notes
Inerts							
Prefire, Controlled		151,076	149,246	149,246	0	0.00	1
Propellant	1,104,714		1,105,712	1,105,712	0	0.00	1
Usable			1,104,854	1,105,192	+338	0.03	2
To Lift-Off			535	440	-95	21.59	
Lift-Off to Action			1,104,319	1,104,752	+433	0.04	2
Unusable			858	520	-338	65.00	
Action to Separation			668	499	-169	33.87	
After Separation			190	21	-169	804.76	
Slag			2,000	2,000	0	0.00	2

Notes:
1. Requirement per CPW1-3600A, Addendum G, Part I, (RSRM CEI specification).
2. Slag included in usable propellant, lift-off to action.
3. Based on 12 Oct 1989, Mass Properties History Log Space Shuttle 360L009-RH (TWR-17351).

90537-7.6

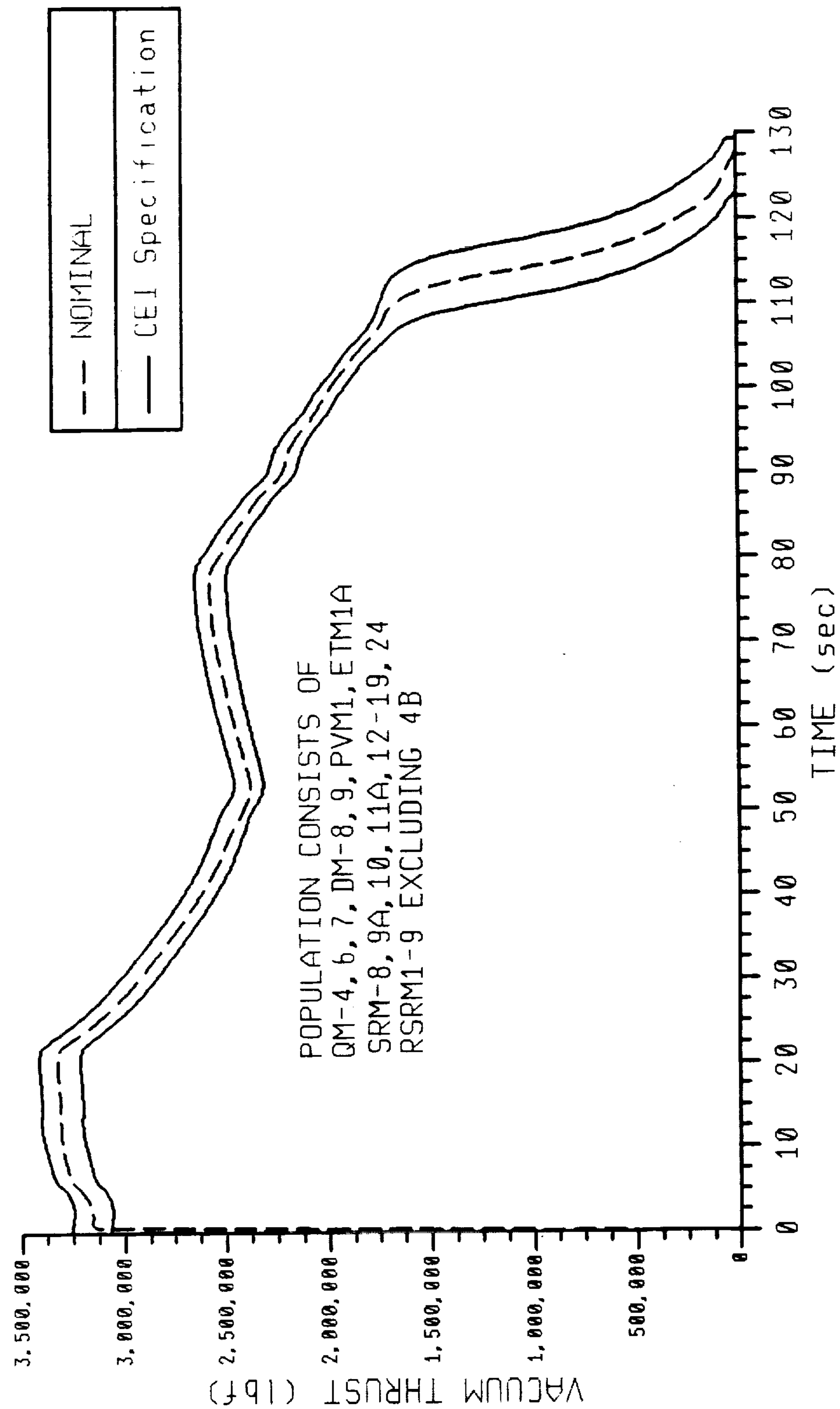


Figure 4.4-1. Thrust-Time Traces

1) Data measurement system error rather than an actual performance error.
2) A continued effort is underway to determine exactly where (OPT, analog/digital (A/D) converter, etc.) the system error is located.
3) The solution to the data measurement system error is to quantify the total system error preflight and compensate for that error in postflight reconstruction.

The reconstructed RSRM propulsion performance is compared to the predicted performance in Table 4.4-1. The following comments are to explain the table value. The RSRM ignition interval is to be between 202 and 302 ms after ignition command to the NASA Standard Initiator (NSI) in the S&A device. The ignition interval ends when the headend chamber pressure has increased to a value of 563.5 psia. The maximum rate of headend chamber pressure build up during the ignition transient is required to be less than 115.9 psia for any 10 ms interval. However, due to the elimination of DFI, no high sample rate ignition data was available for this flight; therefore, no rise rate or ignition interval is reported.

Separation is based upon the 50 psia cue from the last RSRM, plus 4.9 seconds, plus a time delay between the receipt and execution of the command to separate. No time delay is assumed in the prediction. The decay time intervals are measured from the time motor headend chamber pressure has decayed to 59.4 psia to the time corresponding to 85,000 lb of thrust.

4.4.3 Matched Pair Thrust Differential

Table 4.4-2 shows the thrust differential during steady state and tailoff. All the thrust differential values were near the nominal values experienced by previous flight SRMs and were well within the CEI Specification limits. The thrust values used for the assessment were reconstructed at the delivered conditions of each motor.

4.4.4 Performance Tolerances

A comparison of the LH and RH motors calculated and reconstructed parameters at PMBT of 60°F with respect to the nominal values and the SRM CEI Specification maximum 3σ requirements is given in Table 4.4-3.

Table 4.4-1. RSRM Propulsion Performance Assessment

	LH Motor at 67°F		RH Motor at 67°F	
	Predicted	Actual	Predicted	Actual
Impulse Gates				
I-20 (10^6 lbf-sec)	64.81	65.03	64.76	64.91
I-60 (10^6 lbf-sec)	173.07	173.50	172.97	173.16
I-AT (10^6 lbf-sec)	296.97	295.76	296.87	294.93
Vacuum I_{sp} (lbf-sec/lbm)	268.5	267.4	268.5	266.7
Burn Rate (ips)	0.368	0.370	0.368	0.370
Event Times (sec)*				
Ignition Interval	0.232	NA	0.232	NA
Web Time*	111.3	110.6	111.3	110.4
Time of 50 psi Cue	120.9	120.6	120.9	120.6
Action Time	123.0	122.2	123.0	122.4
Separation Command (sec)	125.8	125.5	125.8	125.5
PMBT (°F)	67.0	67.0	67.0	67.0
Maximum Ignition Rise Rate (psia/10 ms)	91.9	NA	91.9	NA
Decay Time (sec) (59.4 psia to 85k)	2.8	2.4	2.8	2.5

	Predicted	Actual
Tailoff Imbalance Impulse Differential (klbf-sec)	NA	-119

Impulse imbalance = LH motor - RH motor
*All times are referenced to ignition command time except where noted by an *. These times are referenced to lift-off time (ignition interval)

Table 4.4-2. RSRM Thrust Imbalance Assessment

Event	Imbalance Spec (klbf)	Maximum Imbalance (klbf)	Time of Max Imbalance (sec)
Steady State (1.0 sec to first web time-4.5 sec, lbf, 4 sec average)	85	+30.6	71.0
Transition (first web time-4.5 sec to first web time, lbf)	85 - 268 linear	-34.9	110.0
Tailoff (first web time to last AT)	710	-69.9	117.0

Thrust imbalance = LH SRM - RH SRM

Table 4.4-3. RSRM Performance Comparisons

Parameter	SRM CEI (±) Max 3σ Var (%)	Nominal Value *	360L009A LH RSRM (60°F)	Var (%)**	360L009B RH RSRM (60°F)	Var (%)**
Web Time (sec)	5.0	111.7	111.4	-0.27	111.2	-0.45
AT (sec)	6.5	123.4	123.0	-0.32	123.3	-0.08
Web Time Avg Pressure (psia)	5.3	660.8	660.1	-0.11	658.5	-0.35
Max Headend Pressure (psia)	6.5	918.4	912.4	-0.65	910.6	-0.85
Max Sea Level Thrust (Mlbf)	6.2	3.06	3.07	+0.33	3.06	+0.00
Web Time Avg Vac Thrust (Mlbf)	5.3	2.59	2.59	+0.00	2.58	-0.39
Vac Delivered I_{sp} (lbf-sec/lbm)	0.7	267.1	267.3	+0.07	266.7	-0.15
Web Time Vac Total Impulse (Mlbf-sec)	1.0	288.9	288.0	-0.31	286.8	-0.73
AT Vac Total Impulse (Mlbf-sec)	1.0	296.3	295.5	-0.27	294.7	-0.54

*QM-4 static test and SRM-8A and B, SRM-9A, SRM-10A and B, SRM-11A, SRM-13A and B flight average at standard conditions

**Variation = ((RSRM-9A - nominal)/nominal) * 100
((RSRM-9B - nominal)/nominal) * 100

4.4.5 Igniter Performance

Due to the elimination of DFI on 360L004 (STS-30R) and subsequent, no evaluation of the igniter performance was possible. Also, no evaluation of the ignition interval, pressure rise rate, and ignition thrust imbalance requirements was possible.

4.5 RSRM NOZZLE TVC PERFORMANCE (FEWG REPORT PARA 2.4.3)

No RSRM nozzle torque calculations for Flight Motor Set 360L009 were possible due to DFI elimination on 360L004 (STS-30R) and subsequent. This section is reserved pending the availability of DFI on future flights. The nozzle char and erosion performance is discussed in Volume I, Section 4.11.4 and Volume V of this report.

4.6 RSRM ASCENT LOADS – STRUCTURAL ASSESSMENT (FEWG REPORT PARA 2.5.2)

Flight Motor Set 360L009 did not have any DFI installed to evaluate the motor structural performance. This section is reserved pending any future motors that incorporate DFI.

4.7 RSRM STRUCTURAL DYNAMICS (FEWG REPORT PARA 2.6.2)

No accelerometer data was available due to the elimination of DFI on 360L004 (STS-30R) and subsequent. This section is reserved pending the installation of accelerometers on future flight motors.

4.8 RSRM TEMPERATURE AND TPS PERFORMANCE (FEWG REPORT PARA 2.8.2)

4.8.1 Introduction

This section documents the thermal performance of the 360L009 (STS-36) SRM external components and TPS as determined by postflight hardware inspection. Assessments of debris, mean bulk temperature (MBT) predictions, on-pad ambient/local induced environments, and GEI/joint heater sensor data are also included. Performance of SRM internal components (insulation, case components, seals and nozzles) is reported in Para 4.11.

4.8.2 Summary

4.8.2.1 Postflight Hardware Inspection. Postflight inspection of the TPS revealed no anomalies or unexpected problems due to flight heating environments. The condition of both SRMs were similar to that of previous flight sets. Table 4.8-1 provides an overall summary of SRM TPS condition. Nozzle erosion is discussed in Volume I, Section 4.11.4 of this report.

4.8.2.2 Debris Assessment. No SRM violations of NSTS debris criteria were noted. All missing TPS cork pieces (generally small) are due to nozzle severance debris and/or splashdown loads and debris or handling scrapes. During ascent film review of previous flights, indications suggest that there were debris particles coming out of the SRM nozzle prior to and following separation. The Debris Team is questioning the likelihood of these being chunks of propellant and/or insulation. A complete SRM debris assessment is given in Volume I, Section 4.8.3.2 of this report.

4.8.2.3 MBT Predictions. These temperature predictions were made at different times during the countdown. A discussion of these predictions is presented in Volume I, Section 4.8.3.3 of this report. The final postflight predictions from reconstructed data yielded a PMBT of 67°F and a flex bearing mean bulk temperature (FBMBT) of 77°F.

4.8.2.4 On-Pad Environment Evaluations. The ambient temperature recorded during a 216-hour period prior to launch varied from 45° to 83°F. Normal temperatures during the month of February range from a low of 54° to a high of 67°F. The 45° and 83°F temperatures which occurred prior to launch were within 1 and 2σ, respectively, for the historical ambient temperature range for February. The wind speeds during this same timeframe were higher than historical conditions. Table 4.8-2 shows environmental conditions prior to launch.

4.8.2.5 LCC. No LCC thermal violations were noted. Measured GEI and heater sensor data, as compared with the LCC requirements, are discussed in Volume I, Section 4.8.3.5 of this report. Highlights of the heating operations are summarized as follows.

The igniter heaters were activated at L-18 hours for all six launch countdowns and deactivated at T-9 minutes for the last three countdowns. The first three launch countdowns were scrubbed before ET loading so the heaters were deactivated

Table 4.8-1. RSRM External Performance Summary (LH and RH)

Component	TPS Material	Performance	Recovered Hardware Performance Assessment
Field Joints	Cork	Typical	All JPS in excellent condition; slight paint blistering; pitting on aft edge of JPS K5NA closeout (largest chunk of JPS K5NA/extruded missing <0.7 in.^{3} due to severance debris impact); K5NA over trunnion/vent valve location intact
Factory Joints	EPDM	Typical	All factory joints in very good condition; typical heat-affected areas on aft segment joints on inboard side of both motors; 3 weatherseals showed unbonds (only 1, LH aft center, violates criteria), no evidence of sooting, indicates that separation occurred at or after splashdown
Systems Tunnel	Cork/K5NA	Typical	Cork TPS adjacent to tunnel floor plate in excellent condition; very little paint blistering; K5NA closeout in excellent condition on both cables and seams
Stiffener Rings	EPDM	Typical	Good condition--No deviations from normal postflight appearance; charring and discoloration on inboard edges and top surfaces; Insta-foam ramps chunked out on 5 of 6 rings, on both motors, at about 180 deg due to water impact; cracks observed in K5NA of several stiffeners; one cracked ring
GEI Closeout	Cork/K5NA	Typical	Very good condition, slight paint blistering; some small cork pieces missing on GEI cable runs--all within established NSTS debris criteria, all caused by nozzle severance/ splashdown loads and debris
Aft Kick Ring Joint	Cork	Typical	Good condition from thermal perspective; shielded from radiation by kick ring
Motor Case	NA	Typical	No hot spots or abnormal discoloration of case paint due to external or internal heating; aft segments extensively sooted
Nozzle Extension	Cork	Unknown	Nozzle extensions not recovered

Table 4.8-2. Actual GEI Countdown and Historically Predicted On-Pad February Temperatures (°F)—LCC Temperatures Included

Component	Daily Cycling		T-6 Hour to T-5 Minutes		
	February Historical	Actual GEI	February Historical	Actual GEI	LCC
Igniter Joint					
RH	59-67	63-75	93-98	91-96	66-123
LH	59-67	64-76	91-96	92-97	66-123
Field Joint					
RH Forward	51-70	45-85	94-109	93-107	85-122*
LH Forward	51-68	64-83	95-106	91-106	85-122*
RH Center	51-70	50-84	95-112	93-103	85-112*
LH Center	52-68	50-83	93-106	93-106	85-122*
RH Aft	51-70	52-82	92-109	94-104	85-122*
LH Aft	52-68	50-82	91-107	91-105	85-122*
Case-to-Nozzle Joint					
RH	55-66	62-75	75-78	82-88	75-115
LH	55-67	61-73	75-79	78-85	75-115
Flex Bearing Aft End Ring					
RH	55-66	65-71	75-78	78-86	NA-115
LH	55-67	65-72	75-79	78-85	NA-115
Case Acreage (deg)					
RH 45	51-63	48-78	53-58	62-69	--
135	52-65	47-88	54-59	56-70	--
215	56-71	50-81	57-63	62-78	--
270	55-70	48-78	57-64	64-69	35-NA
325	53-65	46-78	55-60	62-67	--
LH 45	53-68	48-81	55-61	62-80	--
135	52-64	48-80	54-60	64-74	--
215	53-64	49-77	54-60	62-67	--
270	56-68	48-78	57-63	62-72	35-NA
325	56-70	48-78	57-63	64-77	--
Local Environment					
Temperature	55-67	45-83	56-63	60-69	38-99
Wind Speed (kn)	15	2-30	15	6-24	24
Wind Direction	N	N-SE	N	N-NE	SW-SE
Cloud Cover		Clear to cloudy		Cloudy	

*Field joint sensor lower limit will drop from 85° to 69°F in the case of a complete heater failure at the time of scrub. The igniter heater operation maintained temperatures between 91° and 97°F during the LCC timeframe.

The six field joint heaters were activated at approximately L-11 hours 20 minutes for the first launch attempt and the final three launch countdowns. Due to a scrub called before the activation time for the field joint heaters, the heaters were not activated for the second and third launch countdowns. All field joint heaters operated on their primary circuits and maintained temperatures between 91° and 107°F.

The SRB aft skirt purge operation was activated at or after L-13 hours 20 minutes during the first and final three launch countdowns. The second and third launch countdowns were scrubbed before activation of the aft skirt purge. All case-to-nozzle joint and flex bearing aft end ring temperatures were between 78° and 88°F during the entire LCC timeframe. Several times during the launch countdowns from February 24 on, there came a need to decrease the purge temperature, pressure, or both, to try to avoid an LCC violation on the USBI Fuel Supply Module (FSM) maximum pressure allowable. The maximum pressure currently allowed is 415 psi; a preapproved waiver was written to allow the pressure to increase to 425 psi. The pressure did exceed 415 psi during the high flow cleansing purge initiated at T-15 minutes.

4.8.2.6 Prelaunch Thermal Data Evaluation

IR Temperature Measurements. Because there were essentially three full countdowns with the ET loaded, a great amount of data was obtained from the various thermal imagers. The portable STI and IR gun data collected during the T-3 hour pad walkdowns are compared in Table 4.8-3 with the stationary STI and GEI readings taken at the same time. Stationary STI measurements throughout the walkdowns and countdowns remained consistently 2° to 4°F below the GEI, with the RSS location being more accurate than Camera Site 2 because of its closer proximity to the vehicle. The portable STI scanner was more erratic, ranging from about 7°F low to matching the GEI exactly. The IR gun was even more erratic, ranging from 8°F low to matching the GEI exactly.

Table 4.8-3. STS-36 Measurement Comparisons During T-3 Hour Ice/Debris Walkdown

Date (1990)	IR Gun	Portable STI	Stationary STI	GEI
24 Feb	--	54-59	55-58	58-64
25 Feb	47-50	47-51	51-55	54-58
27 Feb	65-67	63-66	61-63	64-67

4.8.3 Results Discussion

4.8.3.1 Postflight Hardware Inspection. Following the recovery of the STS-36 SRBs, a postflight inspection of the external hardware was conducted at the SRB Disassembly Facility (Hangar AF, KSC). The TPS performance was considered excellent in all areas, with external heating and recession effects being less than predicted (Table 4.8-4). Predictions due to the worst-case design trajectory environments (Table 4.8-5) will be documented in the SRB Thermal Design Data Book, SE-019-068-2H.

The condition of both motors appeared similar to previous flight motors, with most of the heat effects seen on the aft segments on the inboard side of the SRBs. The aft segment inboard regions facing the ET experience high aerodynamic heating, normal to protuberance components. They also receive the high plume radiation and recirculation heating induced by the adjacent SRB and SSMEs to aft facing surfaces. In this area there was slight charring to the TPS over the factory joints, the stiffener rings and stubs, and GEI cabling runs. A concise summary of the external hardware condition is shown in Table 4.8-1.

Field Joints. All field joints on both motors were in excellent condition. There were no signs of ablation on any of the joint protection systems (JPS), with only slight paint blistering on the cork cover. The paint on the K5NA closeout aft of the cork was also slightly darkened and blistered, with occasional pitting. This was probably due to aerodynamic heating and the result of aft edge hits from water impact and nozzle severance debris. All K5NA repair locations were intact over the trunnion/vent valve locations. Two aft edge hits, both with dimensions less than 0.7 in.^{3}, were likely nozzle severance debris scrapes.

Factory Joints. The factory joints on each of the motors were in very good condition. The only signs of heat effect experienced on the factory joints were located on the aft segments of each motor. There was only slight ablation, charring, and discoloration on the inboard regions of the aft segment factory joints. This occurred approximately between 220 and 320 degrees circumferentially on each motor. Again, these are all normal occurrences that have been consistently observed on previous flight motors. Weatherseal unbonds were evident at four locations on the LH aft center factory joint aft edge, with a worst-case depth of 2.6 inches, which extended to the pin retainer band. No evidence of sooting was found under these

Table 4.8-4. STS-36 RSRM External Performance Summary—TPS Erosion (LH and RH)

Component	TPS Material	Maximum Erosion (in.) Predicted	Measured
Field Joints	Cork	0.003	None
Factory Joints	EPDM	0.014	Not measurable*
Systems Tunnel	Cork	0.014	None
Stiffener Rings	EPDM	0.009	Not measurable*
GEI Closeout	Cork	0.036	Not measurable*
Nozzle Extensions	Cork	0.104	NA**

*Evidence of minor erosion apparent only on inboard region of aft segment, where flight-induced thermal environments are most severe
**Nozzle extensions are not recovered

Table 4.8-5. SRB Flight-Induced Design Thermal Environments

Ascent Heating	Document No. STS 84-0575, 24 May 1985
	Change Notice (CN) 2, SE-698-D, 30 Apr 1987
	Data on Computer Tapes No. DN 4044 and DN 9068
	CN 3, SE-698-D, 30 Oct 1987. Tape No. DP 5309
Base Recirculation Heating	Document No. STS 84-0259, October 1984
	CN 1, SE-698-D, 30 Sep 1987
SSME and SRB Plume Radiation	Document No. STS 84-0259, October 1984
	CN 1, SE-698-D, 30 Sep 1987
SSME Plume Impingement After SRB Separation	Document No. STS 84-0259,, October 1984
	CN 1, SE-698-D, 30 Sep 1987
Reentry Heating	Document No. SE-0119-053-2H, Rev D, August 1984; Rev E, 12 Nov 1985

unbonds, indicating that the separation occurred at or after splashdown due to adhesive failure.

Systems Tunnel. The cork TPS adjacent to the systems tunnel floor plate was in excellent condition. There were several very small scrapes on the LH motor that only penetrated the paint on the cork TPS, probably caused by water impact/debris. There was very little paint blistering. All K5NA closeouts over cables and tunnel seams were in excellent condition.

Stiffener Rings. The stiffener ring TPS was generally in very good condition with only slight thermal degradation. The major heat-affected area was again predominantly in the 220- to 320-degree sector, with the EPDM insulation on the outer flange showing signs of brown charring. This region was subjected to aero heating along the outboard tip forward face, while the aft face and top surfaces experienced radiant heating. The K5NA TPS on the top surfaces of the stubs was also slightly charred in the same regions, with intermittent pitting around the whole circumference. Stiffener ring Insta-foam chunkout at water impact was evident on ramps at both motors at approximately 180 degrees: LH forward and center rings, RH all rings. The K5NA on several stiffener rings was cracked in this same region, with at least one cracked stiffener ring.

GEI Closeout. The cork and K5NA TPS covering the GEI and cableways was generally in good condition. Very little heat effect was observed, consisting of only slight paint discoloration and blistering.

Aft Kick Ring Joint. The TPS cork strip over the pin retainer band was in good condition from a thermal perspective. This strip, as well as the case region vicinity, was heavily sooted with no unexpected heating effects. This strip during ascent is shielded from adjacent SRB plume radiation by the kick ring.

4.8.3.2 Debris Assessment. NSTS debris criteria for missing TPS was not violated. The missing TPS cork pieces were all caused by nozzle severance debris, splashdown loads/debris, or handling problems. There were a total of 28 aft edge hits, 26 on GEI cork runs and 2 on the FJPS: 10 on the LH motor and 18 on the RH motor. The largest TPS piece missing was from a GEI cork run; major dimensions were approximately 4.9 by 0.9 by 0.25 in., or 3.0 in^3 (L-shaped). It was located on the RH aft segment at approximately 135 deg, Station 1751, in the vicinity of the cavity collapse loads and missing stiffener ring insta-foam. Probable causes are splashdown loads/debris, or a handling scrape.

4.8.3.3 MBT Predictions. MBT predictions were performed at various times for the time of launch of STS-36 and are summarized as follows:

	Historical	L-9 Days 13 Feb 90	L-2 Days 19 Feb 90	L-1 Day 21 Feb 90	L-1 Day 22 Feb 90	L-1 day 25 Feb 90
PMBT	60	68	70	69	69	67
FBMBT	60	73	--	--	--	--

	L-2 Day 26 Feb 90	L-1 Day 27 Feb 90	Post
PMBT	66	66	67
FBMBT	--	--	77

The final postflight predictions from reconstructed data yield a PMBT of 67°F and a FBMBT of 77°F.

All predictions were based on the following three sources of data:

1) Thiokol Launch Support Services (LSS) Office – FAXed weather data

2) KSC weather stations – modem transmission

3) Florida Solar Energy Center (FSEC) – modem transmission

Data from the Thiokol LSS Office was used wherever possible, and was the primary source of environmental data. The ambient temperature from the KSC weather station was used as the next source, along with wind speed and direction from FSEC. The ambient temperature data from FSEC was used only when the other sources were unavailable. Sky temperature and solar flux were received from FSEC.

Flex bearing temperature predictions were not performed at the same times or frequencies as PMBT predictions. The uncertainty of predicting ambient conditions seven days in advance, along with the question of how the aft skirt purge system will be operated, make it difficult to accurately predict FBMBT in advance. Required FBMBT calculations are usually performed to determine the current bulk temperature from which aft skirt purge operations can be based.

4.8.3.4 On-Pad Environment Evaluations. The ambient temperature dropped below -1σ and above $+2\sigma$ historical values while the vehicle was on the pad. This occurred during the morning hours of 24 Feb 1990, and the afternoon hours of 19 Feb 1990, respectively. The ambient temperature recorded during a 216-hour period prior to launch varied from a low of 45° to a high of 83°F.

The ambient temperature recorded from L-216 to L-24 hours varied from 45° to 83°F. The ambient temperatures during this eight-day period were higher than normal. Normal temperatures during the month of February range from a low of 54° to a high of 67°F, with the $\pm 1\sigma$ temperature ranging from 44° to 75°F.

Actual environmental data for the final 24 hours prior to launch (60° to 70°F) can be seen in Figures 4.8-1 through 4.8-5 and summarized together with GEI in Table 4.8-2. The wind speeds from L-24 up through launch were above normal (≈15 knots).

The local on-pad environment due to February historical predictions suggest an average 0.3°F temperature depression while the ET is loaded and when winds are from the south to southeast. The actual wind direction during the LCC timeframe was from the north to northeast. The 6 to 24 knot wind from the north to northeast during the actual launch on 28 Feb 1990, prohibited the SRBs from experiencing the formation of a temperature depression due to GOx venting and ET chill. However, the launch attempt on 25 Feb 1990, with a 5 to 13 knot wind from the northwest to southwest, provided a situation where a significant temperature depression was experienced by the SRBs due to GOx venting and ET chill. From GEI assessments, there was approximately a 3°F temperature suppression on the East SRB due to ET chill effects. Historically, winds from the east have caused chilling on the inboard side of the west SRB (STS-30R) and winds from the west have caused chilling on the inboard side of the East SRB (STS-29R and STS-28R).

4.8.3.5 LCC. No LCC thermal violations were noted. Measured GEI and heater sensor data for the end of the LCC timeframe (T-5 minutes) are presented in Table 4.8-6 and are compared with the LCC requirements.

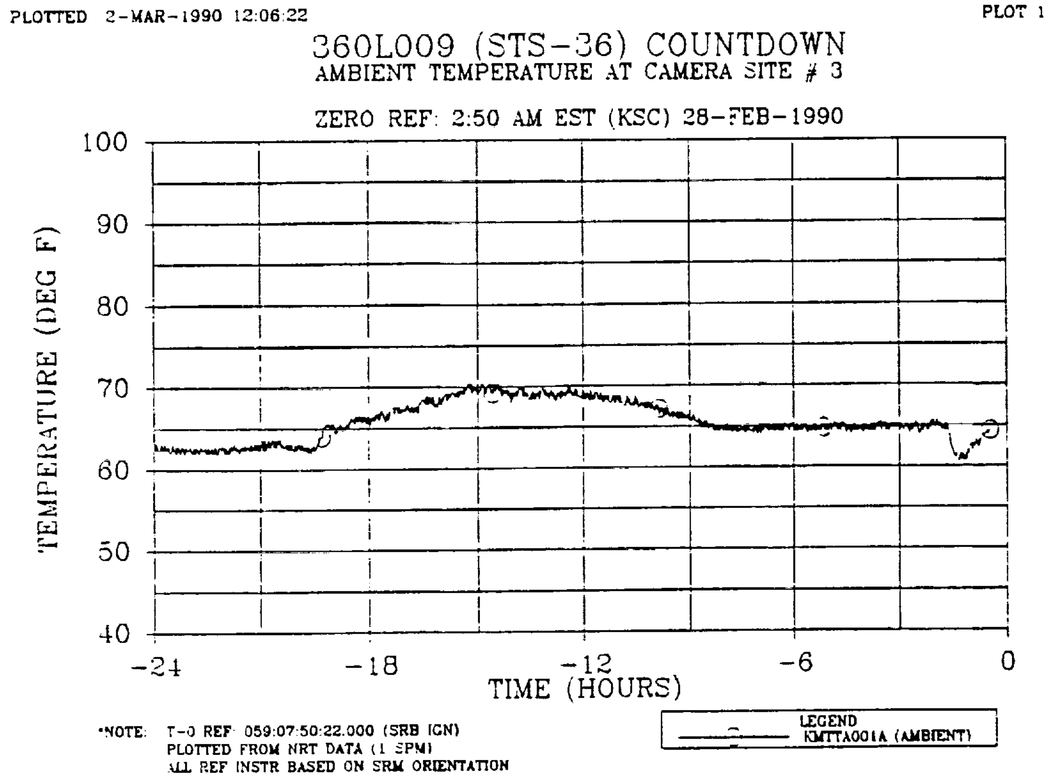


Figure 4.8-1 Countdown Ambient Temperature at Camera Site 3

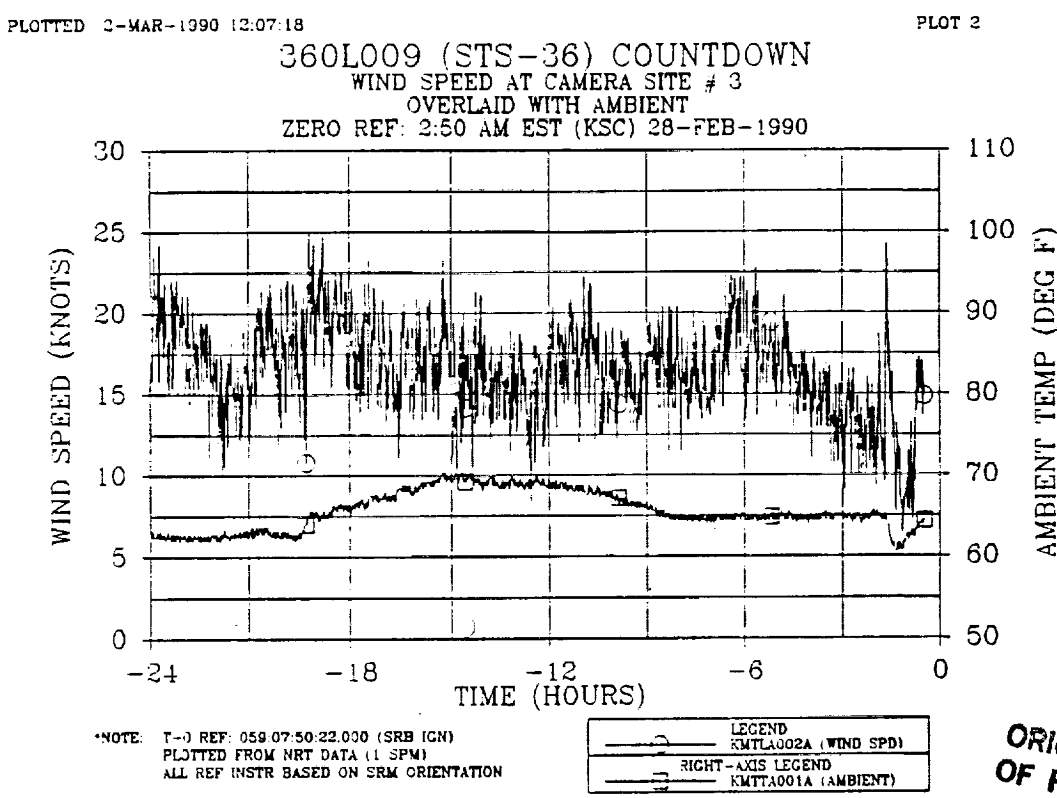


Figure 4.8-2 Countdown Wind Speed at Camera Site 3

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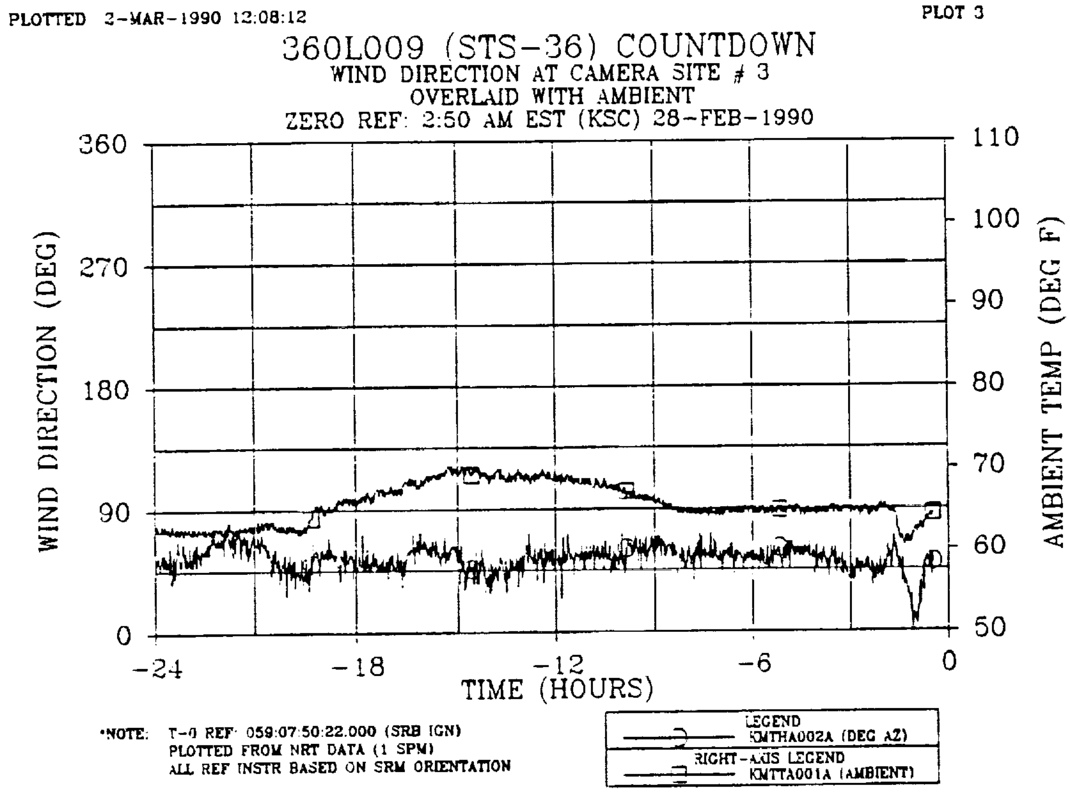

Figure 4.8-3 Countdown Wind Direction at Camera Site 3

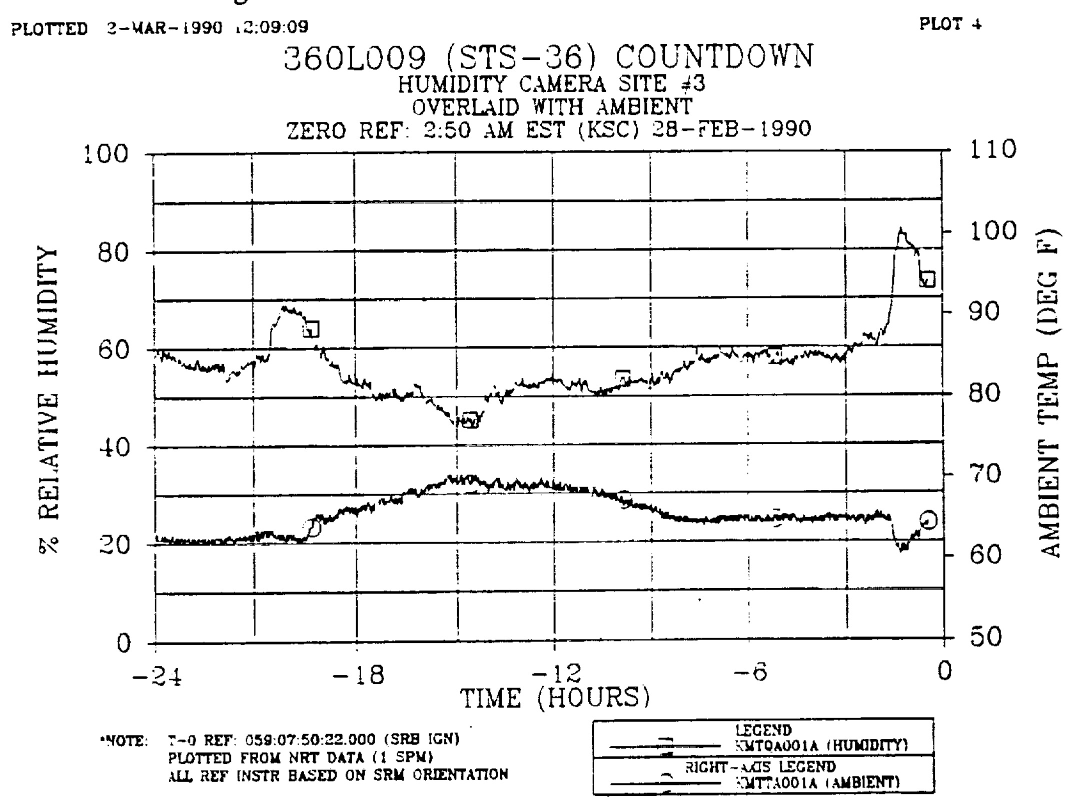

Figure 4.8-4 Countdown Humidity at Camera Site 3

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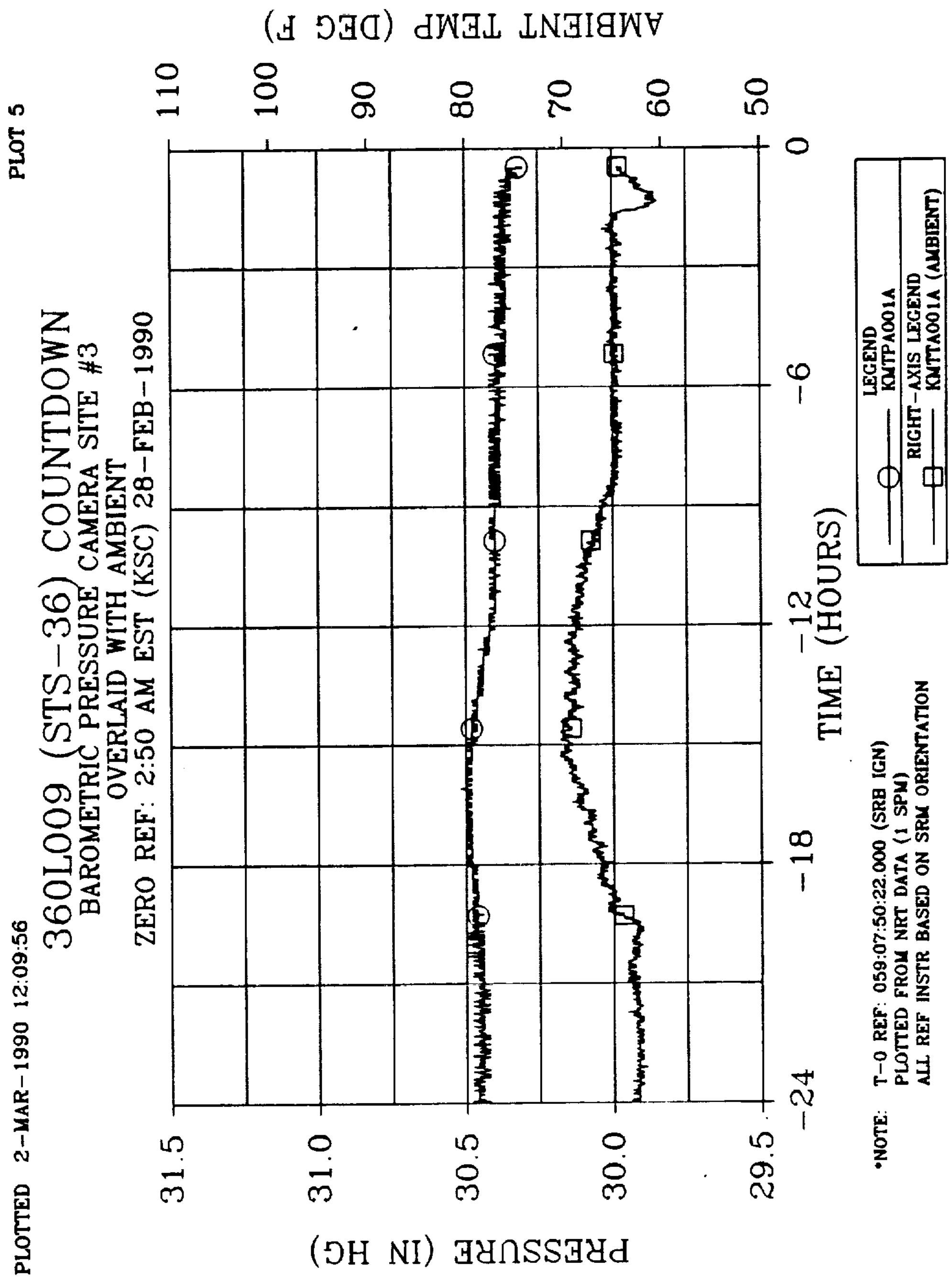

Figure 4.8-5 Countdown Barometric Pressure at Camera Site 3

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Table 4.8-6. T-5 Minute On-Pad Temperatures (end of LCC timeframe)

Component	L-12 Hour Predictions*	February Historical	Actual GEI	LCC
Igniter Joint				
RH	92-95	93	92-93	66-123
LH	92-95	91	93-94	66-123
Field Joint				
RH Forward	94-102	93-98	97-106	85-122**
LH Forward	94-102	95-100	96-100	85-122**
RH Center	94-102	95-100	96-100	85-122**
LH Center	94-102	94-101	98-99	85-122**
RH Aft	94-102	93-97	98-101	85-122**
LH Aft	94-102	92-96	96-100	85-122**
Case-to-Nozzle Joint				
RH	82-84	77-78	85-88	75-115
LH	81-83	81-83	83-85	75-115
Flex Bearing Aft End Ring				
RH	82-84	77-78	82-86	NA/115
LH	81-83	81-83	83-85	NA/115
Case Acreage (deg)				
RH 45	--	53	62-66	--
135	--	54	59-67	--
215	--	57-58	64-69	--
270	64-67	57-58	64-67	35-NA
325	--	57-58	62-64	--
LH 45	--	54-55	64-67	--
135	--	54-55	64-66	--
215	--	54-55	62-64	--
270	64-67	57-58	64-66	35-NA
325	--	57-58	64-66	--
Local Environment				
Temperature	66	56	65	38-99
Wind Speed (kn)	--	15	19	24
Wind Direction	--	N	N-NE	SW-SE
Cloud Cover			Cloudy	

*Predictions for anticipated launch window at T-5 minutes
**Field joint sensor lower limit will drop from 85° to 69°F in the event of a complete heater failure

The igniter heaters were activated at L-18 hours and deactivated at T-9 minutes for the actual launch on 28 Feb 1990. The igniter heaters performed adequately and as expected with a 5°F sensor temperature range from 91° to 96°F during the LCC timeframe. The igniter heaters were activated for 75 hours 47 minutes over all six launch countdowns and maintained the required temperatures. This is the longest time the heaters have been operated for any flight to date.

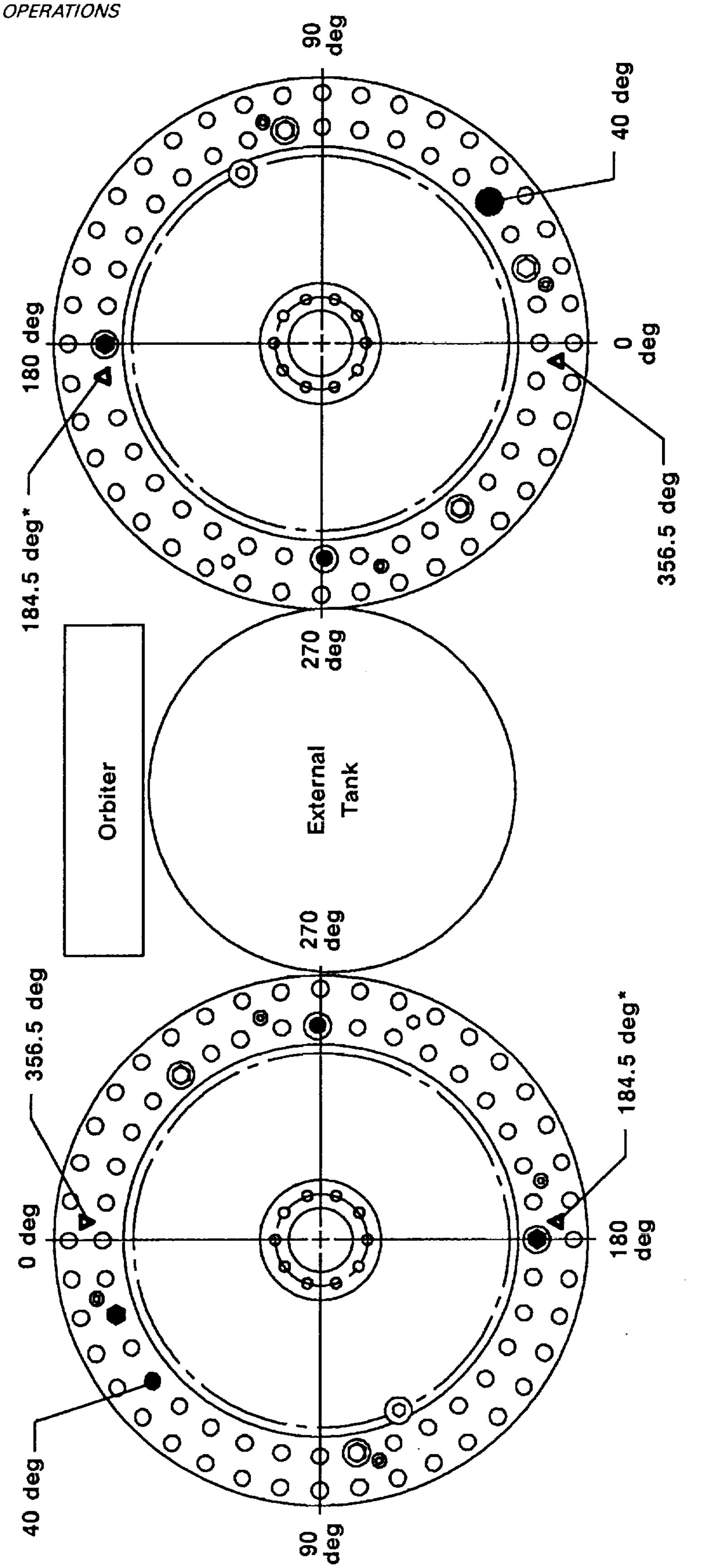
The six field joint heaters performed adequately and as expected with a 16°F sensor temperature range from 91° to 107°F during the LCC timeframe. All 24 field joint sensors recorded temperatures in the expected range. No problems were encountered with field joint heaters themselves, but there was a front end processor (FEP) return error encountered when a request to activate the heater failed during the launch countdown on 24 Feb 1990. Another request was immediately sent to initiate the heater; it was successful. The heater system thereafter continued to function normally, and no constraints to launch resulted. A related incident occurred on the last flight, 360L008 (STS-32R). IPR No. 36RV-0168 was written concerning this situation. The problem was determined to be in the mobile launch platform (MLP) electronics (not Thiokol related). Prior to launch, an LCC contingency was created to lower the minimum redline temperature, at a given field joint, from 85°F to 69°F in the event of a complete heater failure. This modification was a change unique to STS-36 and was a precaution taken in the event that both primary and redundant heaters fail on a given field joint. The six field joint heaters were activated for 43 hours and 23 minutes over four of the six launch countdowns and maintained the required temperatures.

The SRB aft skirt purge operation was activated for 51 hours 52 minutes over four of the six launch countdowns. When the LCC timeframe began for the launch on 28 Feb 1990, all six case-to-nozzle joint temperature readings were 75°F or above. At the end of the LCC timeframe, the temperature range of the case-to-nozzle joint sensors was 83° to 88°F and the flex bearing sensors were 82° to 86°F. Several times during the launch countdowns from 24 to 28 Feb 1990, there was a need to decrease the purge temperature, or pressure, or both, to try to avoid an LCC violation on the USBI FSM maximum pressure allowable. The maximum pressure currently allowed is 415 psi; a preapproved waiver was written to allow the pressure to increase to 425 psi. The pressure did exceed 415 psi during the high flow cleansing purge initiated at T-15 minutes.

The LCC temperature sensors for the case acreage were from 56° to 72°F during the LCC timeframe, with all sensors working properly. During a previous launch attempt on 24 Feb 1990, Sensor B06T8013A on the right SRM case acreage at Station 931.5, the 270-deg location, witnessed several temperature spikes over approximately a two-hour period. There was no recurrence and the temperature sensor operated correctly during future launch countdowns. IPR No. 36RV-0163 was written concerning this situation and was dispositioned to be in the MLP (not Thiokol related).

4.8.3.6 <u>Prelaunch Thermal Data Evaluation Infrared (IR) Temperature Measurements</u>. Because there were essentially three full countdowns with the ET loaded, a great amount of data was obtained from the various thermal imagers. The portable STI and IR gun data collected during the T-3 hour pad walkdowns are compared with the stationary STI and GEI readings taken at the same time (Table 4.8-3). Stationary STI measurements throughout the walkdowns and countdowns remained consistently 2° to 4°F below the GEI, with the RSS location being more accurate than Camera Site 2 because of its closer proximity to the vehicle. The portable STI scanner was more erratic, ranging from approximately 7°F low to matching the GEI exactly. The IR gun was even more erratic, ranging from 8°F low to matching the GEI exactly.

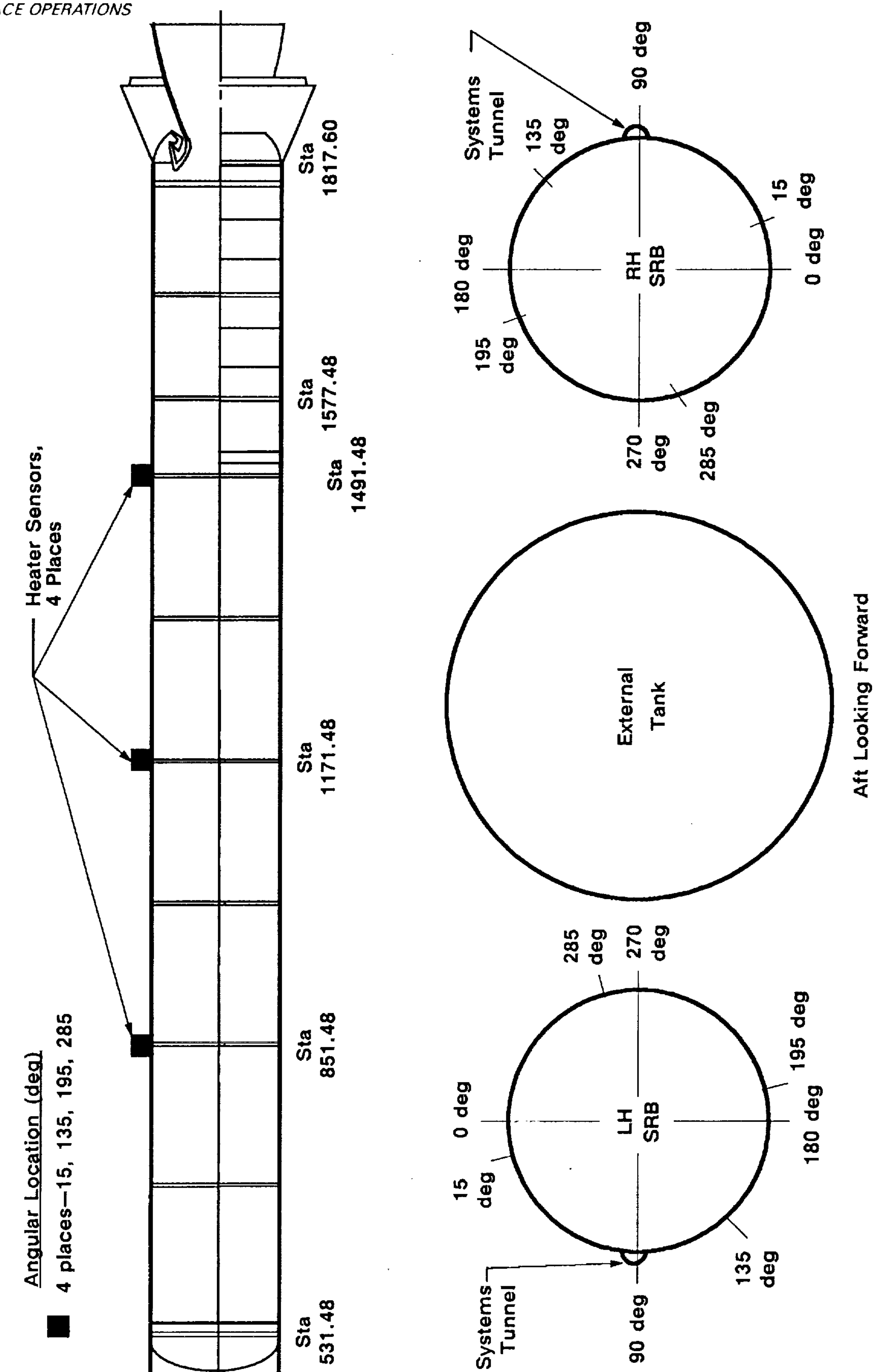
<u>GEI Temperature Measurements</u>. Figures 4.8-6 through 4.8-10 show locations of the GEI and joint heater sensors for the igniter adapter, field joints, case acreage, nozzle region, and aft exit cone, respectively. Figures 4.8-11 through 4.8-40 present February historical predictions. These predictions are based on event sequencing, as specified in Table 4.8-7. Figures 4.8-41 through 4.8-97 show actual STS-36 countdown data. Despite the difference between actual and historical ambient temperatures during the days and weeks prior to launch, temperatures during the LCC timeframe were similar, the actual was slightly warmer. Due to the warmer than ambient actual temperatures, the historical predictions in the nozzle regions and the case acreage differed significantly from the actual GEI data. The T-5 minute historical versus actual temperature comparisons were in close agreement



Legend
△ GEI Temperature
● Pressure (OFI)

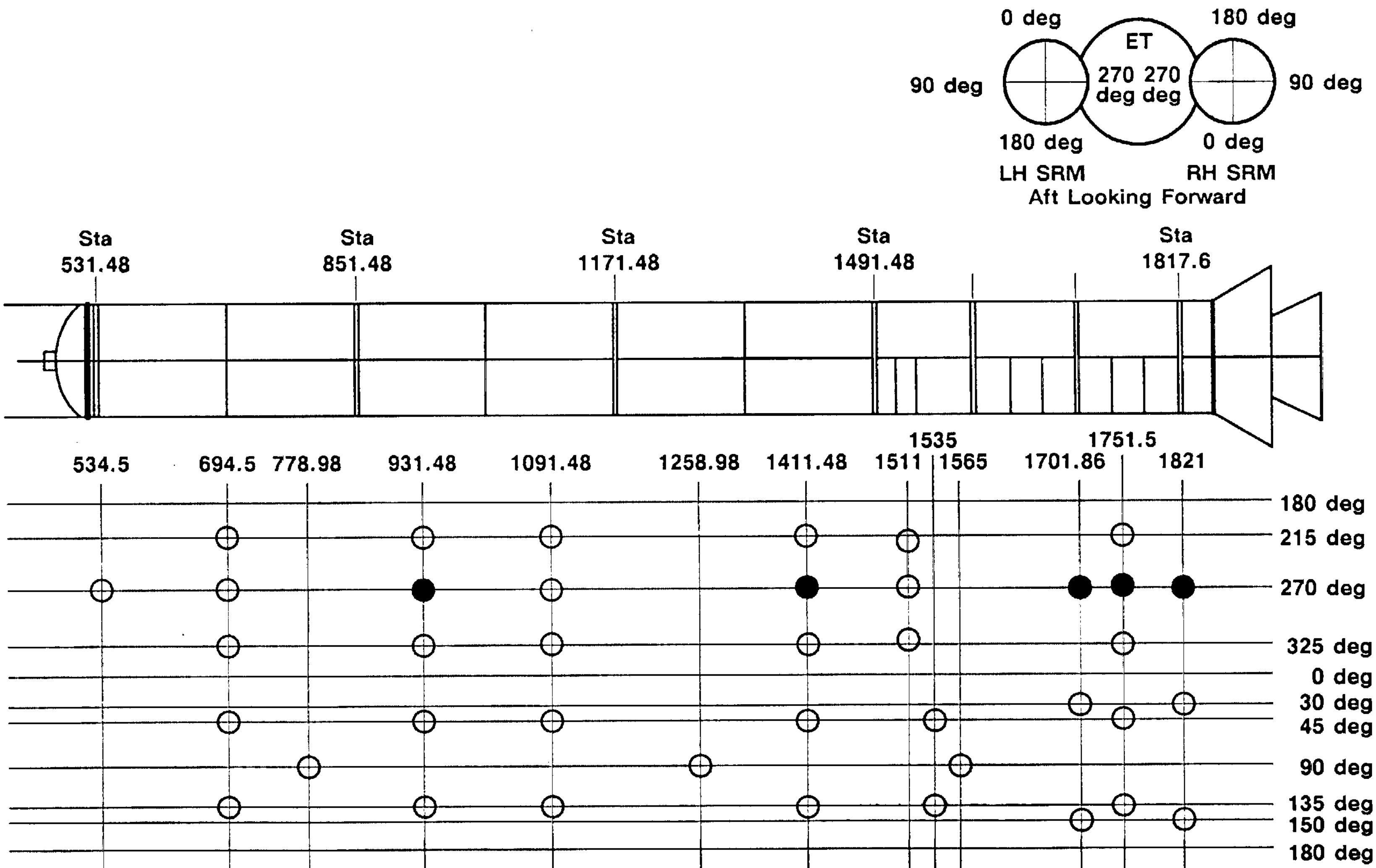
*One of two per booster required for LCC compliance

Figure 4.8-6. Forward Dome GEI



A023172a

Figure 4.8-7. Field Joint Heater Temperature Sensors

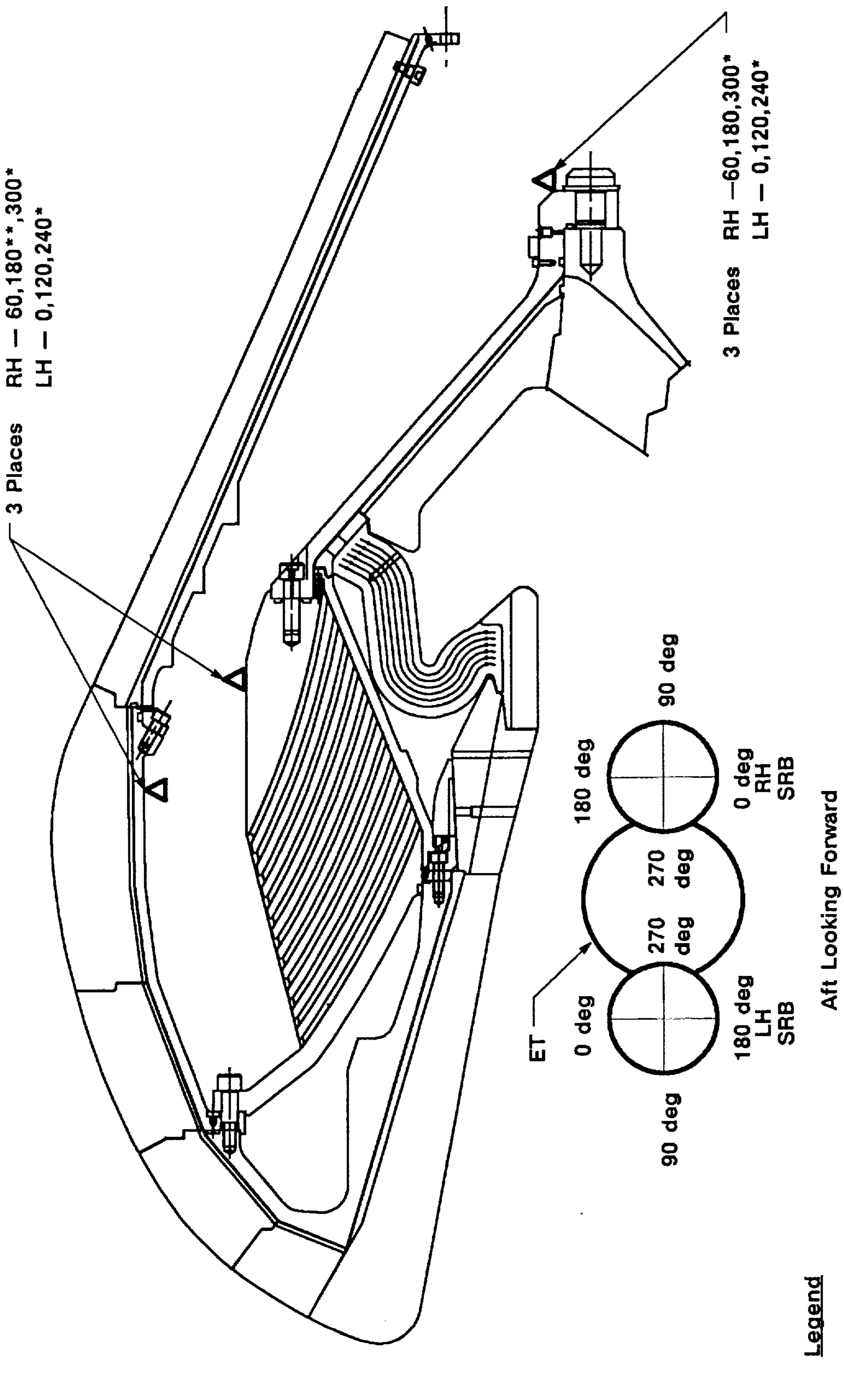


○ Denotes case GEI temperature sensors
● Denotes case GEI temperature sensors required for LCC

Note: Three of five per motor required for LCC compliance

Figure 4.8-8. Case Acreage GEI

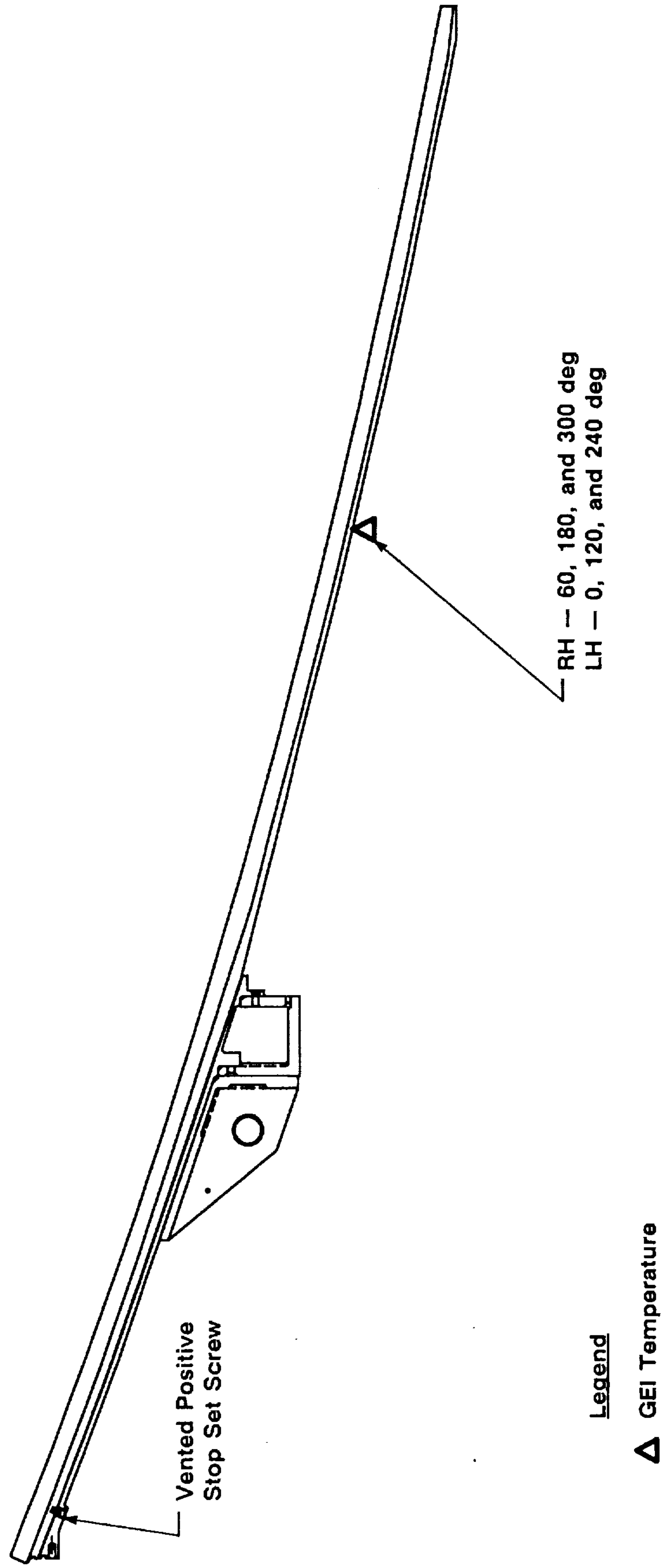
A023168a



Legend

△ GEI Temperature
*Two of three per each location required for LCC compliance
**Actual flex bearing location at 108 deg

Figure 4.8-9. Nozzle/Exit Cone GEI



A023170a

Figure 4.8-10. Aft Exit Cone GEI

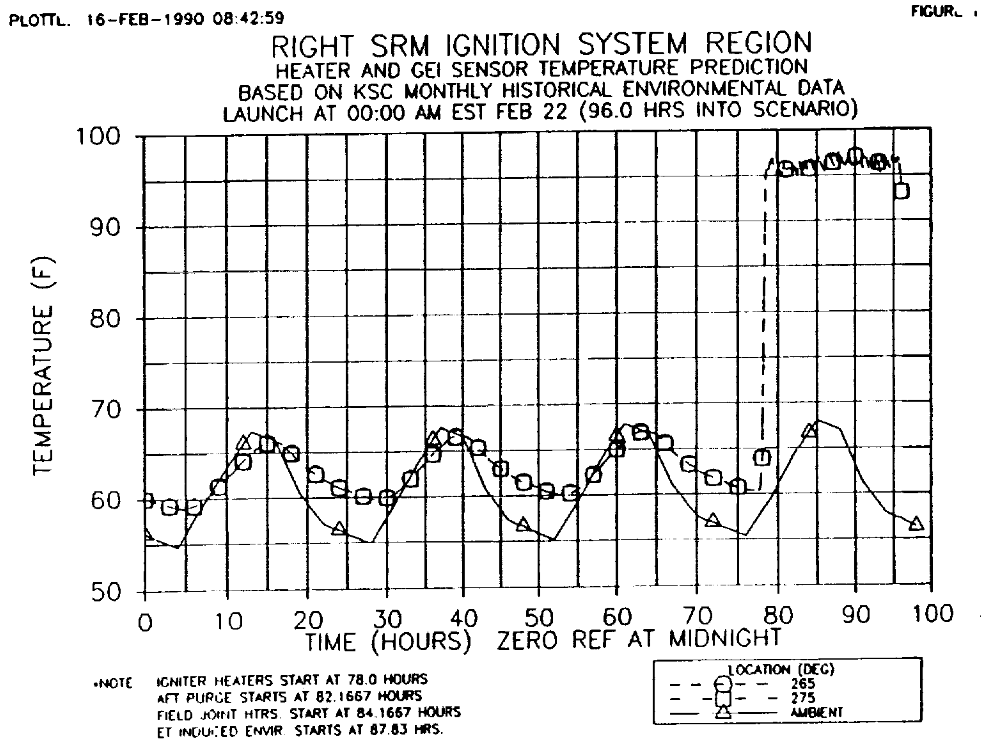


Figure 4.8-11 RH Igniter System Heater and GEI Sensor Temperature Prediction

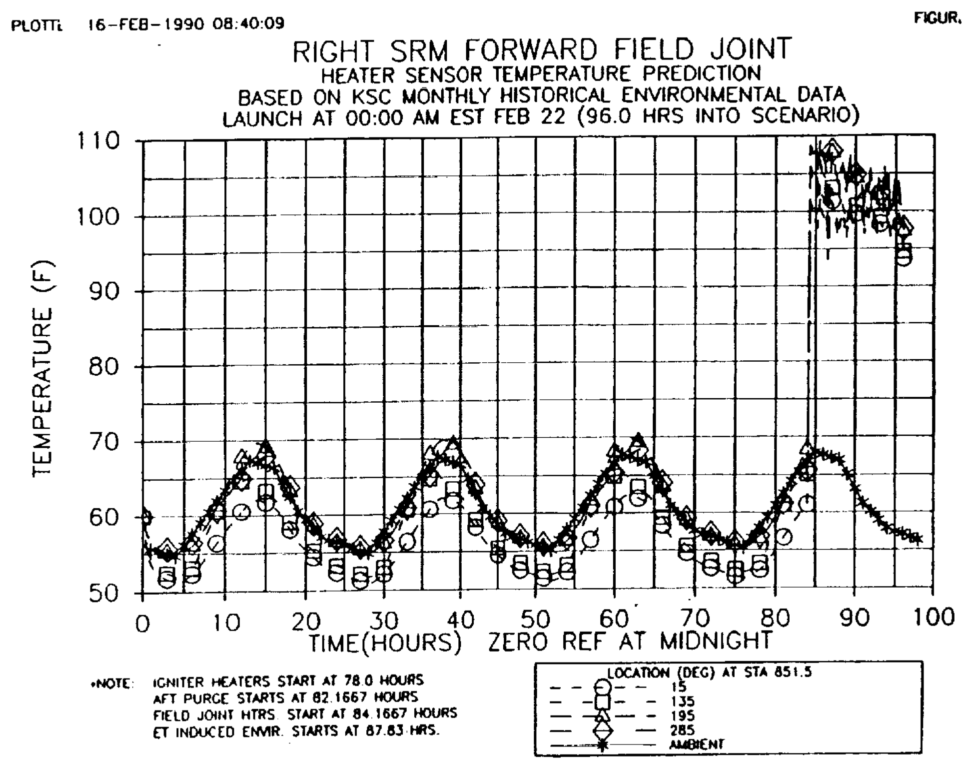


Figure 4.8-12 RH Forward Field Joint Heater Sensor Temperature Prediction

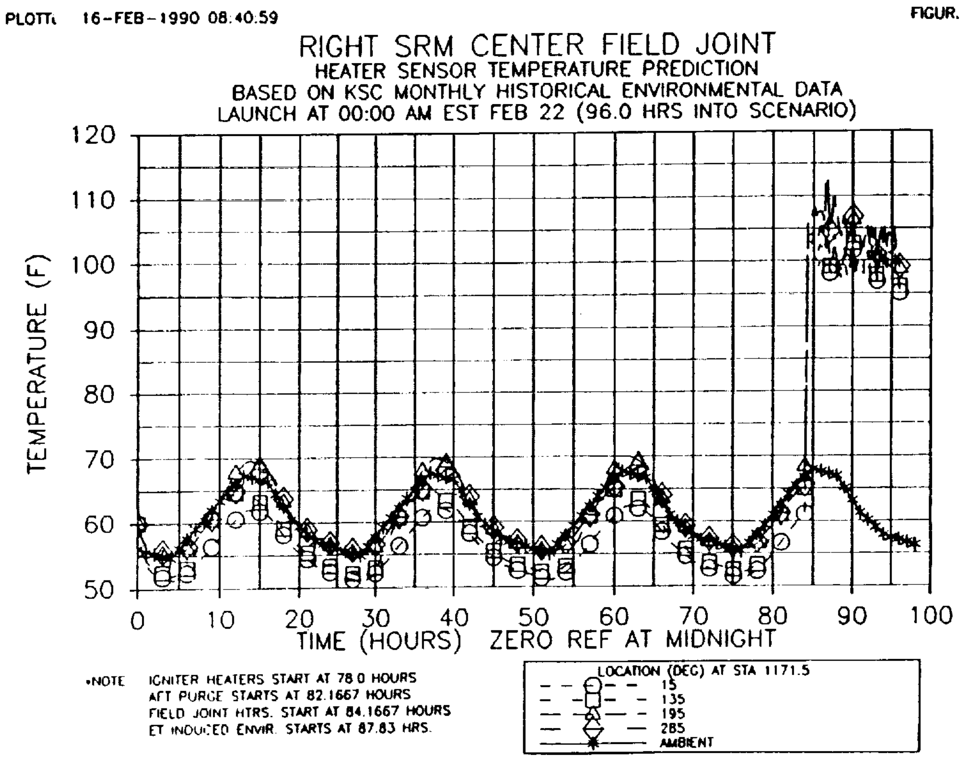


Figure 4.8-13 RH Center Field Joint Heater Sensor Temperature Prediction

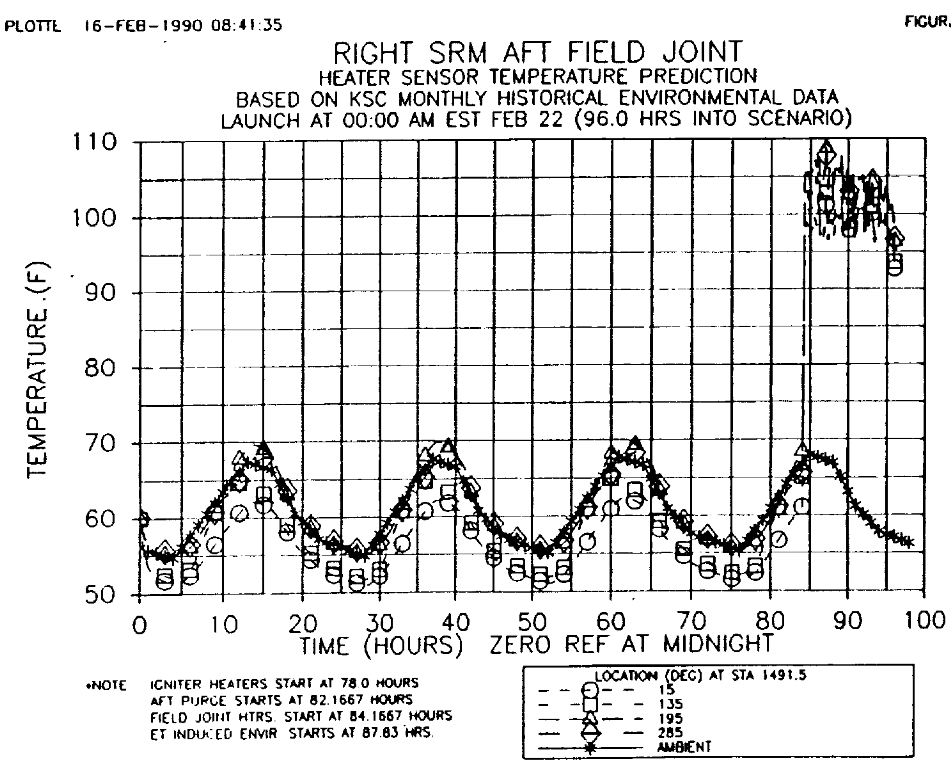


Figure 4.8-14 RH Aft Field Joint Heater Sensor Temperature Prediction

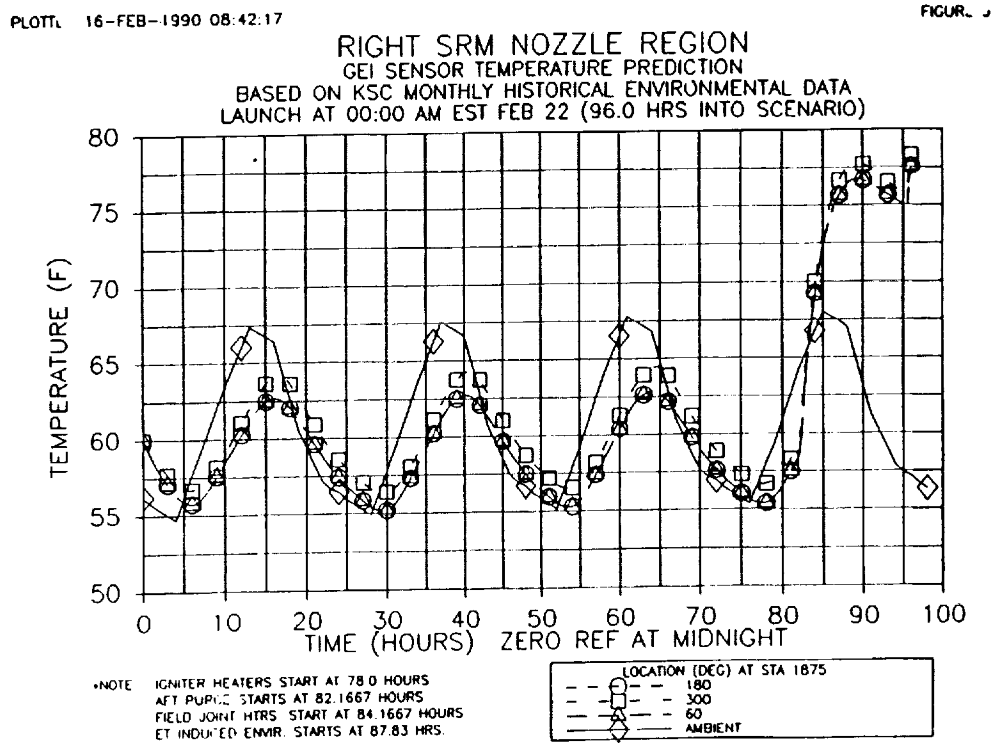


Figure 4.8-15 RH Nozzle GEI Sensor Temperature Prediction

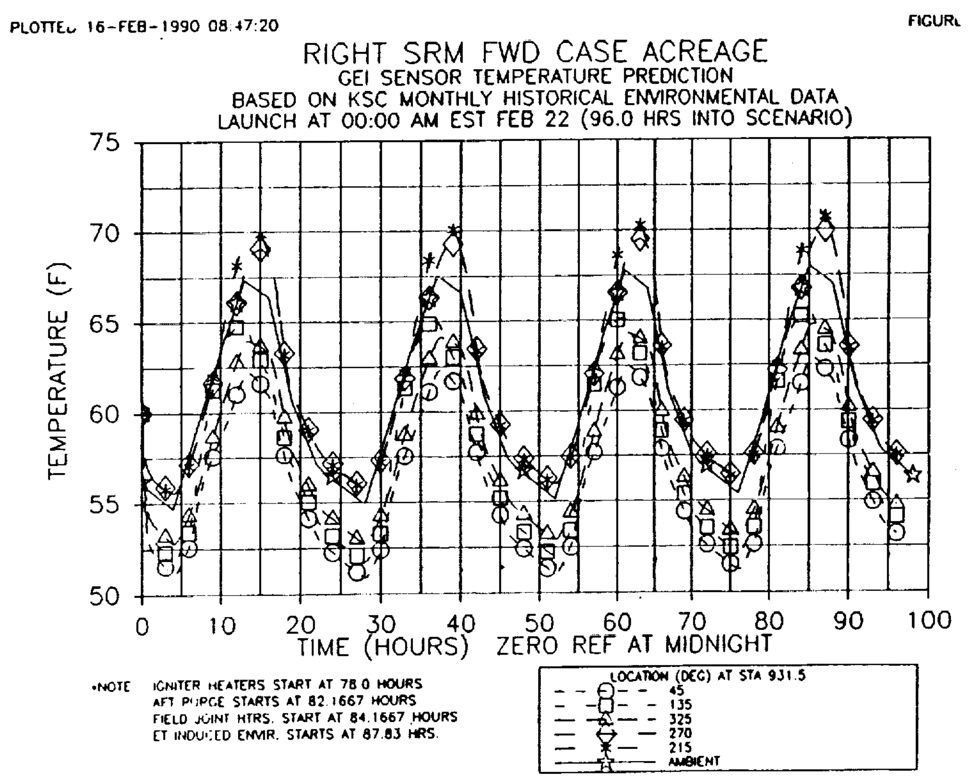


Figure 4.8-16 RH Forward Case Acreage GEI Sensor Temperature Prediction

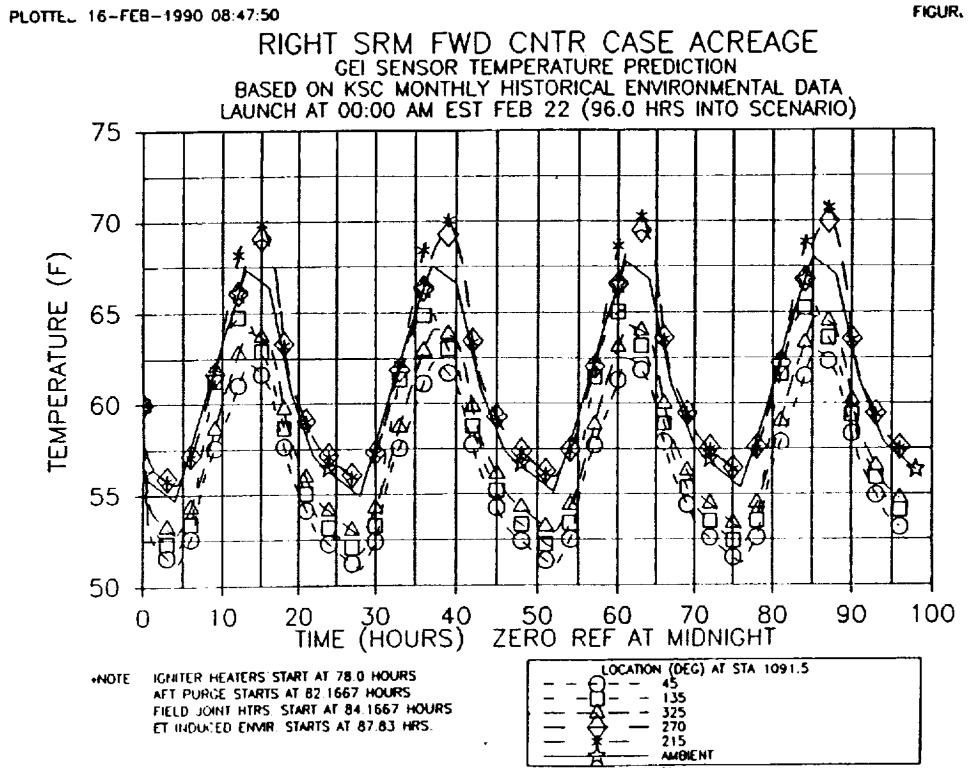


Figure 4.8-17 RH Forward Center Case Acreage GEI Sensor Temperature Prediction

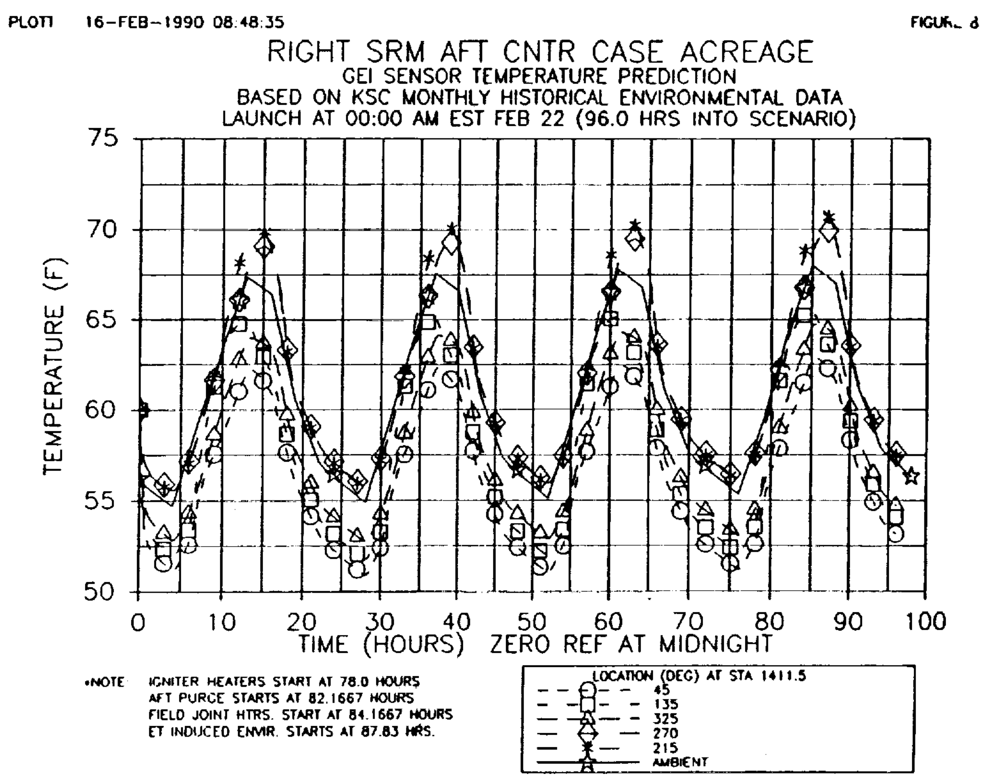


Figure 4.8-18 RH Aft Center Case Acreage GEI Sensor Temperature Prediction

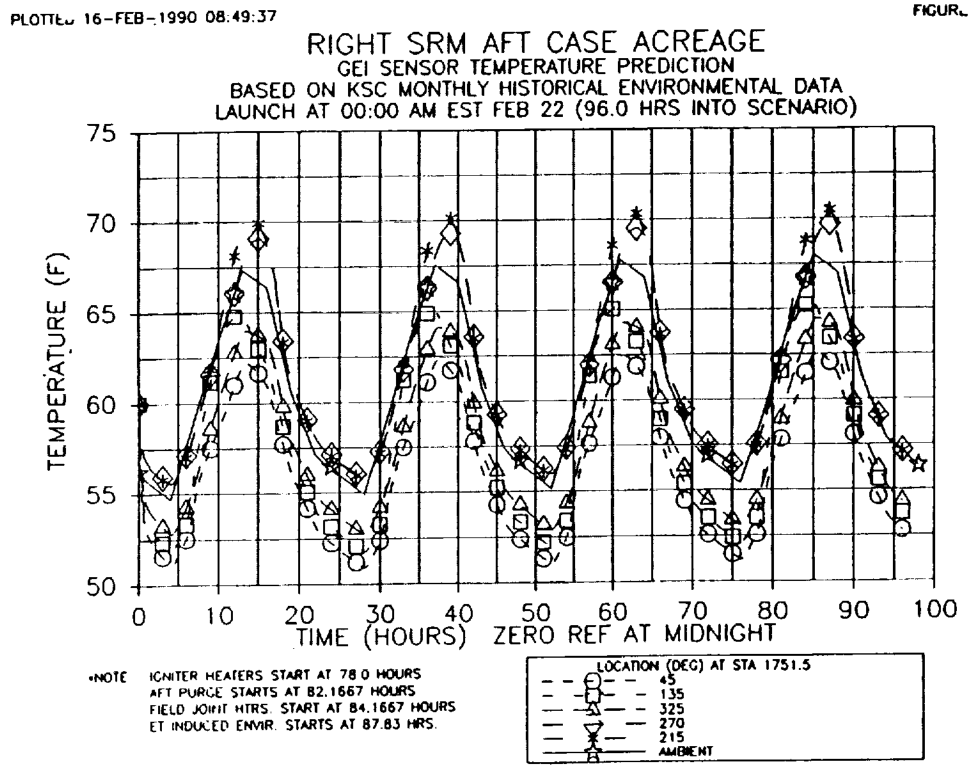


Figure 4.8-19 RH Aft Case Acreage GEI Sensor Temperature Prediction

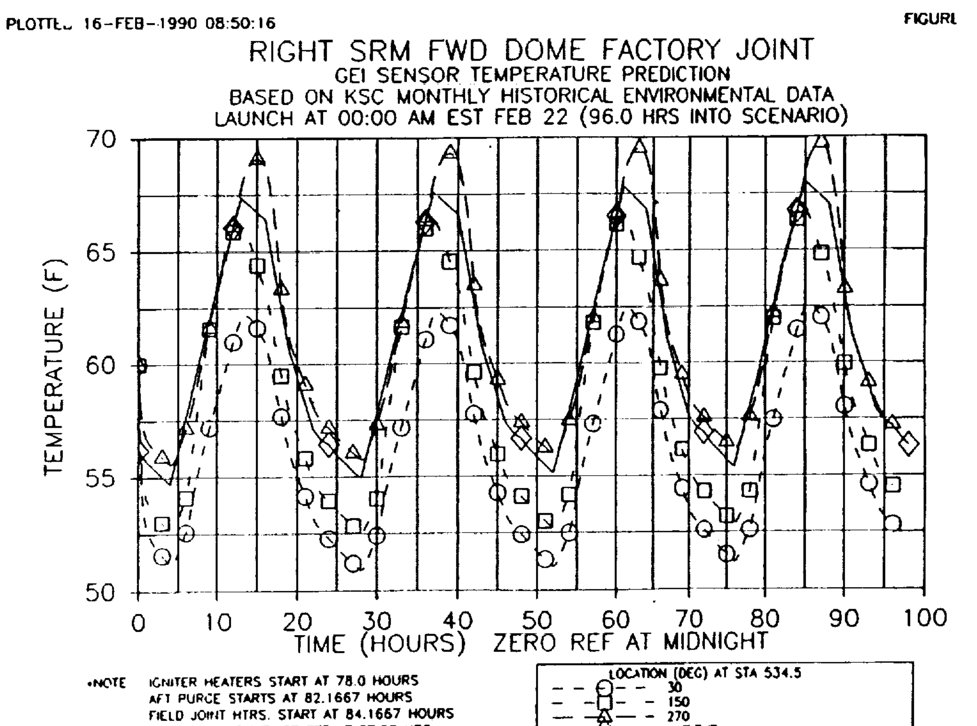


Figure 4.8-20 RH Forward Dome Factory Joint GEI Sensor Temperature Prediction

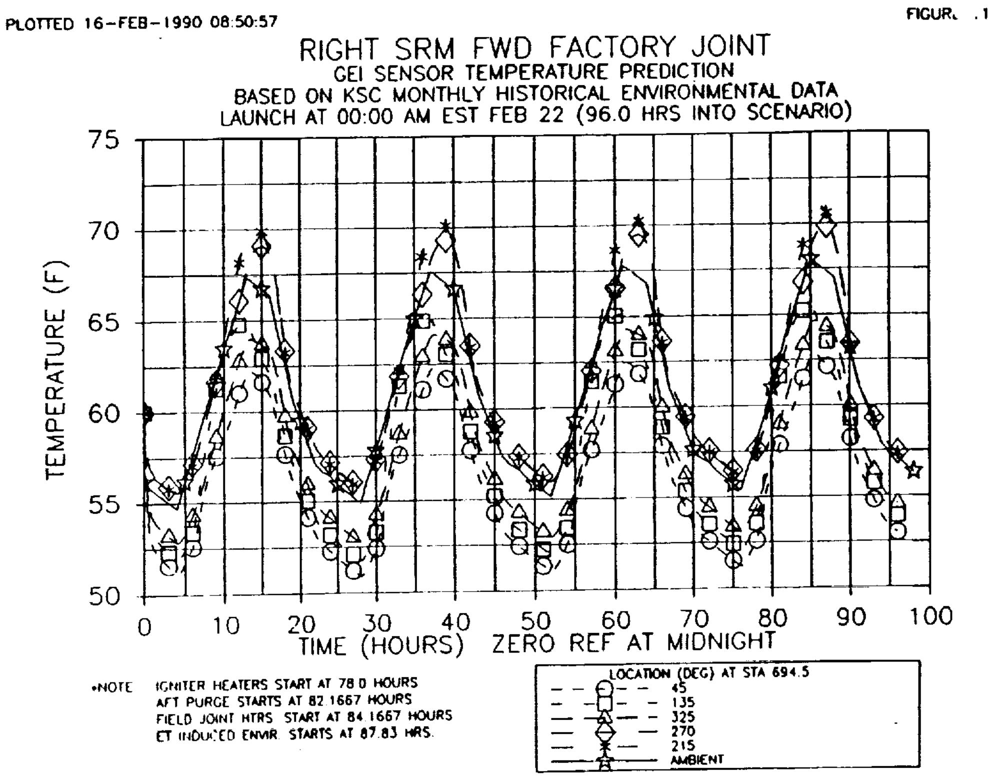


Figure 4.8-21 RH Forward Factory Joint GEI Sensor Temperature Prediction

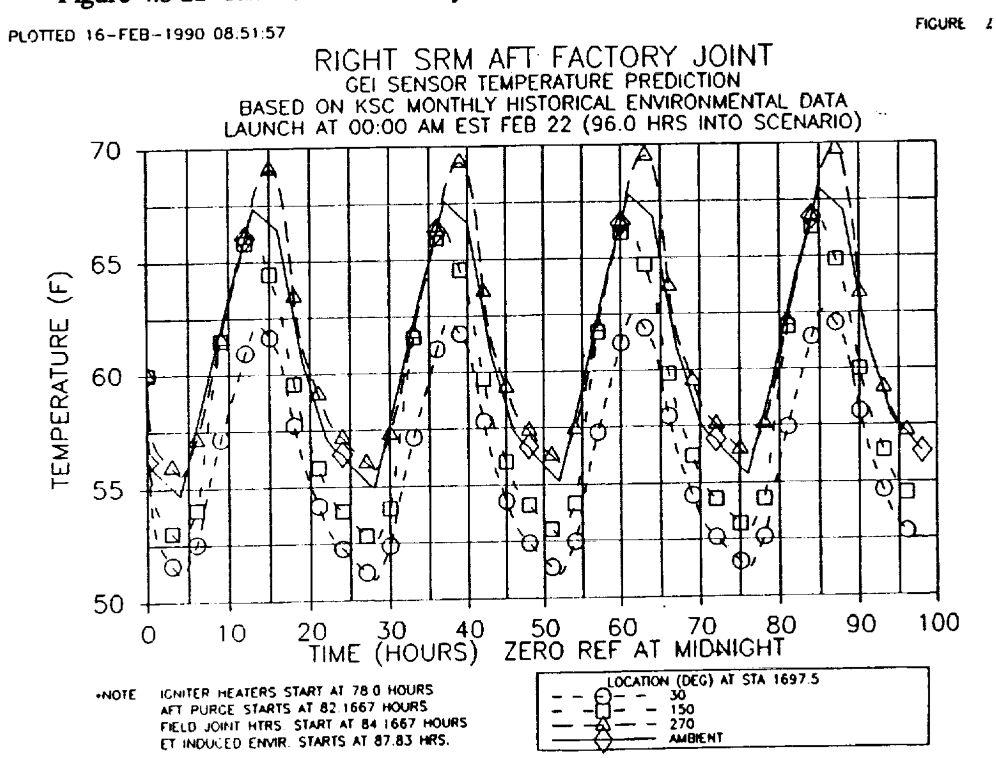


Figure 4.8-22 RH Aft Factory Joint GEI Sensor Temperature Prediction

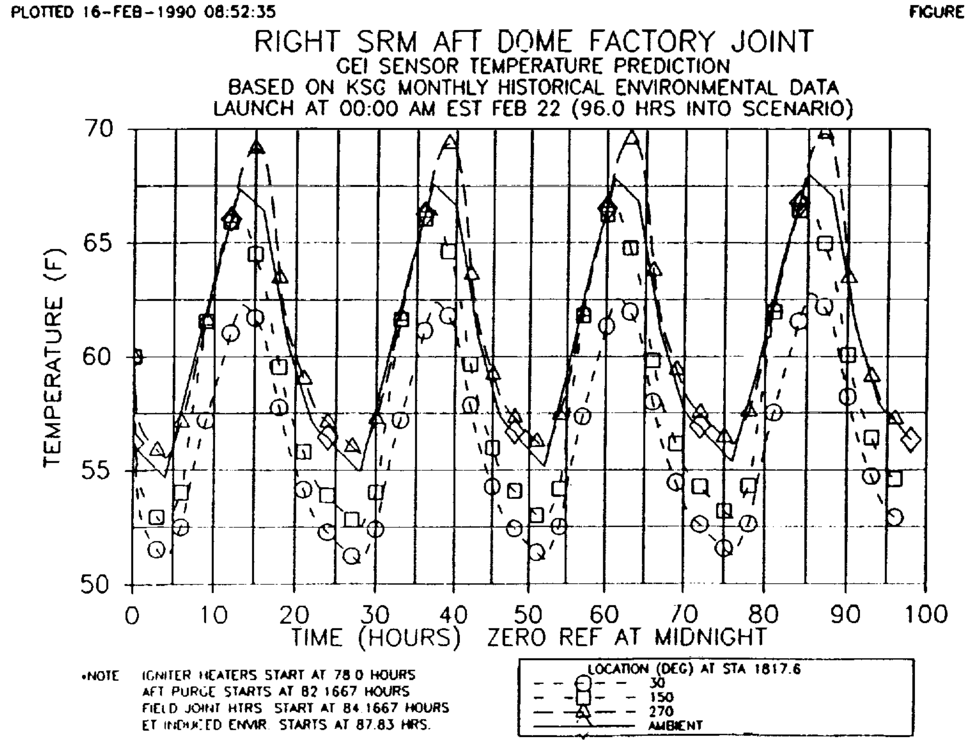


Figure 4.8-23 RH Aft Dome Factory Joint GEI Sensor Temperature Prediction

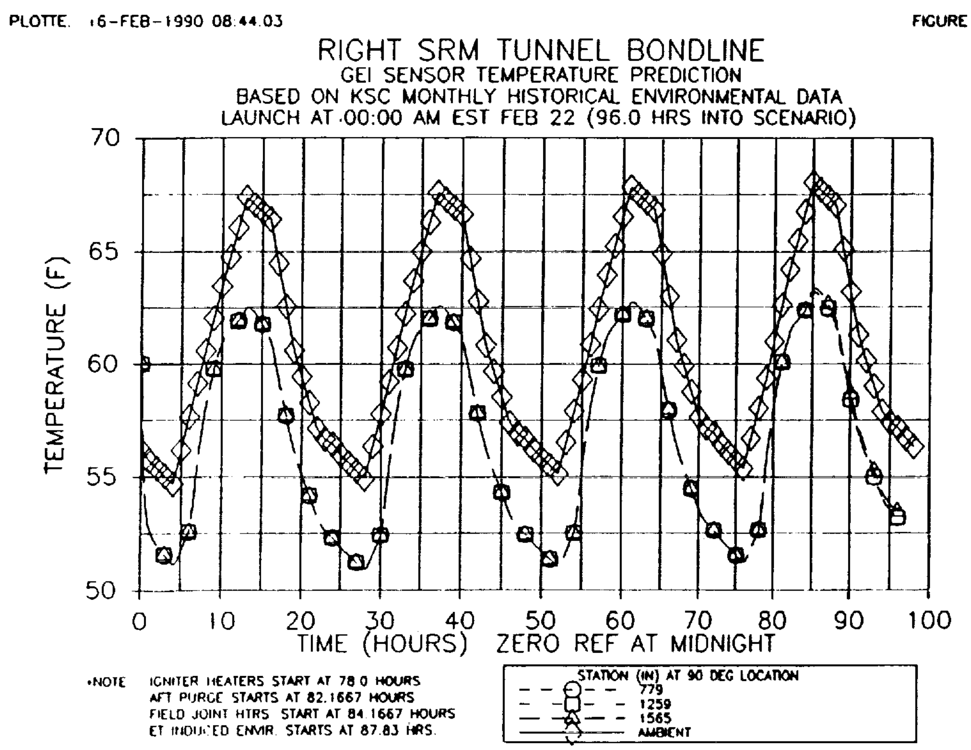


Figure 4.8-24 RH Tunnel Bondline GEI Sensor Temperature Prediction

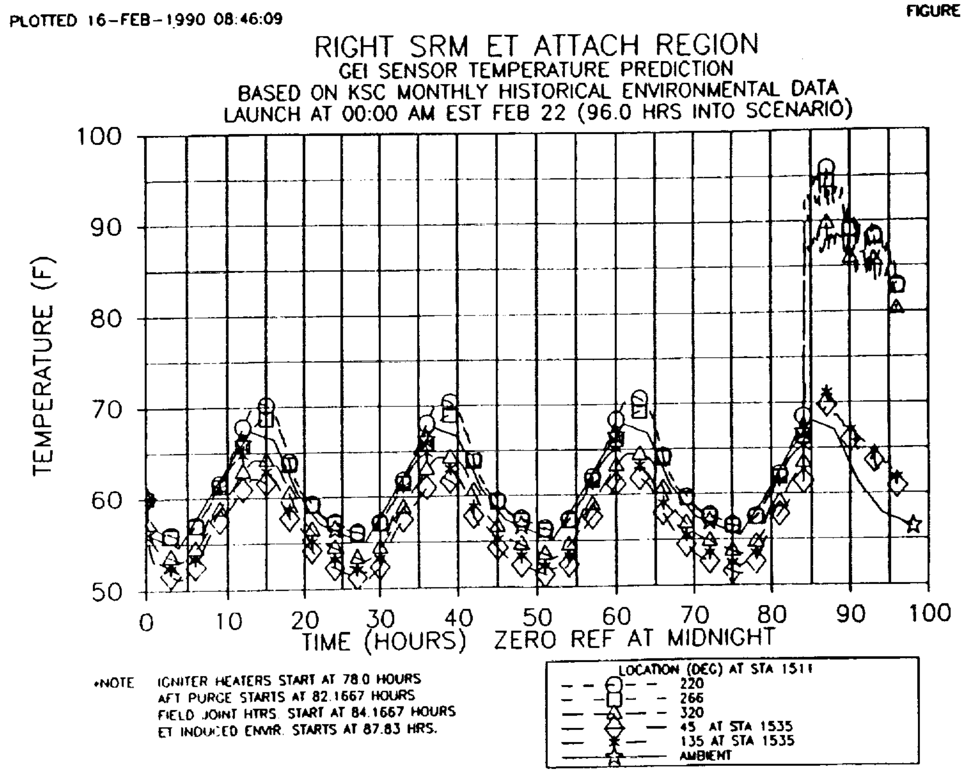


Figure 4.8-25 RH ET Attach Region GEI Sensor Temperature Prediction

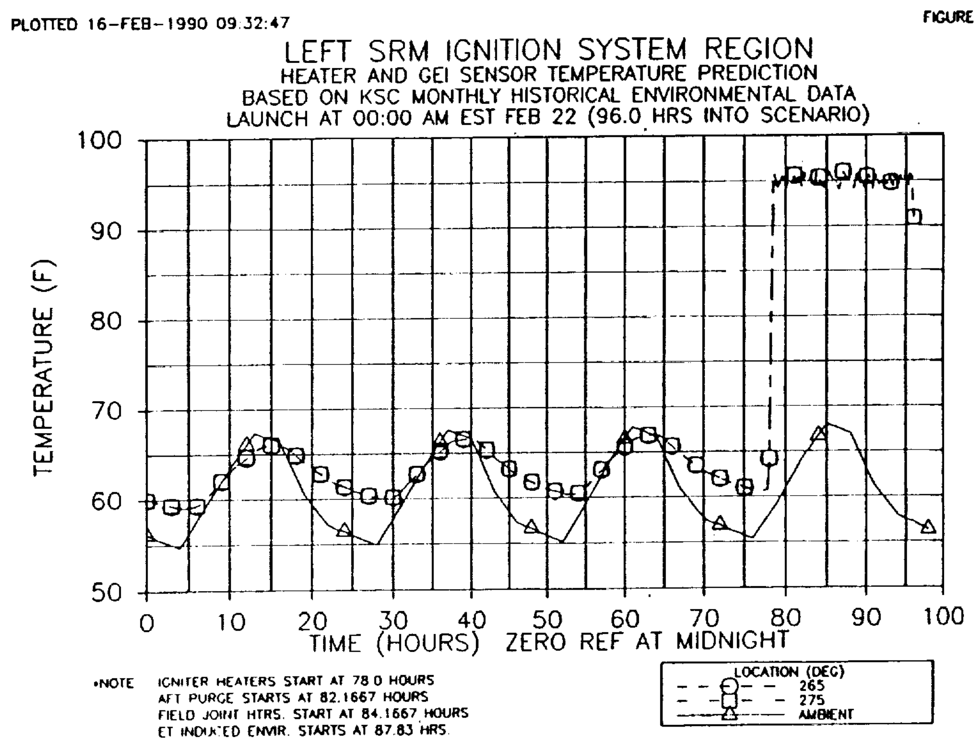


Figure 4.8-26 LH Ignition System Heater and GEI Sensor Temperature Prediction

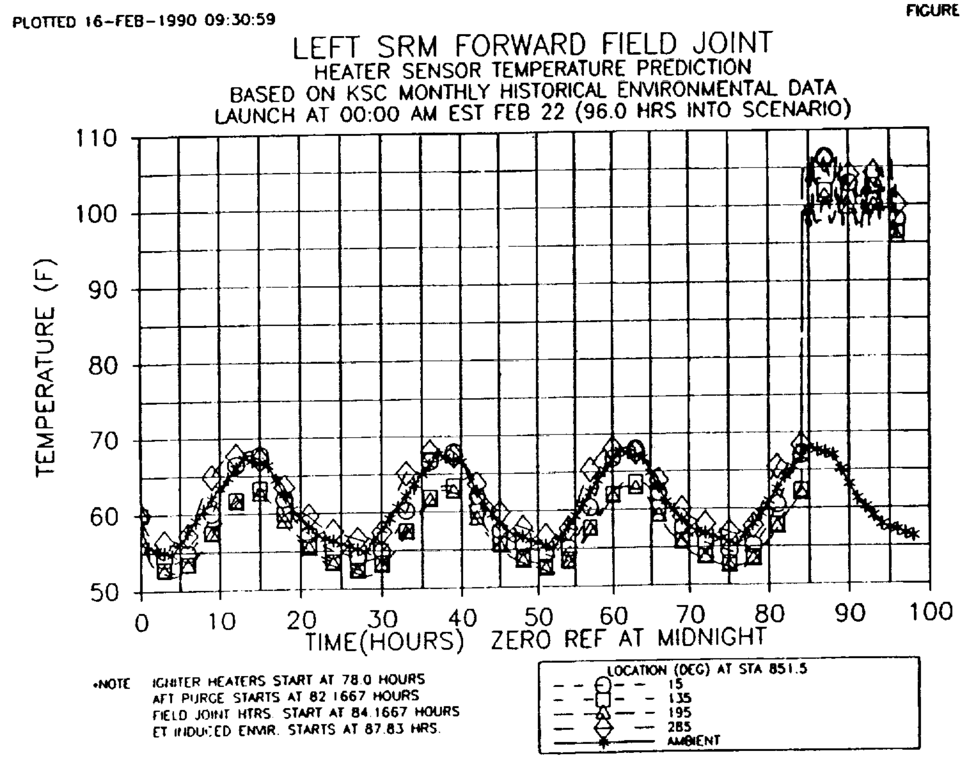


Figure 4.8-27 LH Forward Field Joint Heater Sensor Temperature Prediction

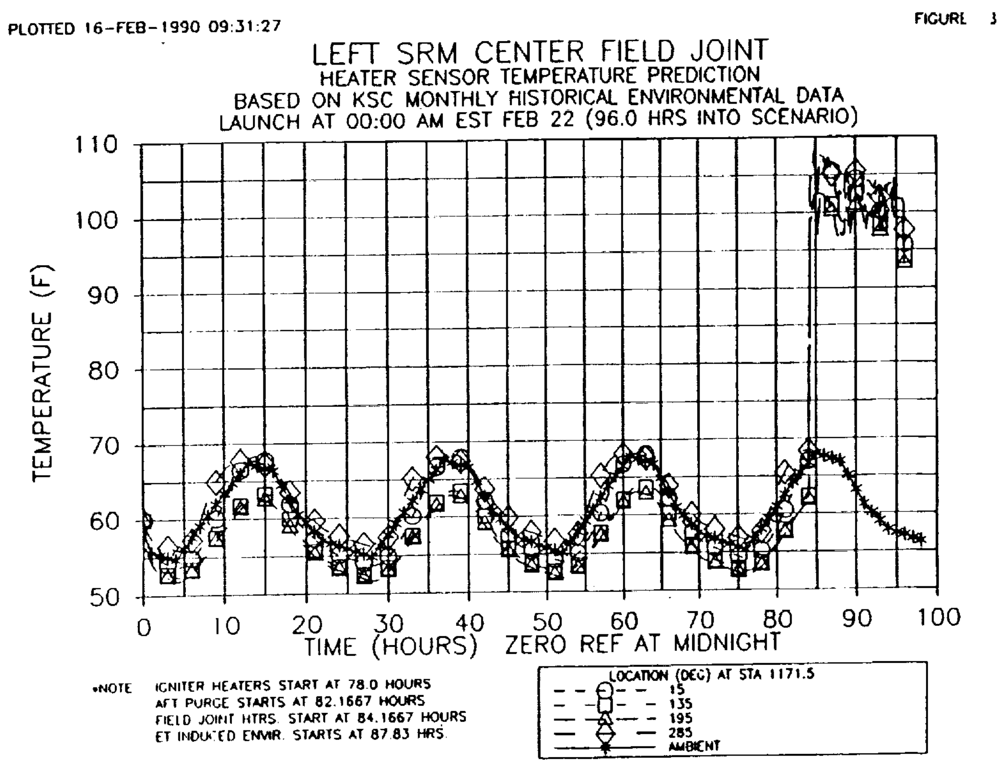


Figure 4.8-28 LH Center Field Joint Heater Sensor Temperature Prediction

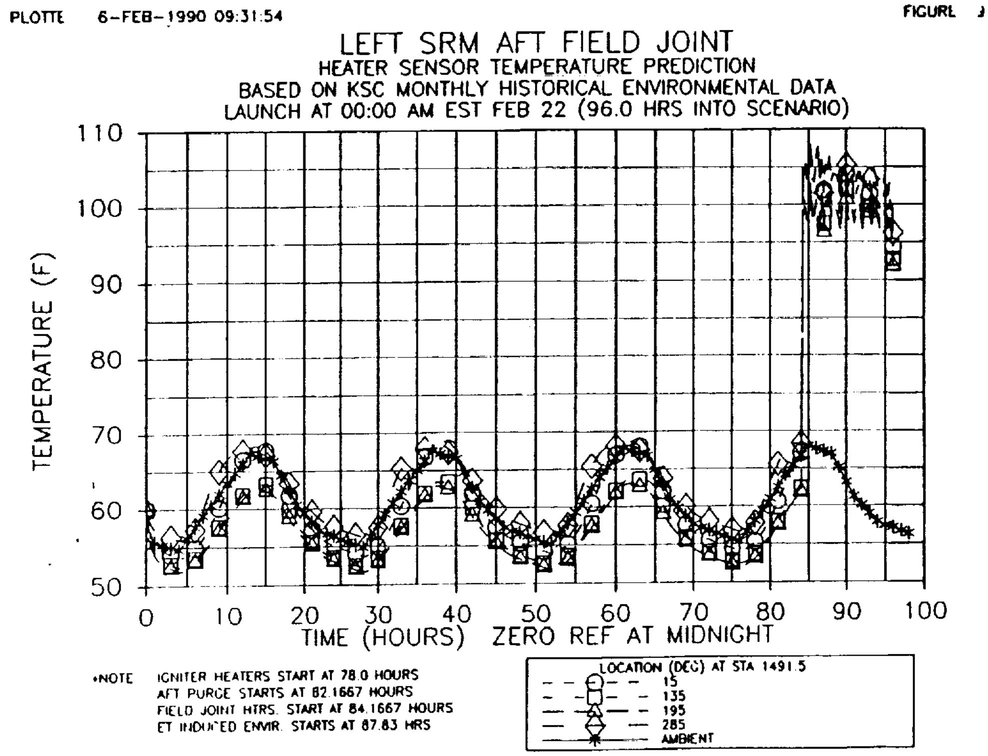


Figure 4.8-29 LH Aft Field Joint Heater Sensor Temperature Prediction

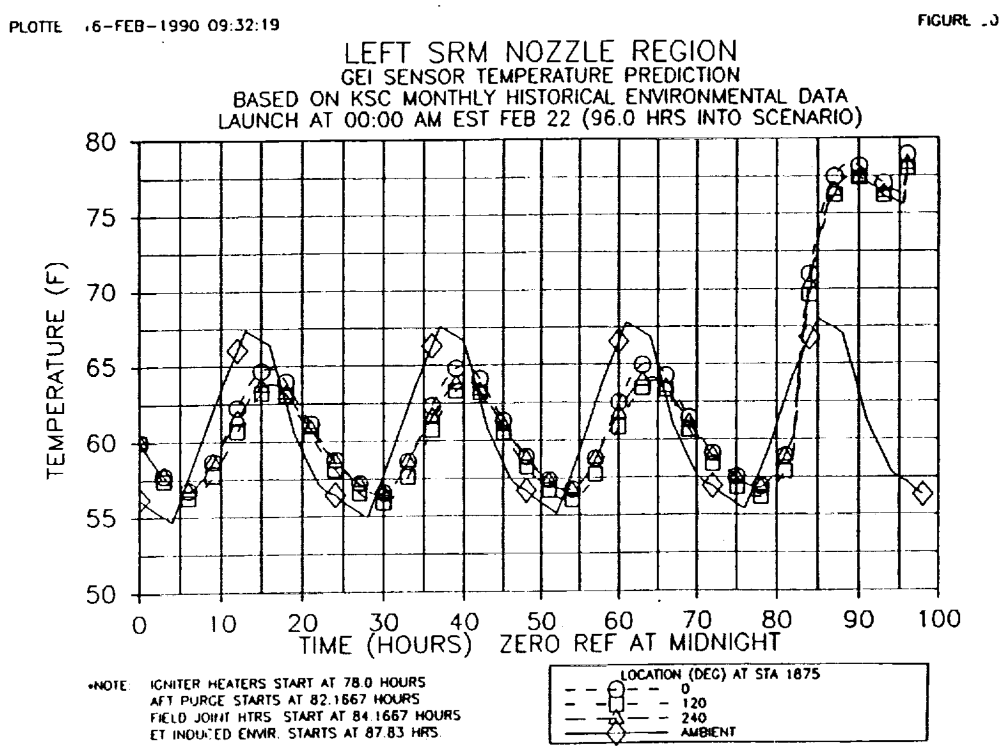


Figure 4.8-30 LH Nozzle GEI Sensor Temperature Prediction

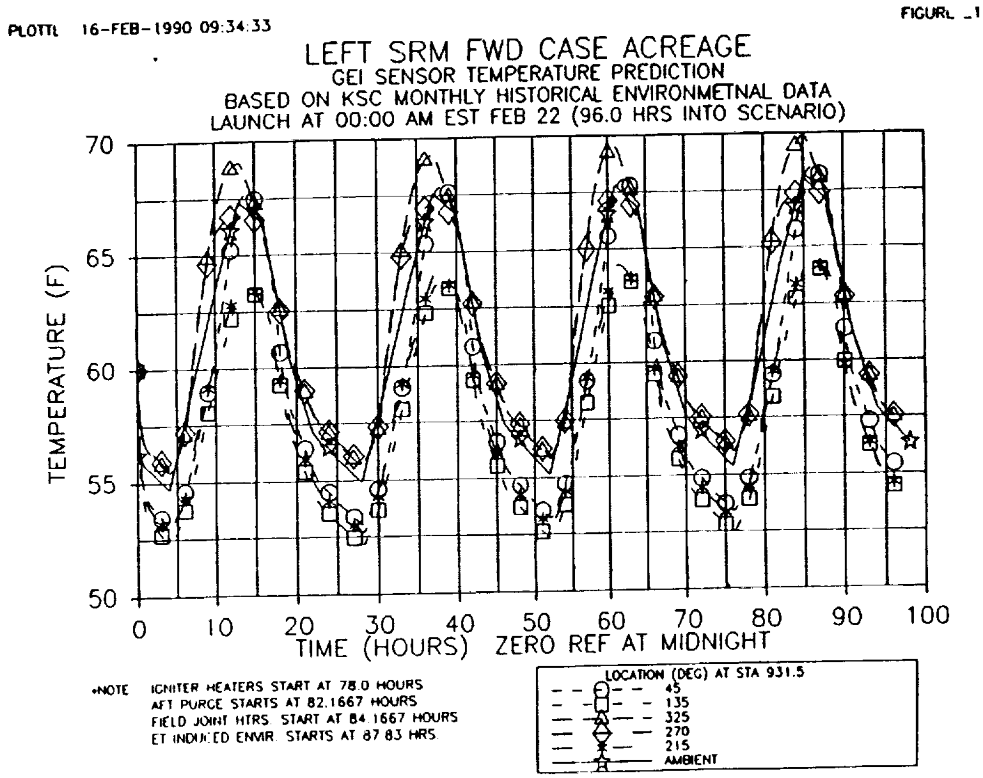


Figure 4.8-31 LH Forward Case Acreage GEI Sensor Temperature Prediction

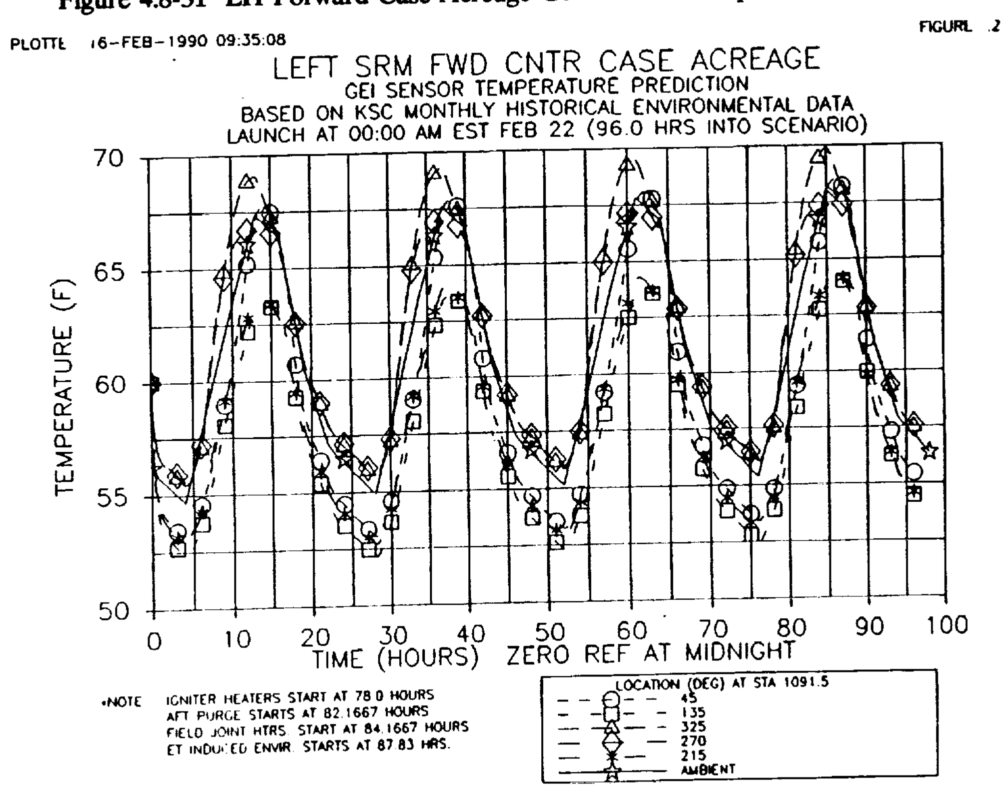


Figure 4.8-32 LH Forward Center Case Acreage GEI Sensor Temperature Prediction

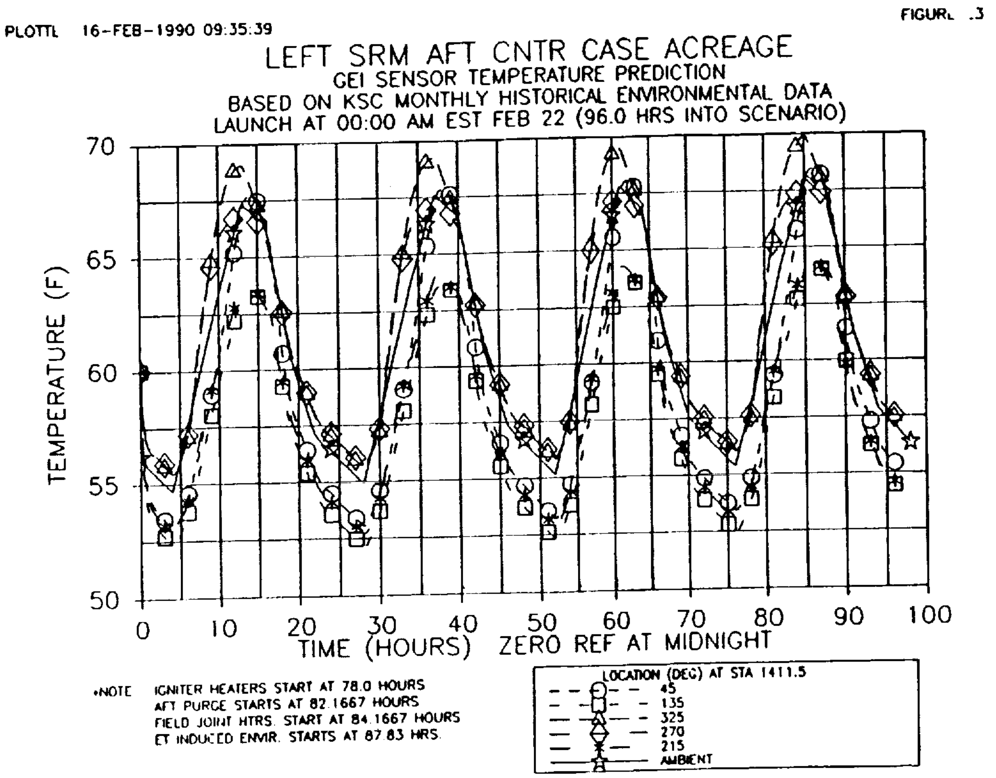


Figure 4.8-33 LH Aft Center Case Acreage GEI Sensor Temperature Prediction

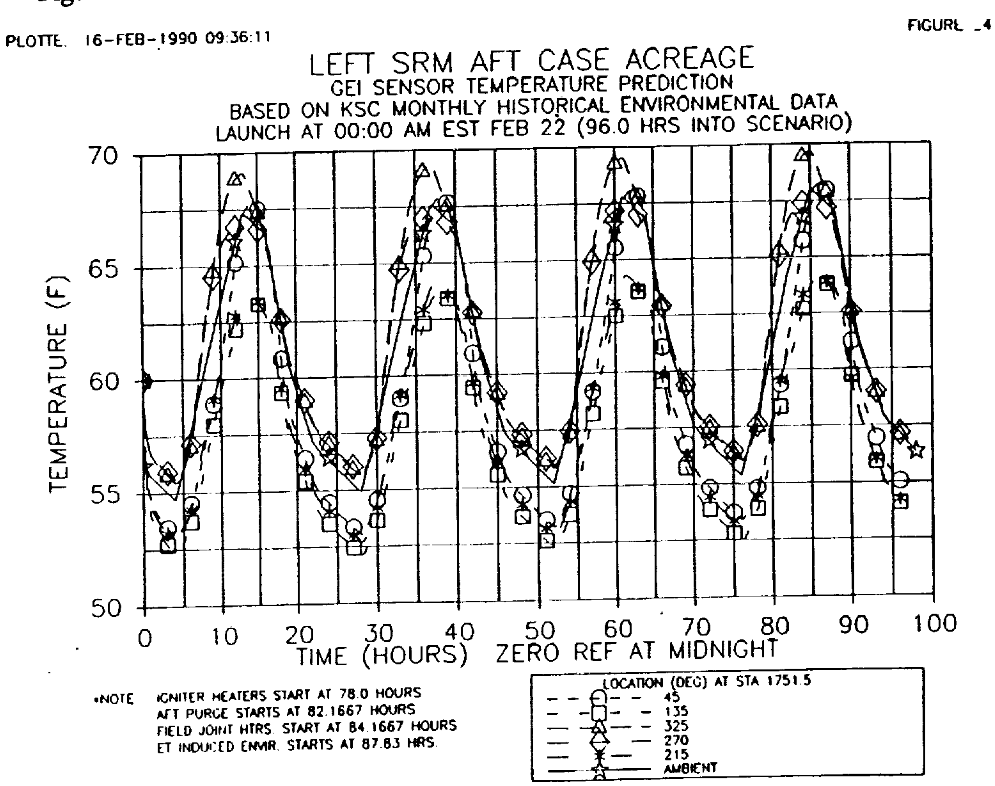


Figure 4.8-34 LH Aft Case Acreage GEI Sensor Temperature Prediction

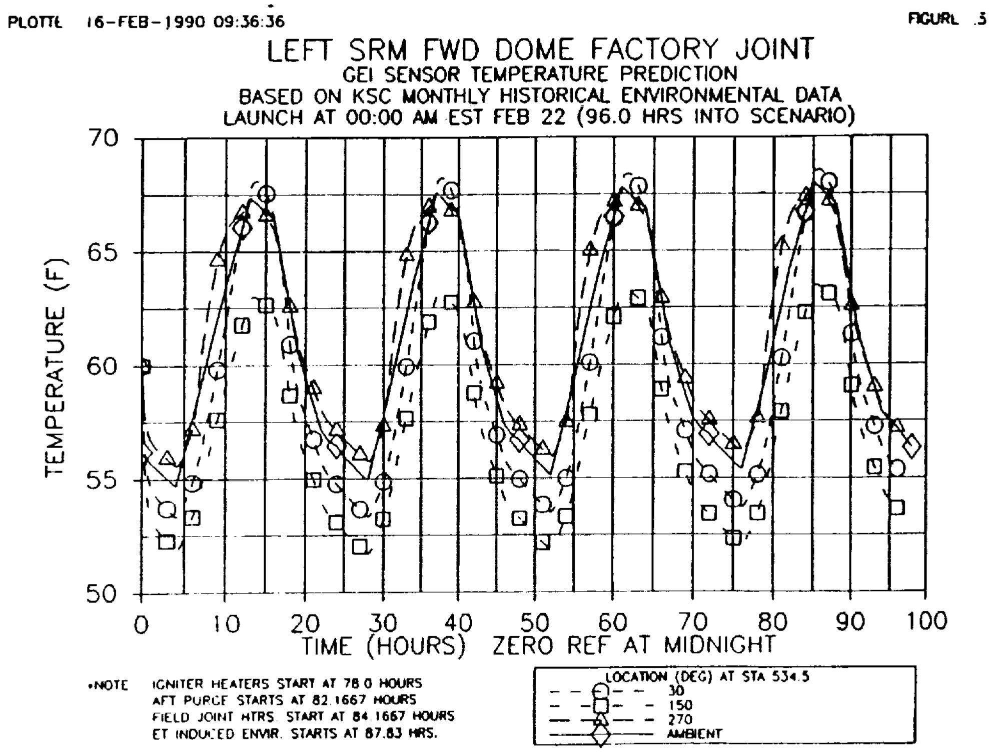


Figure 4.8-35 LH Forward Dome Factory Joint GEI Sensor Temperature Prediction

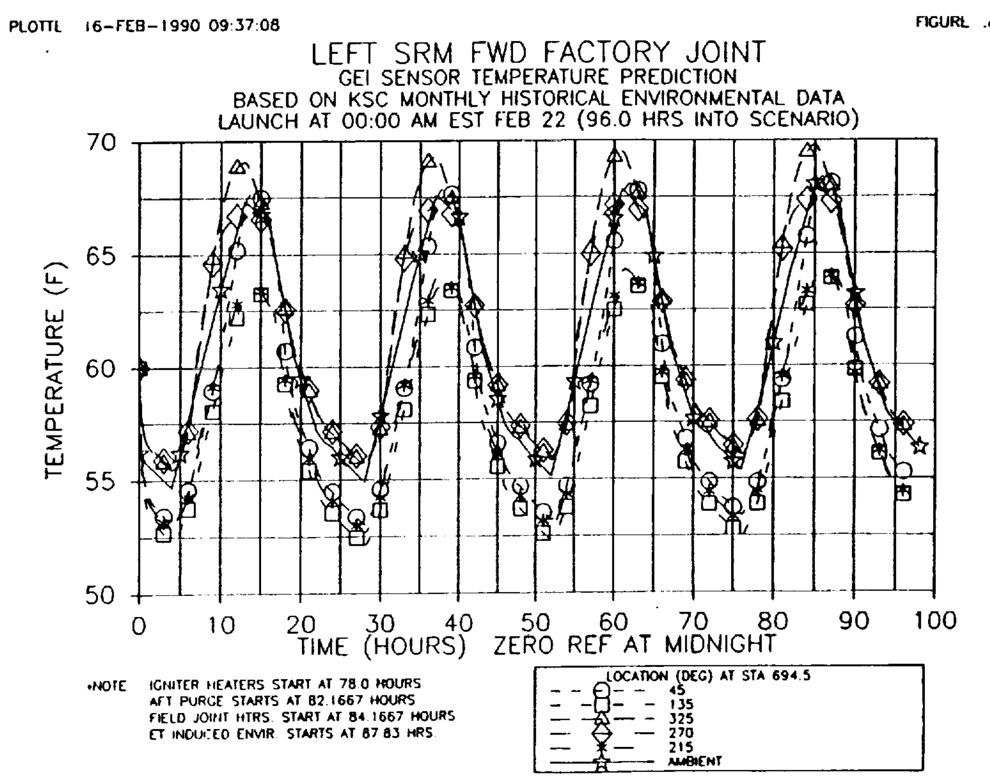


Figure 4.8-36 LH Forward Factory Joint GEI Sensor Temperature Prediction

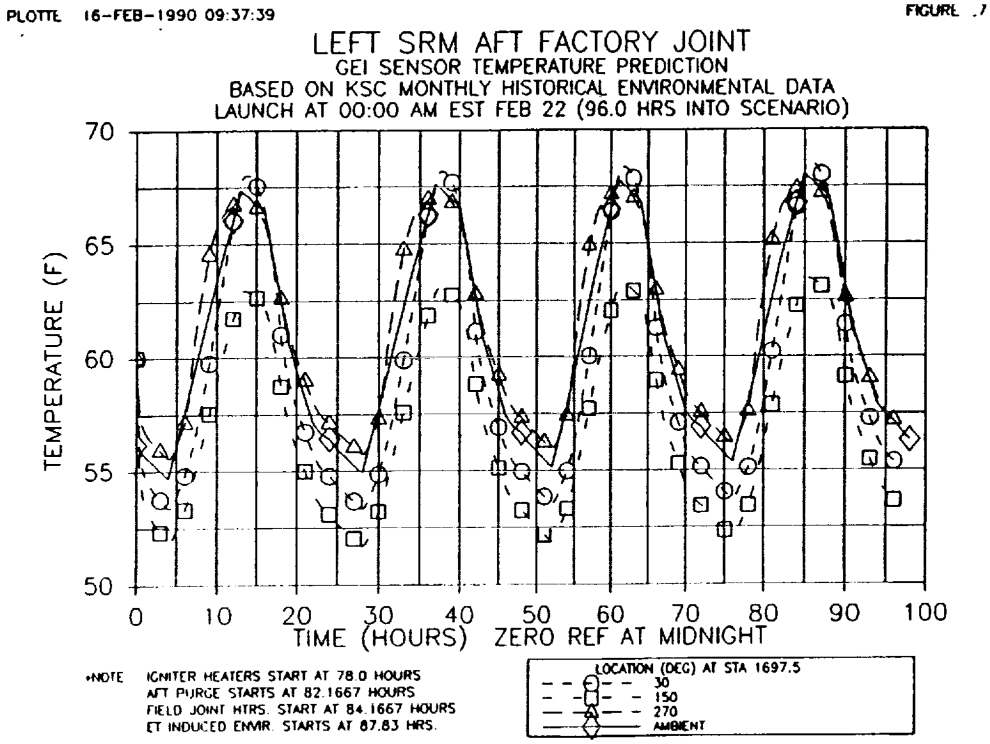


Figure 4.8-37 LH Aft Factory Joint GEI Sensor Temperature Prediction

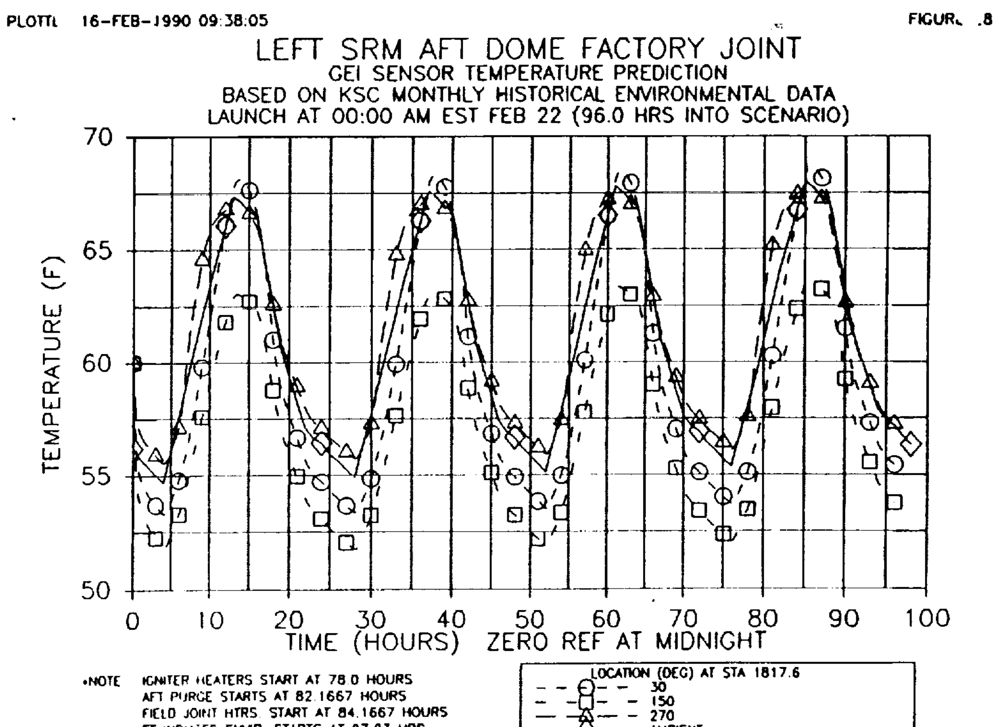


Figure 4.8-38 LH Aft Dome Factory Joint GEI Sensor Temperature Prediction

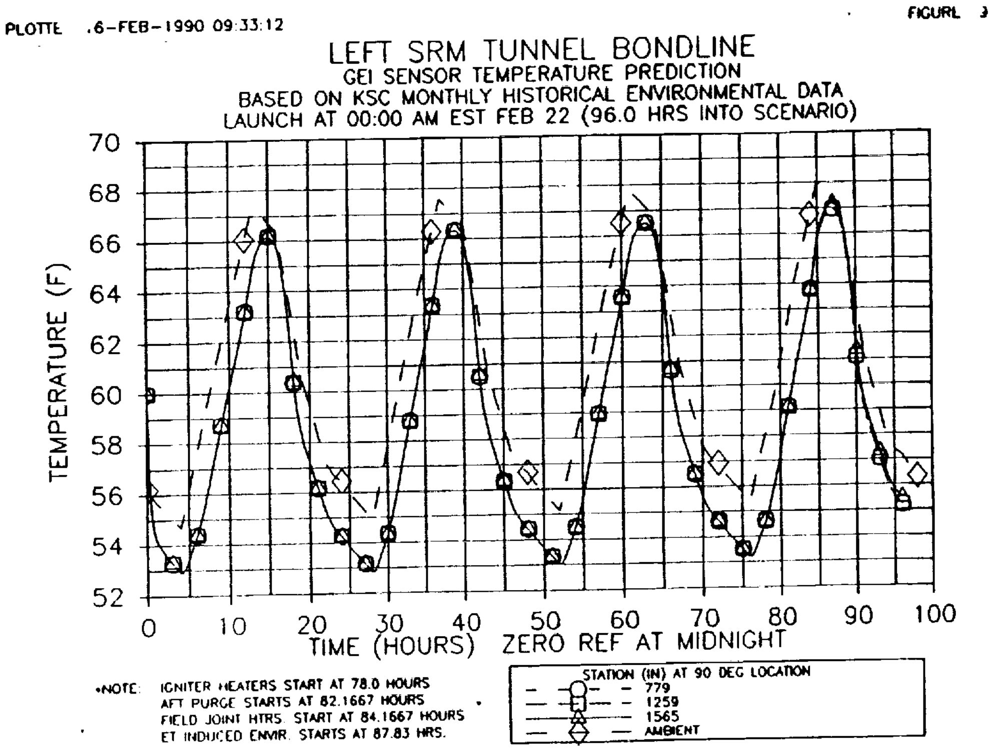


Figure 4.8-39 LH Tunnel Bondline GEI Sensor Temperature Prediction

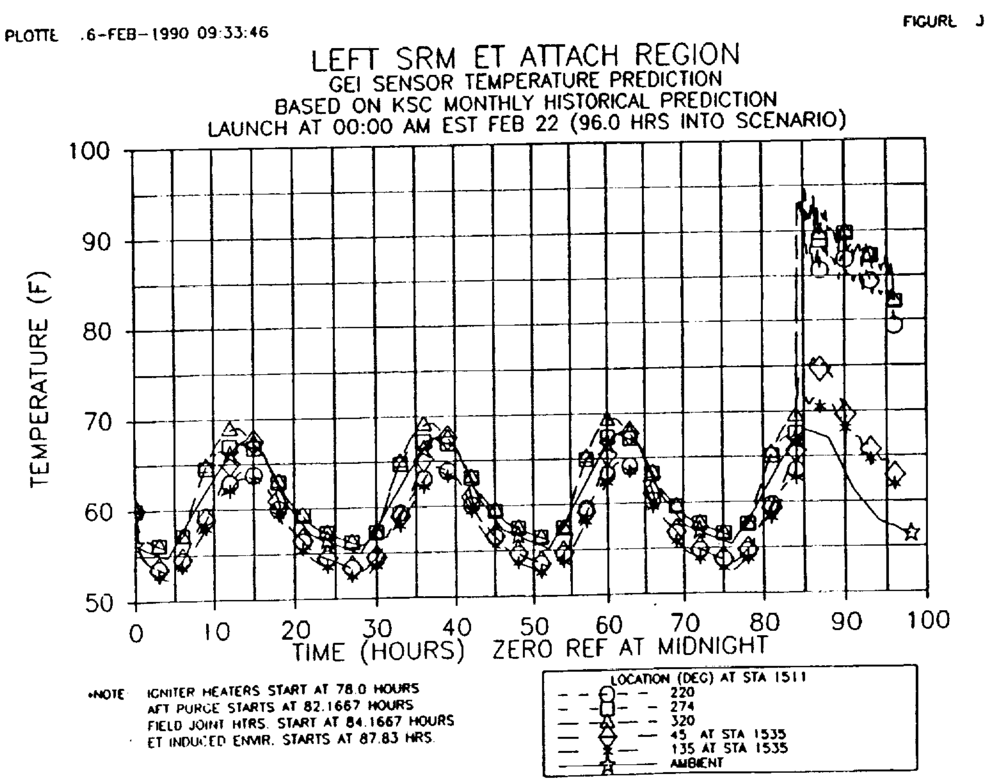


Figure 4.8-40 LH ET Attach Region GEI Sensor Temperature Prediction

Table 4.8-7. STS-36 Analytical Timeframes for Estimating Event Sequencing of February Historical Joint Heater and GEI Sensor Predictions

Time (hr)	Countdown Events in Analysis
0:01	00:01 a.m. KSC EST (18 Feb 1990)
78:00	Igniter Joint Heater Operation begins on 21 Feb 1990 (L-18 hours)
82:10	Aft Skirt Conditioning Operation begins on 21 Feb 1990 (L-13 hours 50 minutes)
84:10	Field Joint Heater Operation begins on 21 Feb 1990 (L-11 hours 50 minutes)
87:50	Induced Environments Due to ET Refrigeration Effects begins on 21 Feb 1990 (approx. L-8 hours 10 minutes)
95:51	Igniter heaters shut off on 21 Feb 1990 (T-9 minutes)
95:59	Field joint heaters shut off on 21 Feb 1990 (T-1 minute)
96:00	Assumed time of launch 22 Feb 1990, 00:00 a.m. KSC EST

Figures 4.8-11 through 4.8-40 consist of a 4 day plus 1 hour scenario

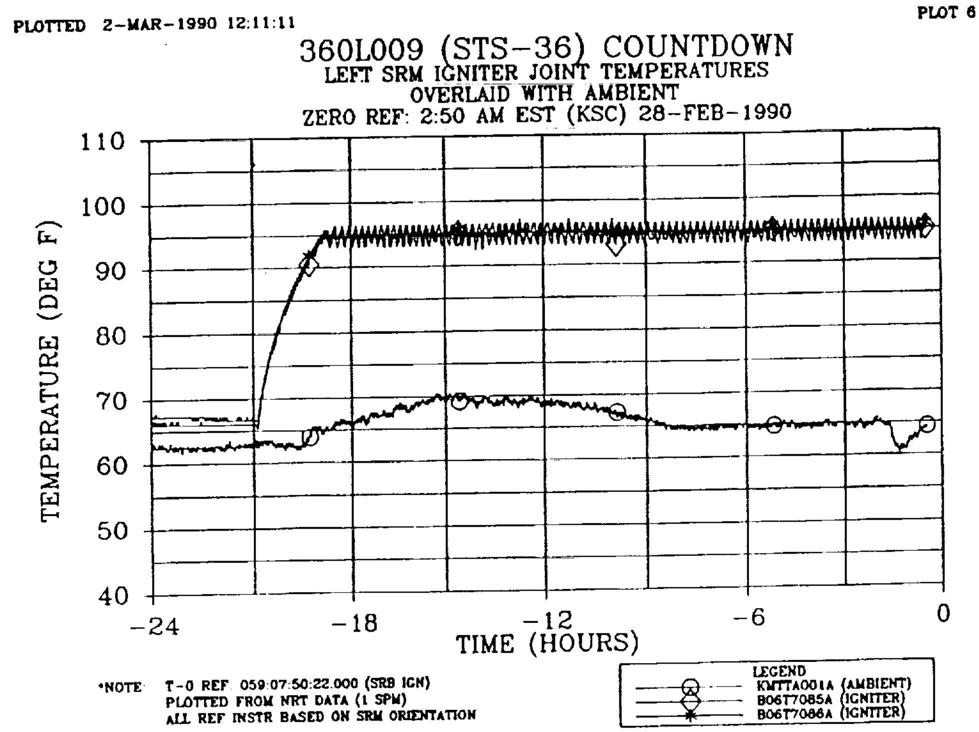


Figure 4.8-41 Countdown LH Igniter Joint Temperatures

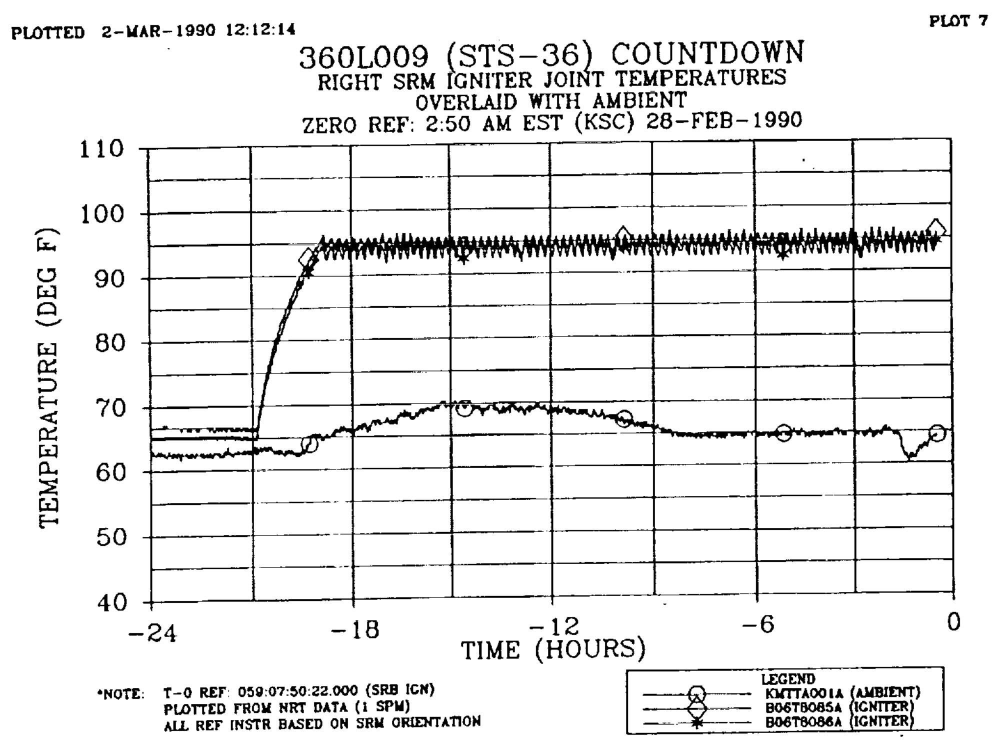


Figure 4.8-42 Countdown RH Igniter Joint Temperatures

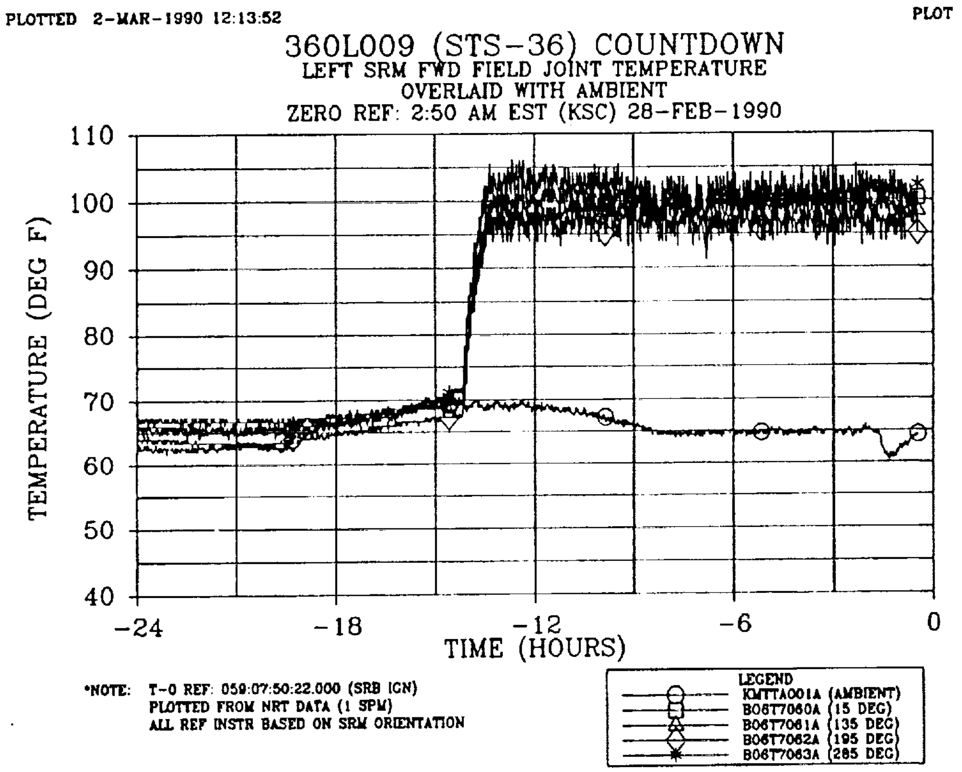


Figure 4.8-43 Countdown LH Forward Field Joint Temperatures

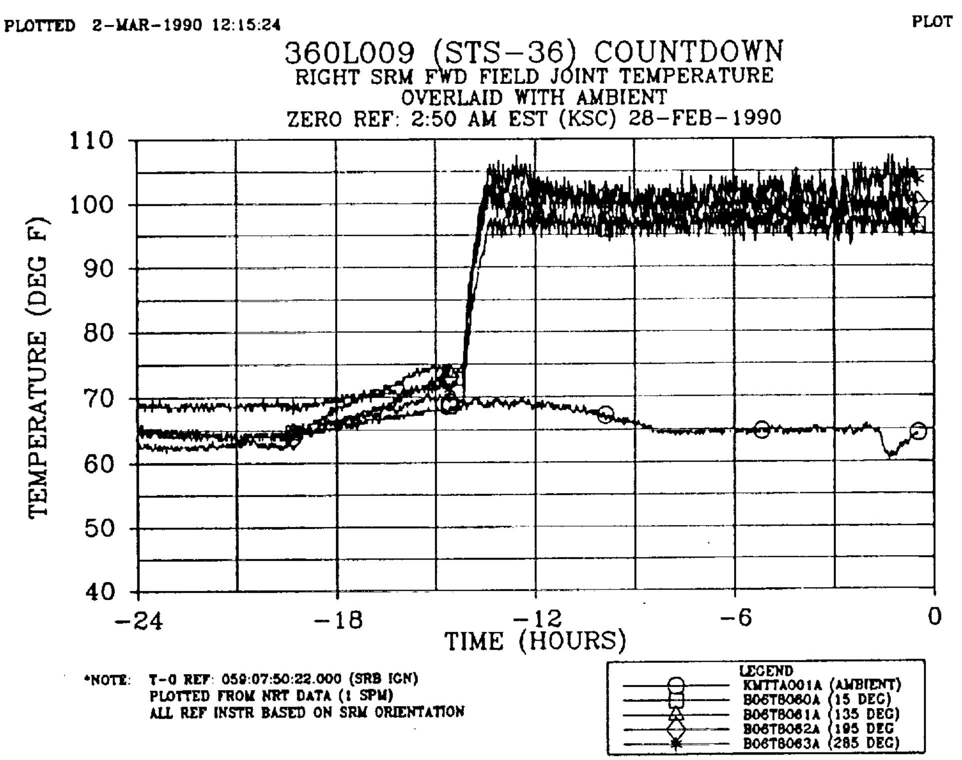


Figure 4.8-44 Countdown RH Forward Field Joint Temperatures

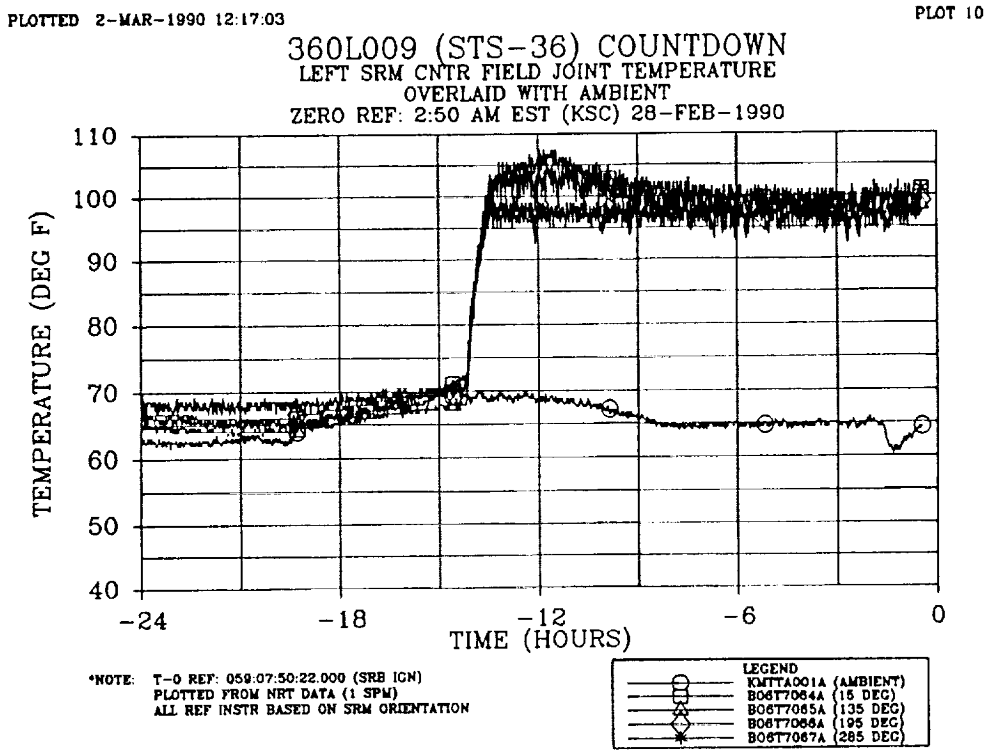


Figure 4.8-45 Countdown LH Center Field Joint Temperatures

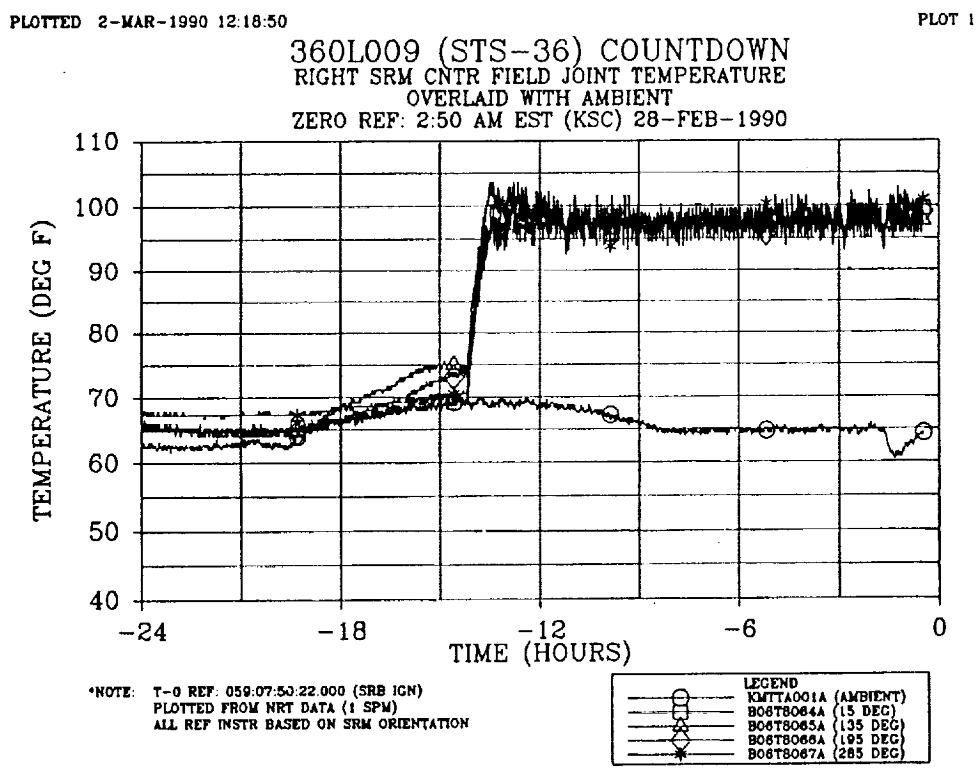


Figure 4.8-46 Countdown RH Center Field Joint Temperatures

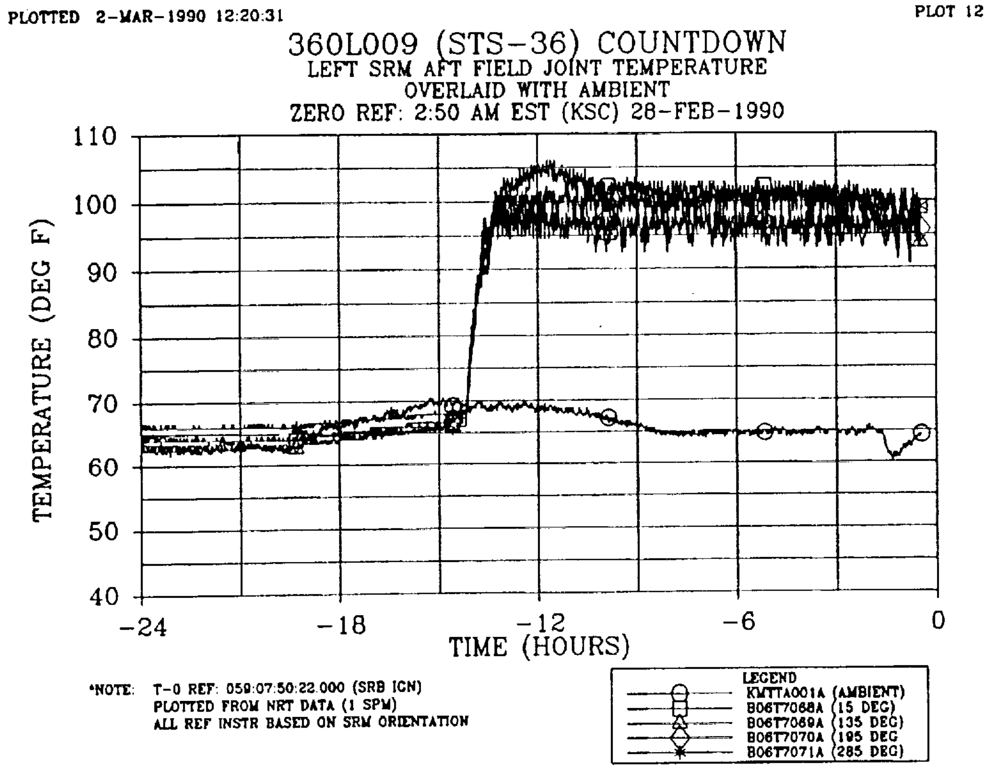


Figure 4.8-47 Countdown LH Aft Field Joint Temperatures

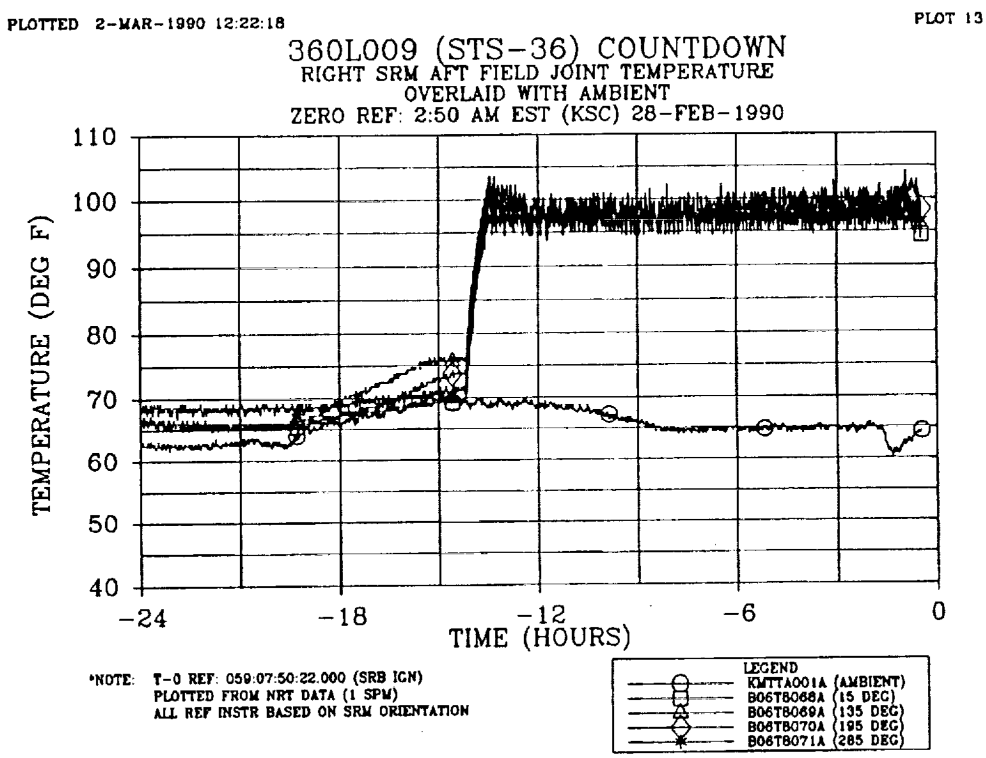


Figure 4.8-48 Countdown RH Aft Field Joint Temperatures

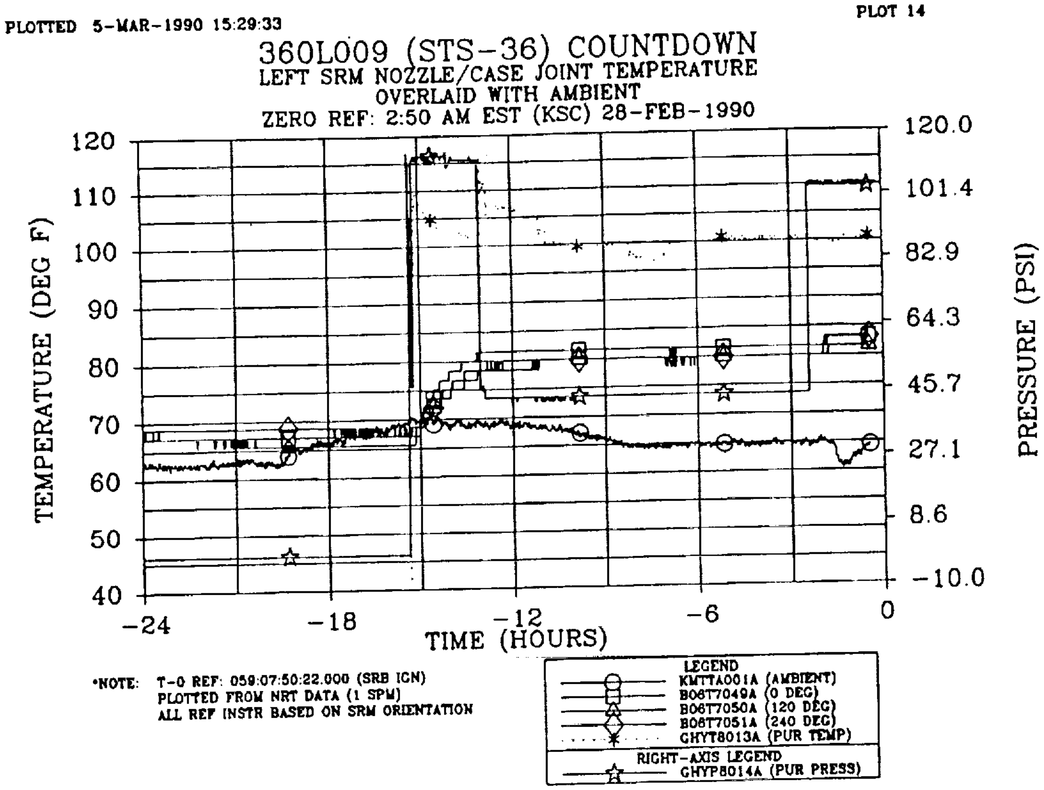


Figure 4.8-49 Countdown LH Case-to-Nozzle Joint Temperatures

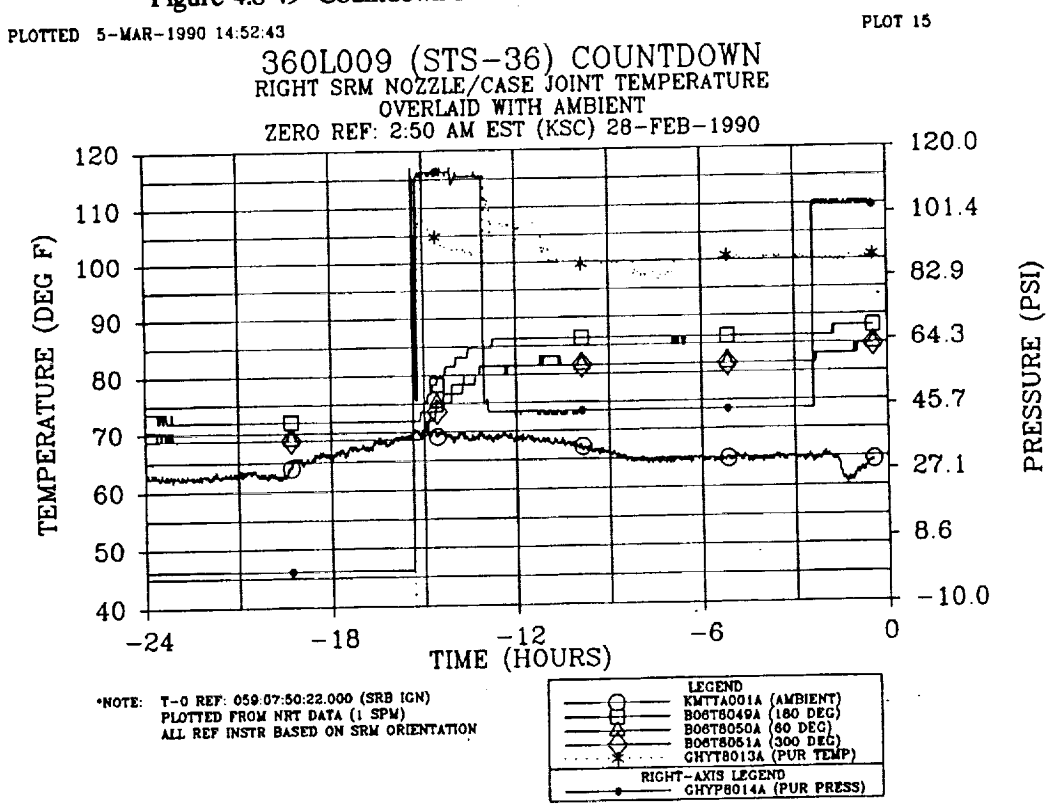


Figure 4.8-50 Countdown RH Case-to-Nozzle Joint Temperatures

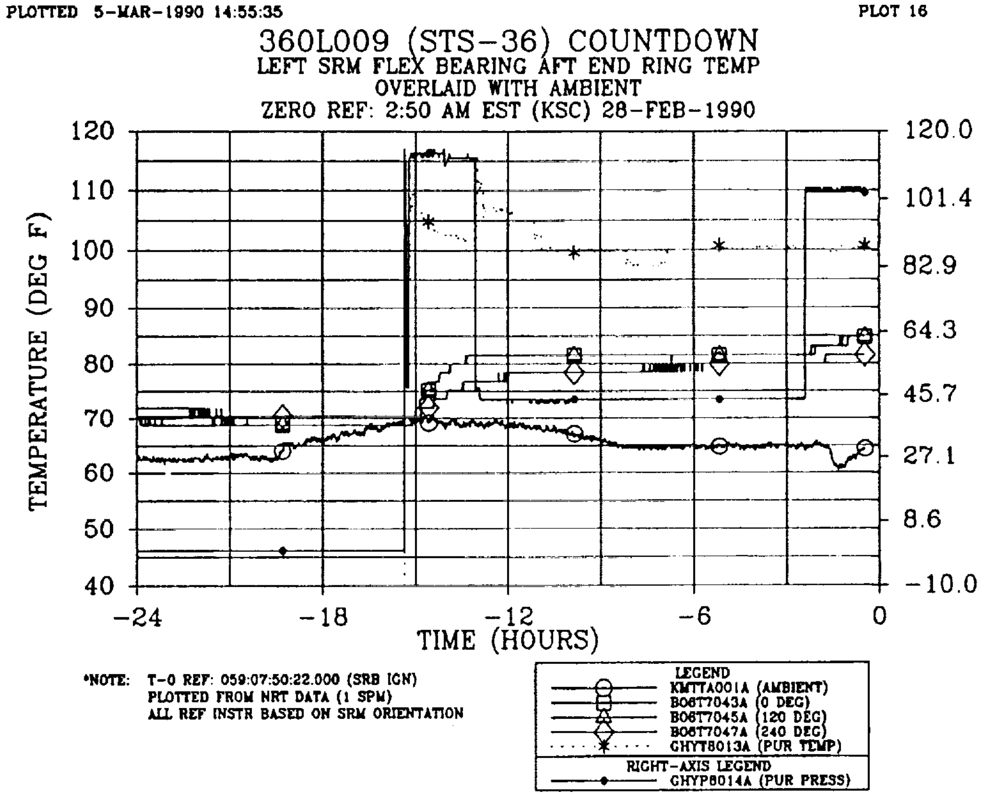


Figure 4.8-51 Countdown LH Flex Bearing Aft End Ring Temperatures

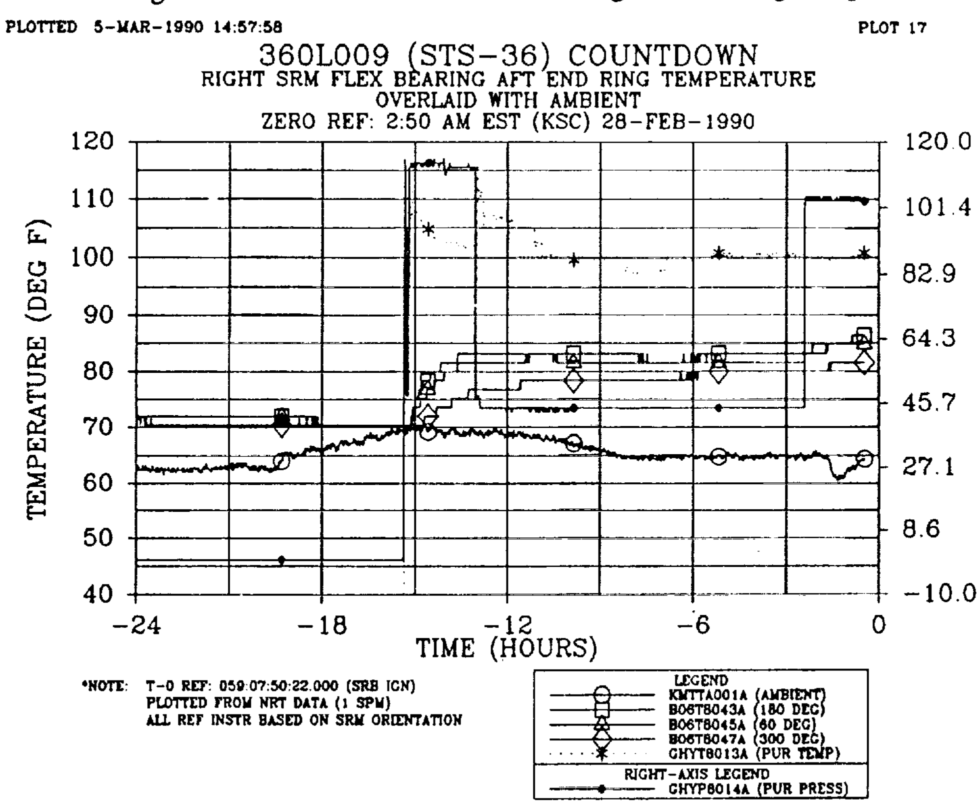


Figure 4.8-52 Countdown RH Flex Bearing Aft End Ring Temperatures

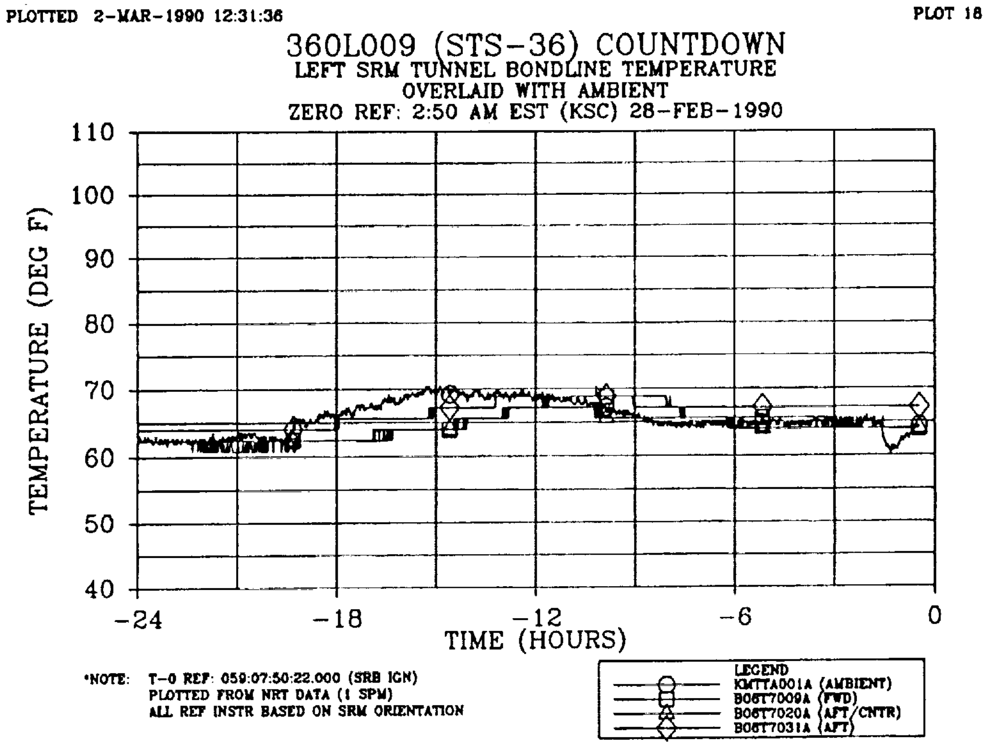


Figure 4.8-53 Countdown LH Tunnel Bondline Temperatures

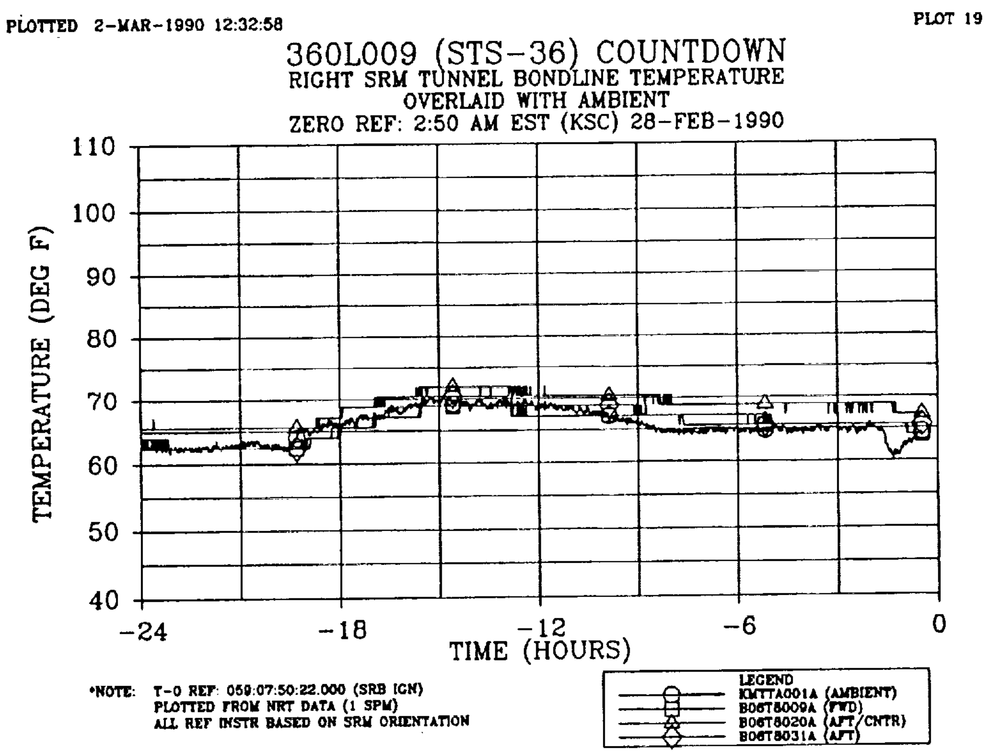


Figure 4.8-54 Countdown RH Tunnel Bondline Temperatures

PLOTTED 2-MAR-1990 12:34:22 PLOT 20

360L009 (STS-36) COUNTDOWN
LEFT SRM FIELD JOINT TEMP AT 285 DEG LOCATION
OVERLAID WITH AMBIENT
ZERO REF: 2:50 AM EST (KSC) 28-FEB-1990

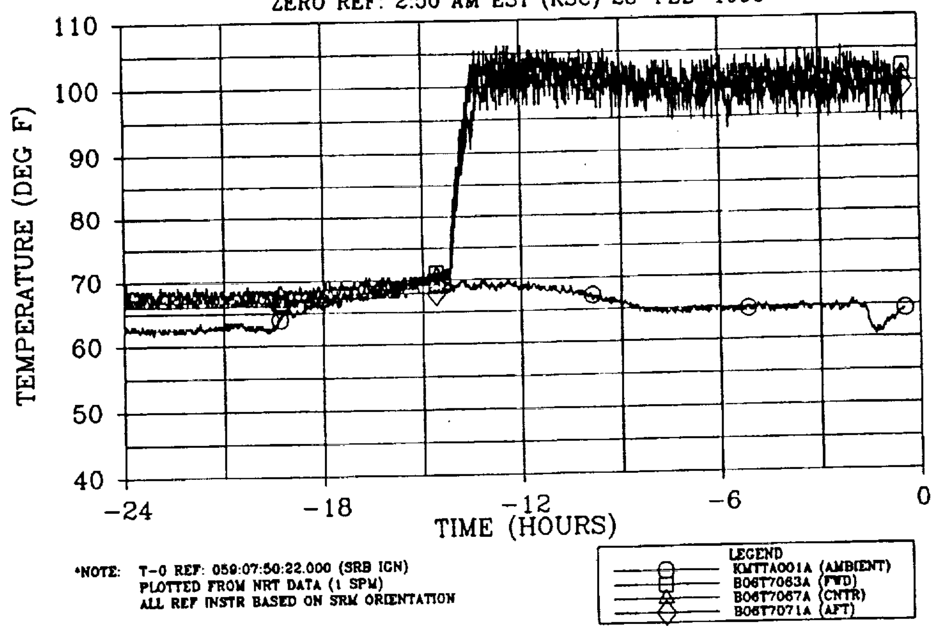


Figure 4.8-55 Countdown LH Field Joint Temperatures at 285-deg Location

PLOTTED 2-MAR-1990 12:35:49 PLOT 21

360L009 (STS-36) COUNTDOWN
RIGHT SRM FIELD JOINT TEMP AT 285 DEG LOCATION
OVERLAID WITH AMBIENT
ZERO REF: 2:50 AM EST (KSC) 28-FEB-1990

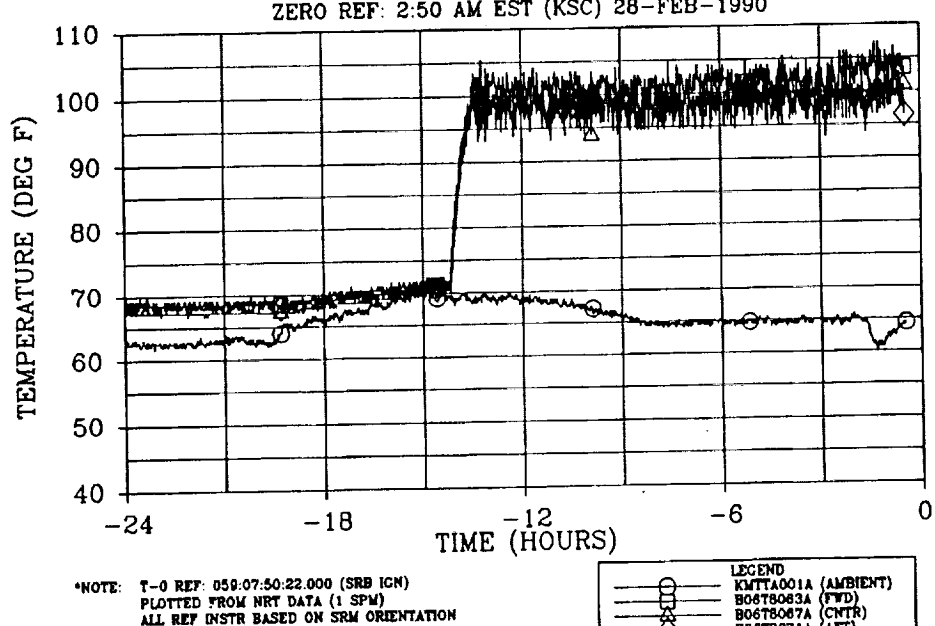


Figure 4.8-56 Countdown RH Field Joint Temperatures at 285-deg Location

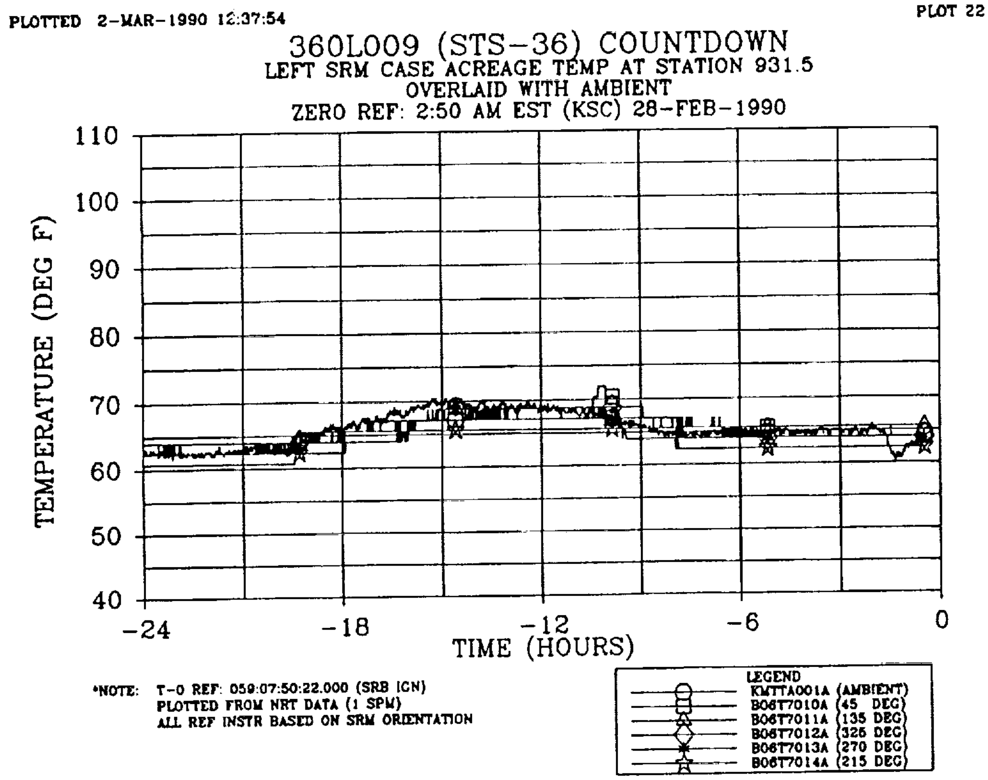


Figure 4.8-57 Countdown LH Case Acreage Temperatures at Station 931.5

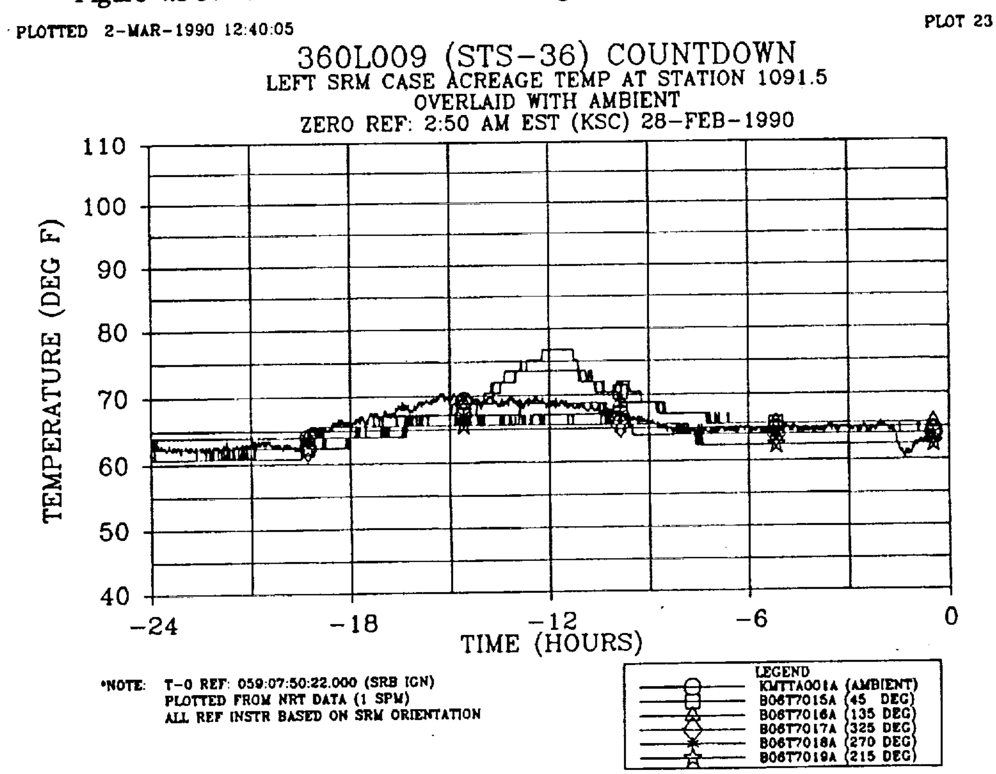


Figure 4.8-58 Countdown LH Case Acreage Temperatures at Station 1091.5

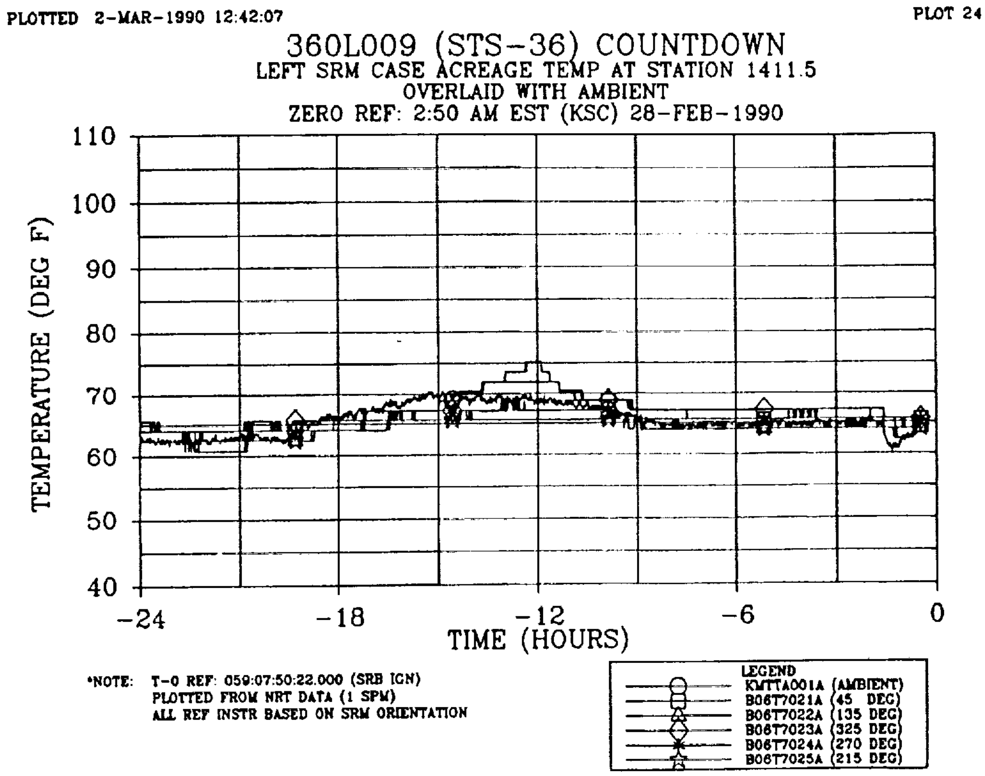


Figure 4.8-59 Countdown LH Case Acreage Temperatures at Station 1411.5

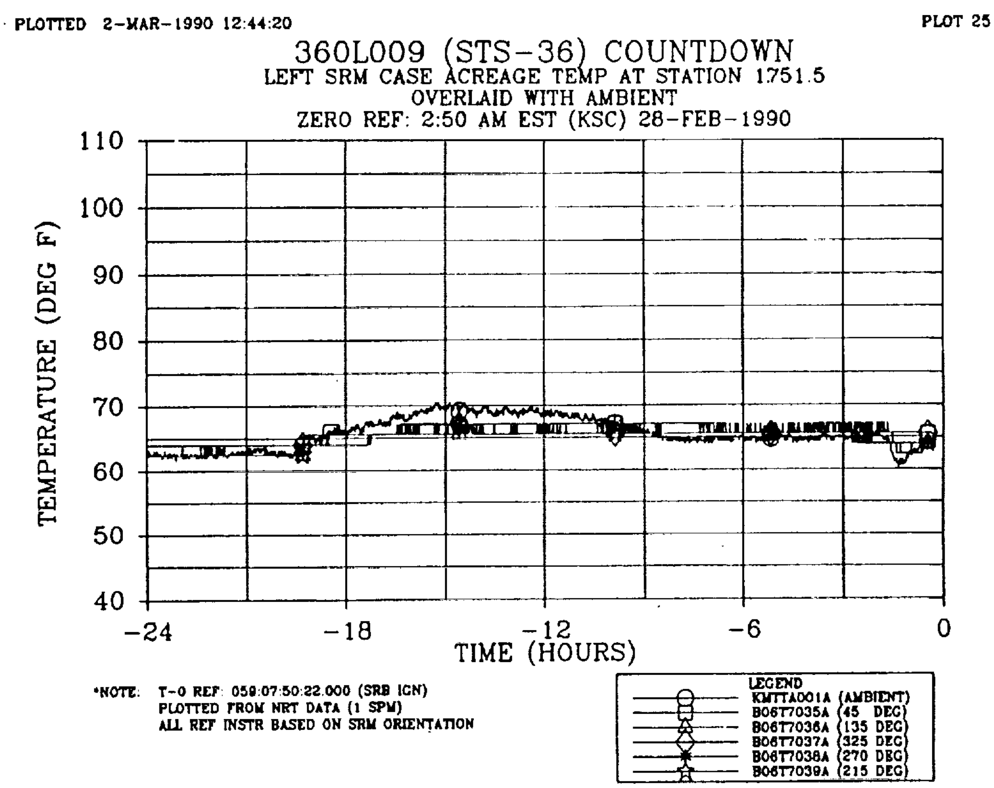


Figure 4.8-60 Countdown LH Case Acreage Temperatures at Station 1751.5

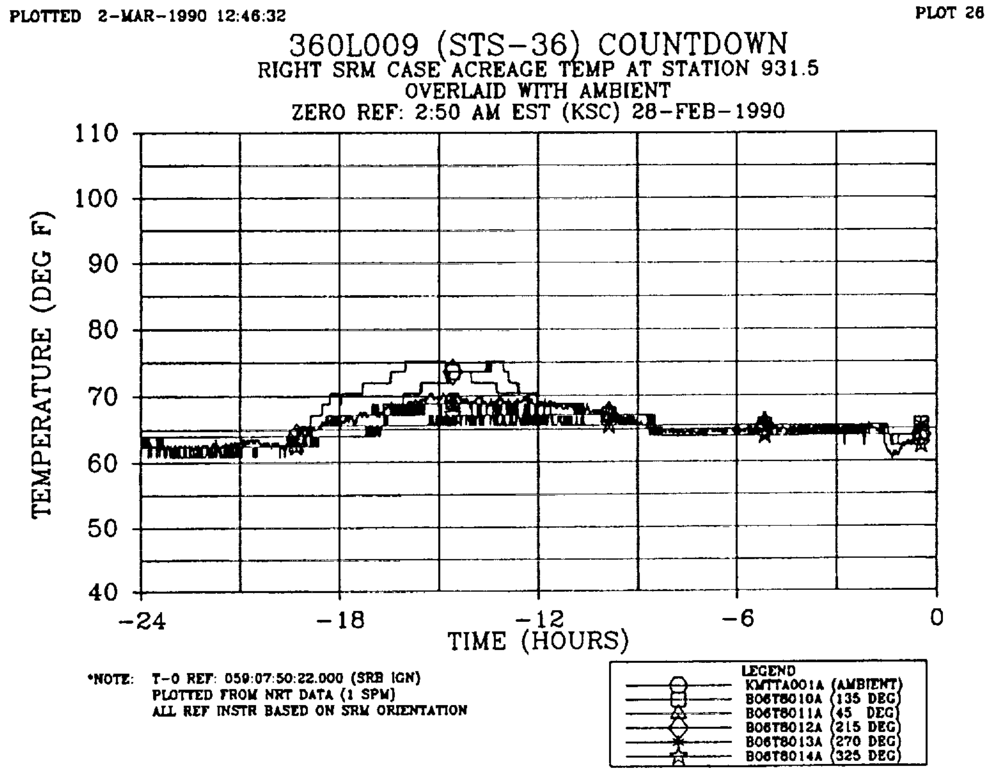


Figure 4.8-61 Countdown RH Case Acreage Temperatures at Station 931.5

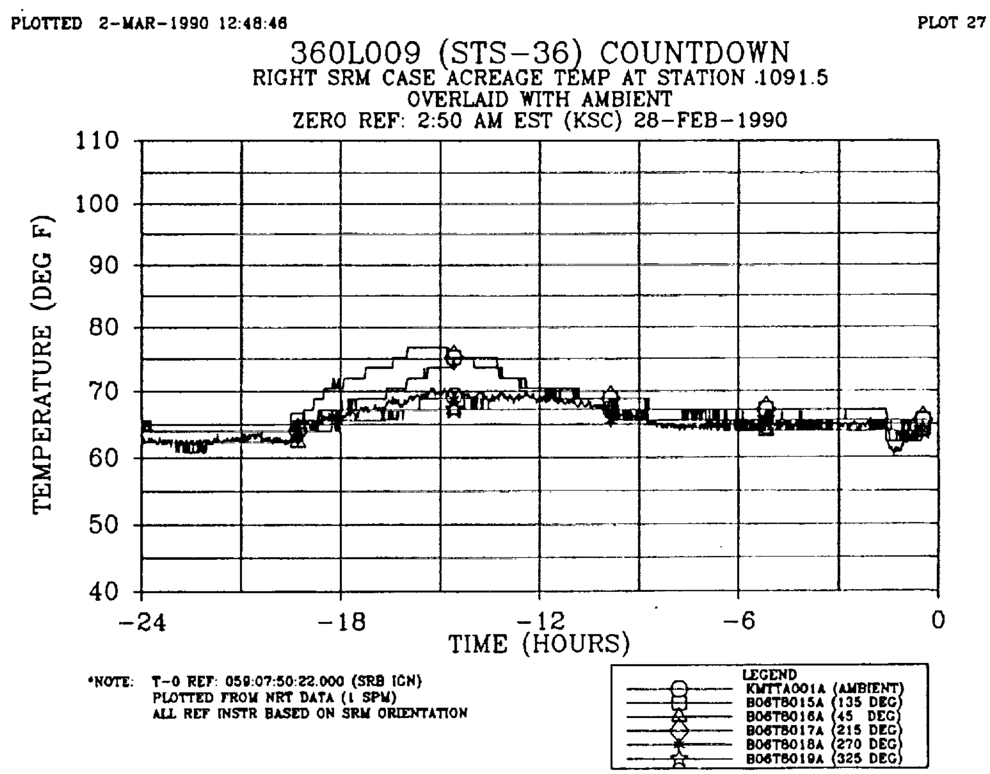


Figure 4.8-62 Countdown RH Case Acreage Temperatures at Station 1091.5

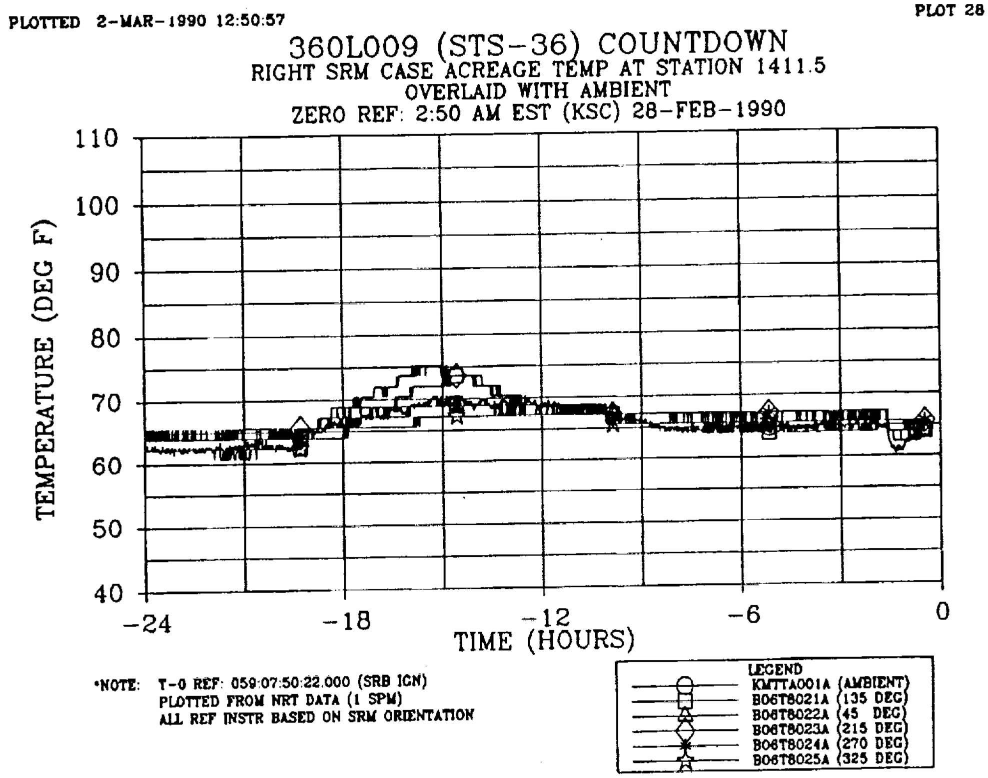


Figure 4.8-63 Countdown RH Case Acreage Temperatures at Station 1411.5

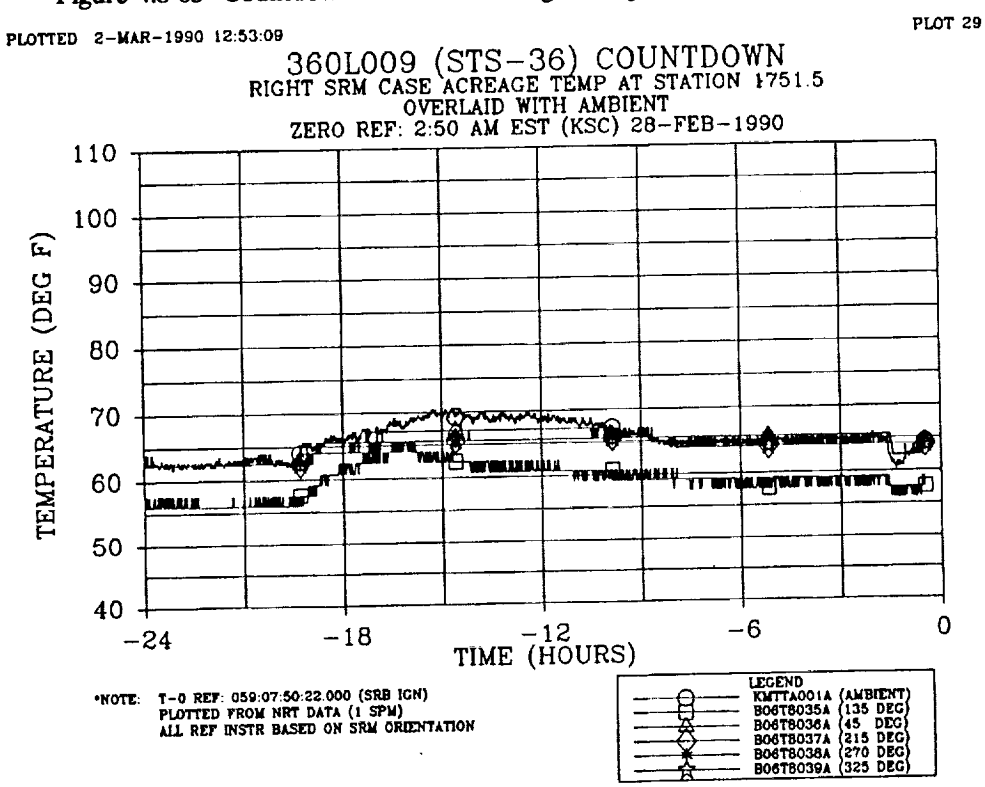


Figure 4.8-64 Countdown RH Case Acreage Temperatures at Station 1751.5

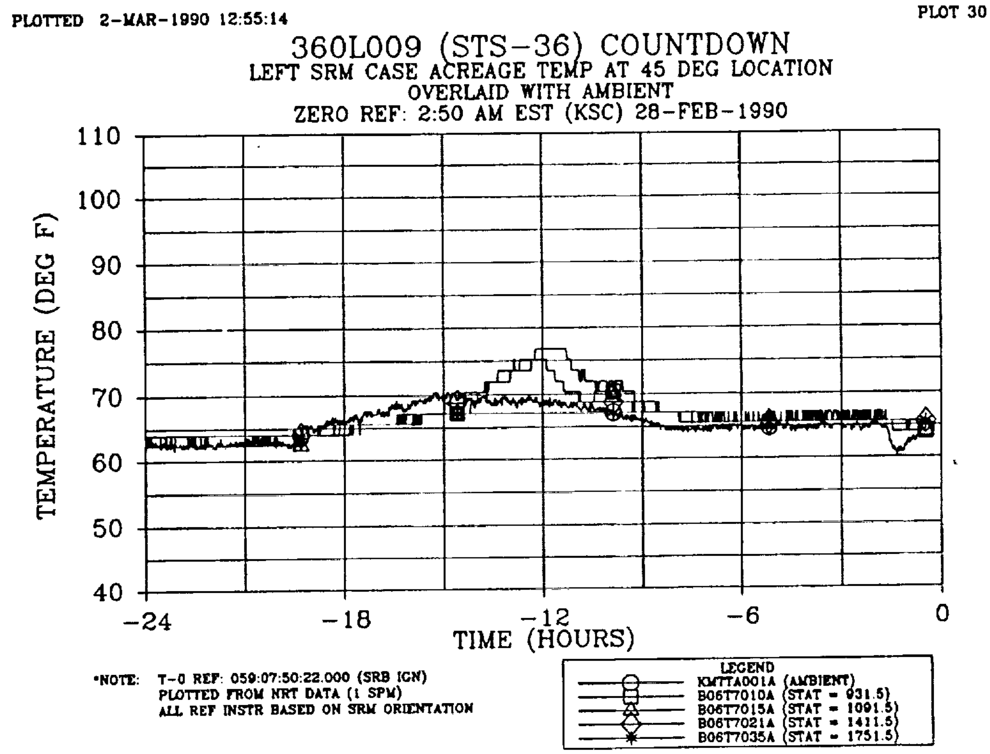


Figure 4.8-65 Countdown LH Case Acreage Temperatures at 45-deg Location

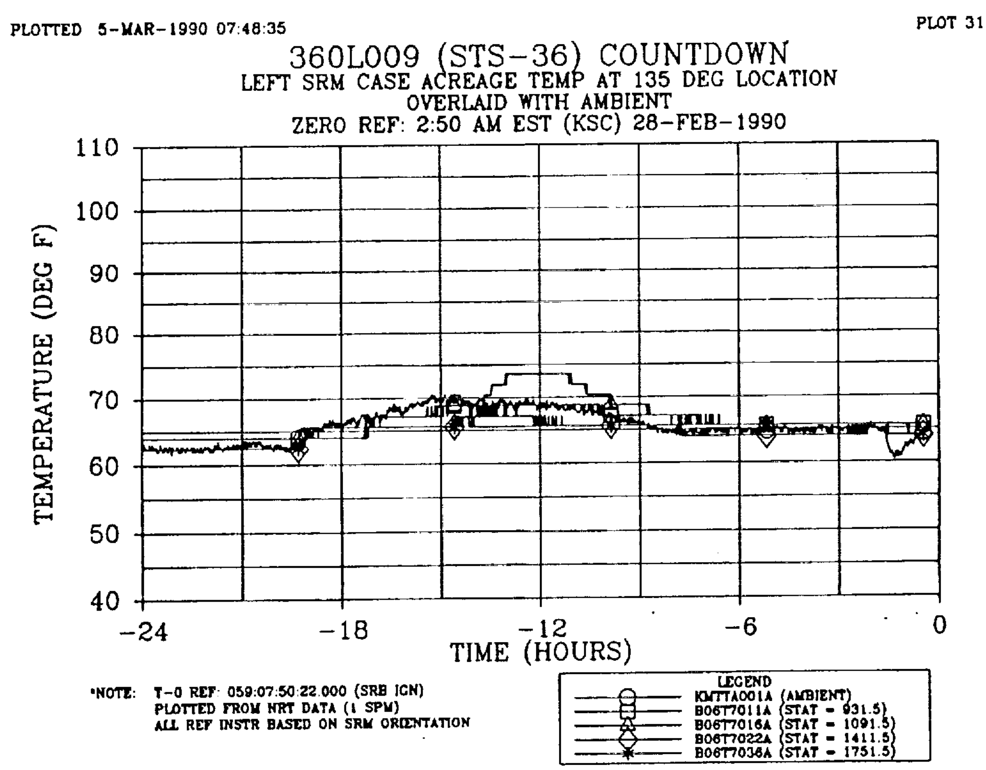


Figure 4.8-66 Countdown LH Case Acreage Temperatures at 135-deg Location

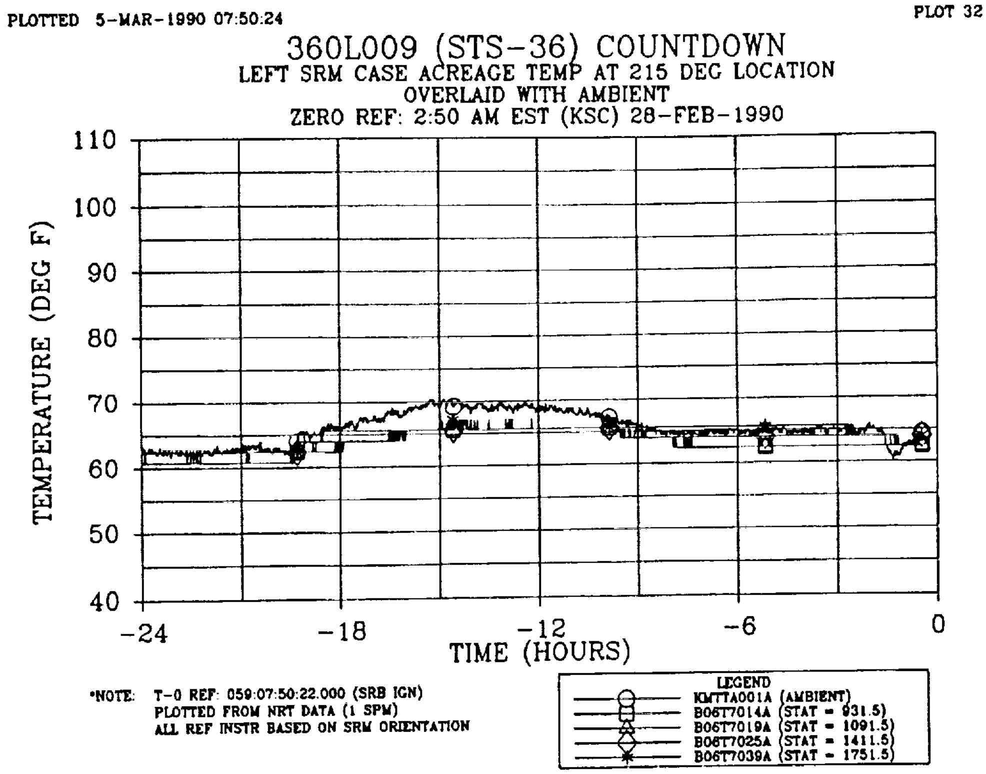


Figure 4.8-67 Countdown LH Case Acreage Temperatures at 125-deg Location

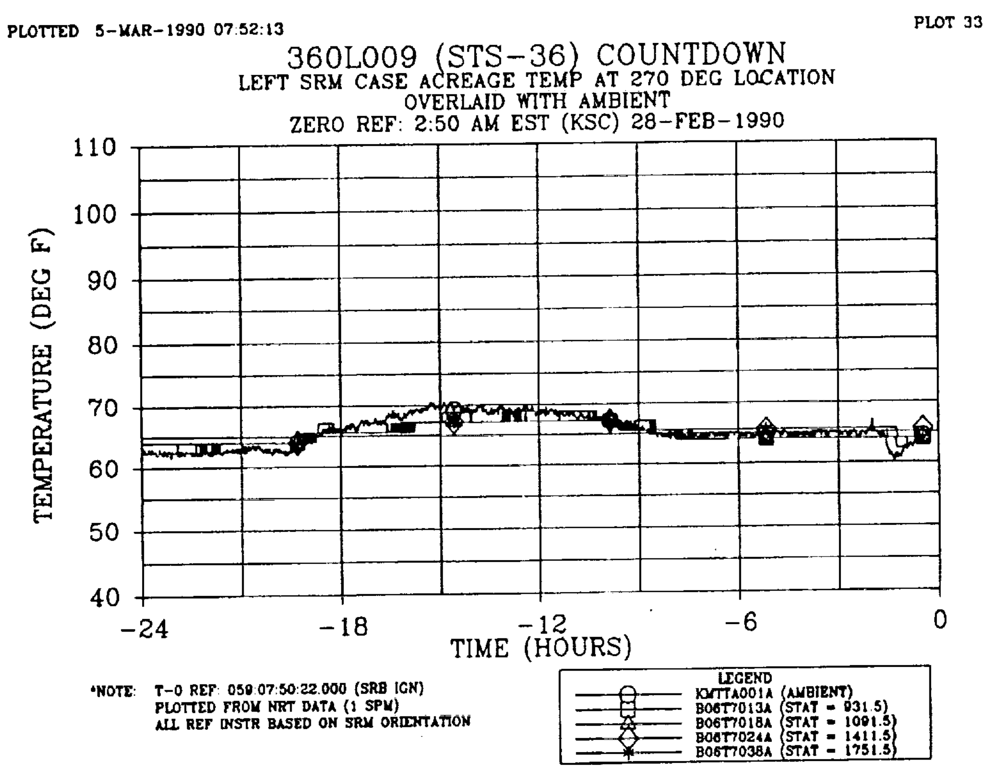


Figure 4.8-68 Countdown LH Case Acreage Temperatures at 270-deg Location

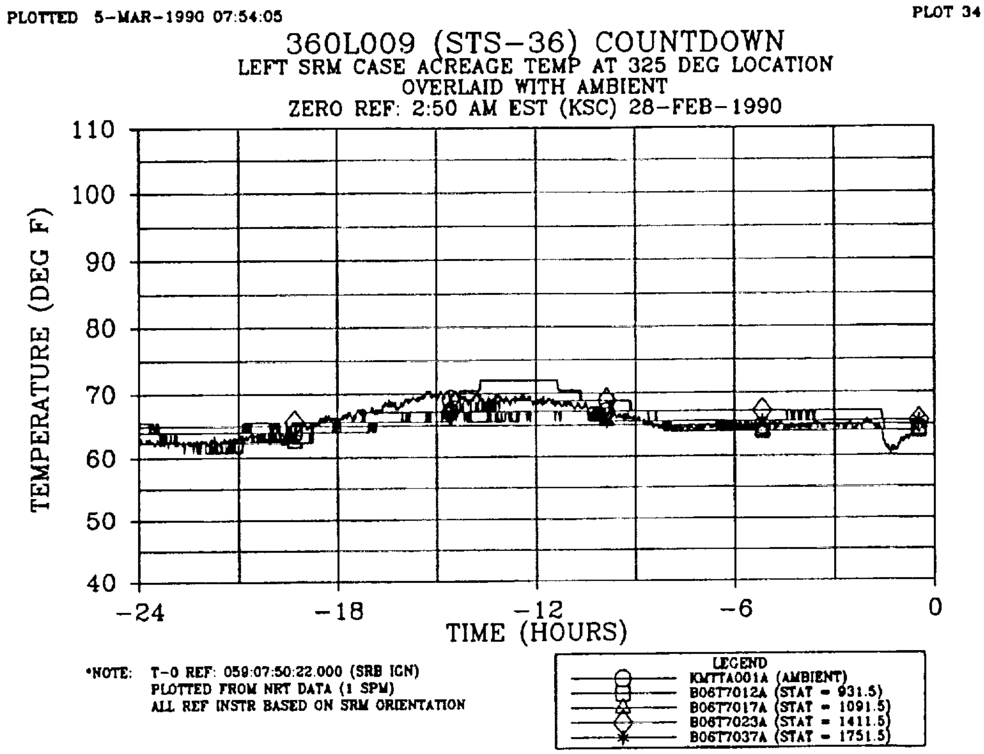


Figure 4.8-69 Countdown LH Case Acreage Temperatures at 325-deg Location

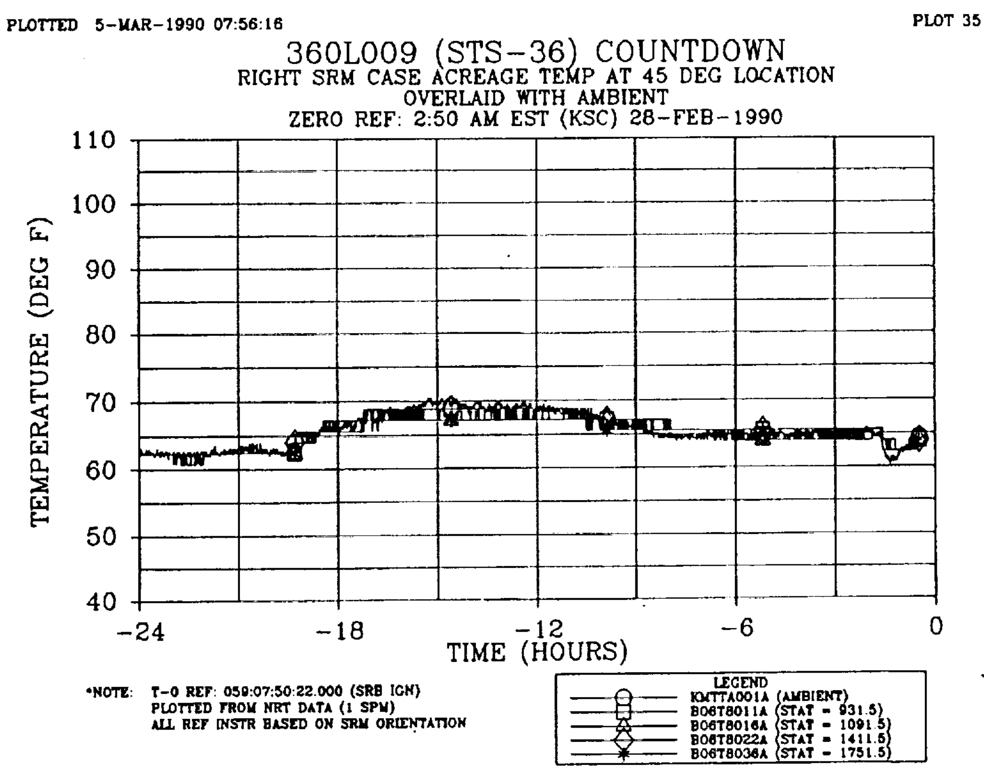


Figure 4.8-70 Countdown RH Case Acreage Temperatures at 45-deg Location

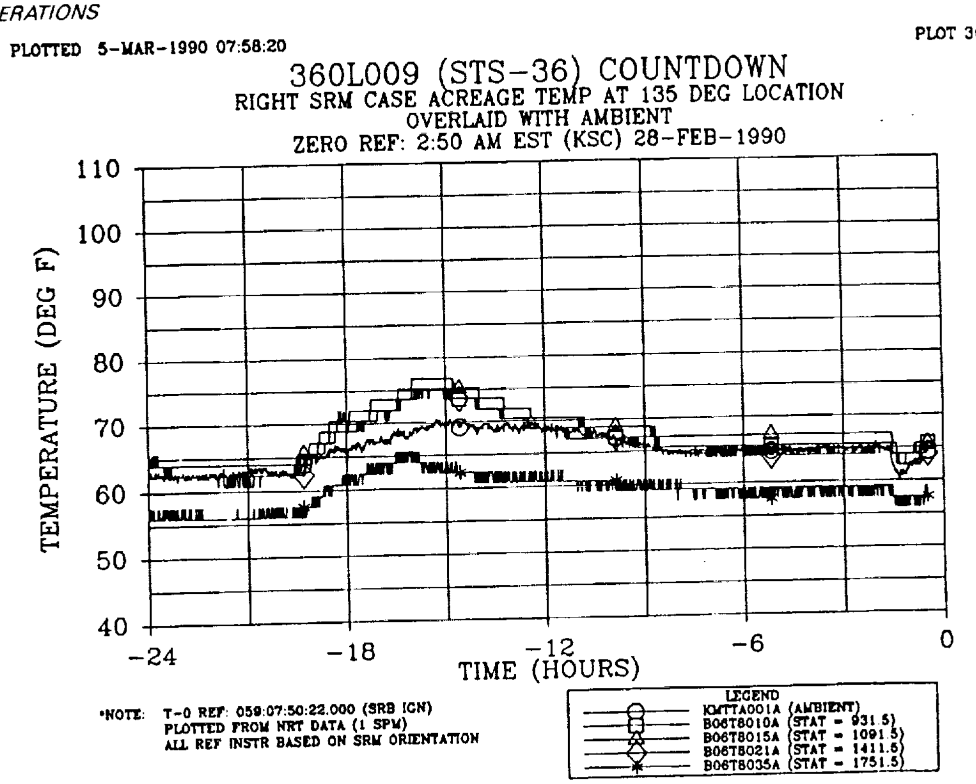


Figure 4.8-71 Countdown RH Case Acreage Temperatures at 135-deg Location

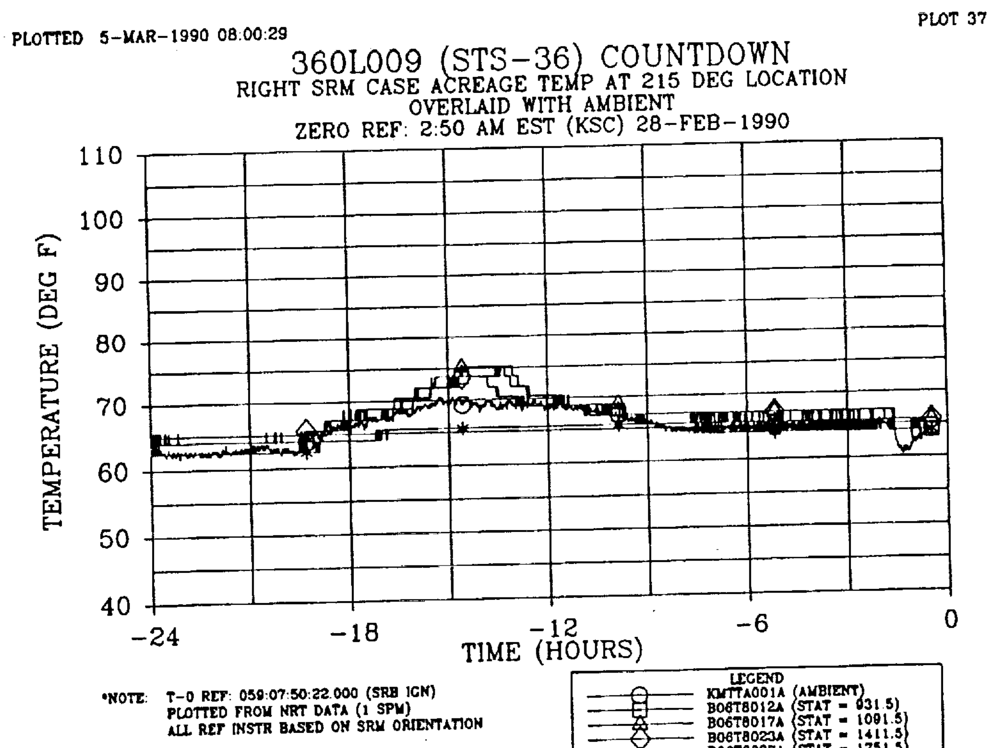


Figure 4.8-72 Countdown RH Case Acreage Temperatures at 215-deg Location

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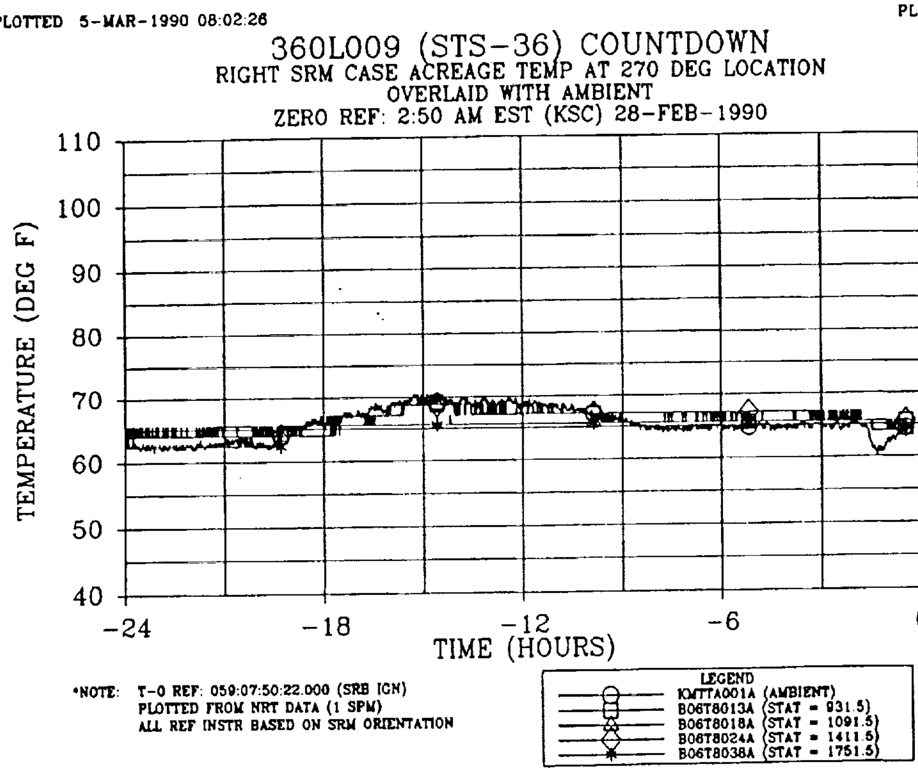

Figure 4.8-73 Countdown RH Case Acreage Temperatures at 270-deg Location

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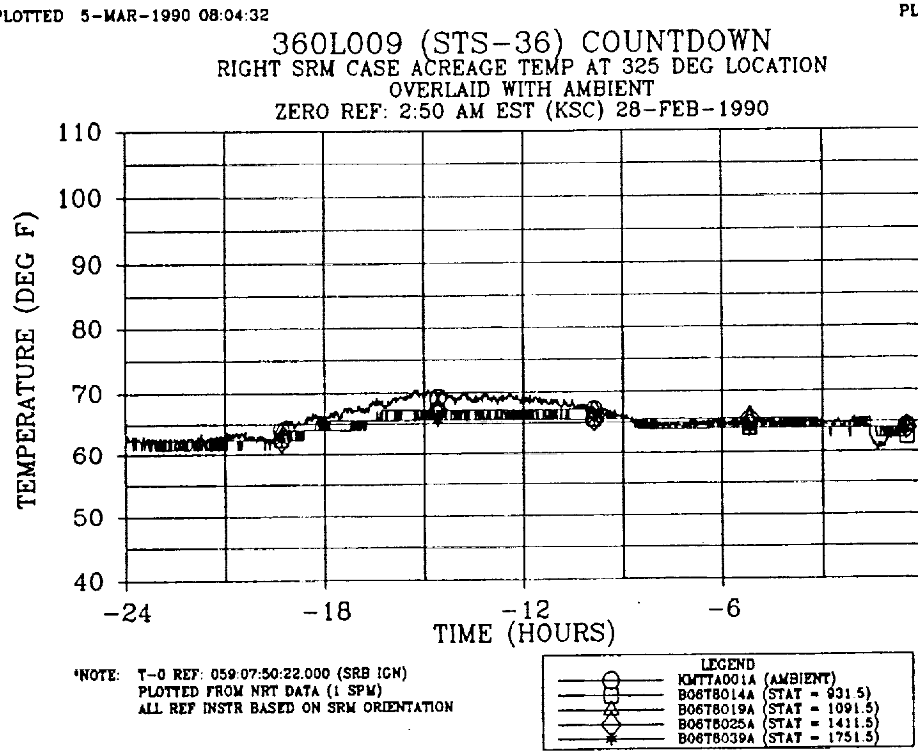

Figure 4.8-74 Countdown RH Case Acreage Temperatures at 325-deg Location

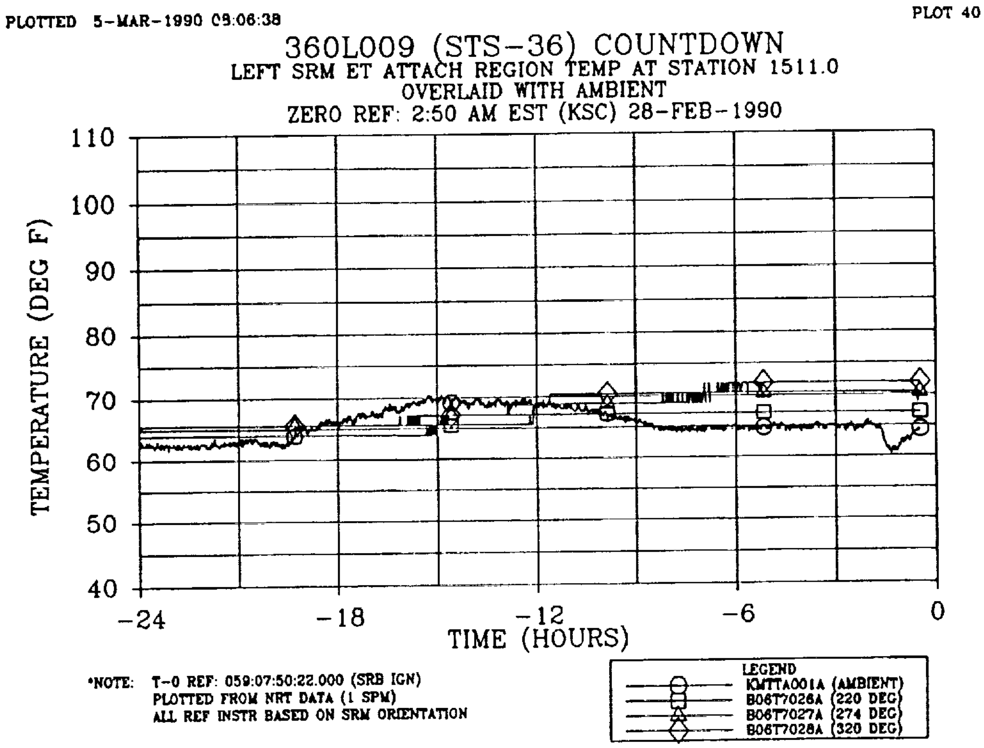

Figure 4.8-75 Countdown LH ET Attach Region Temperatures at Station 1511.0

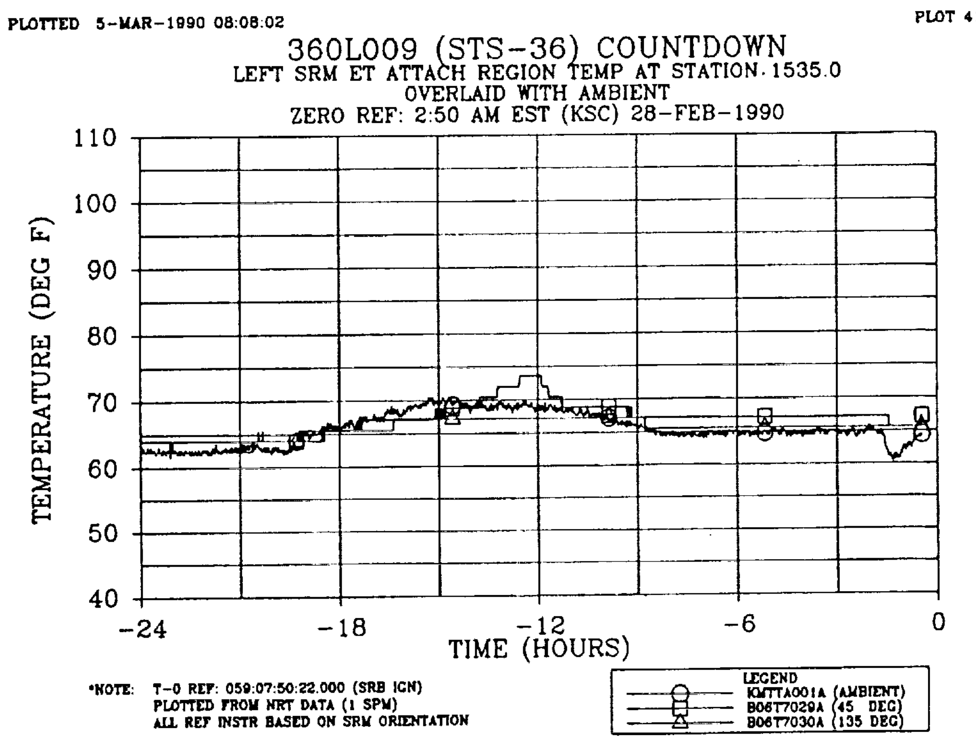

Figure 4.8-76 Countdown LH ET Attach Region Temperatures at Station 1535.0

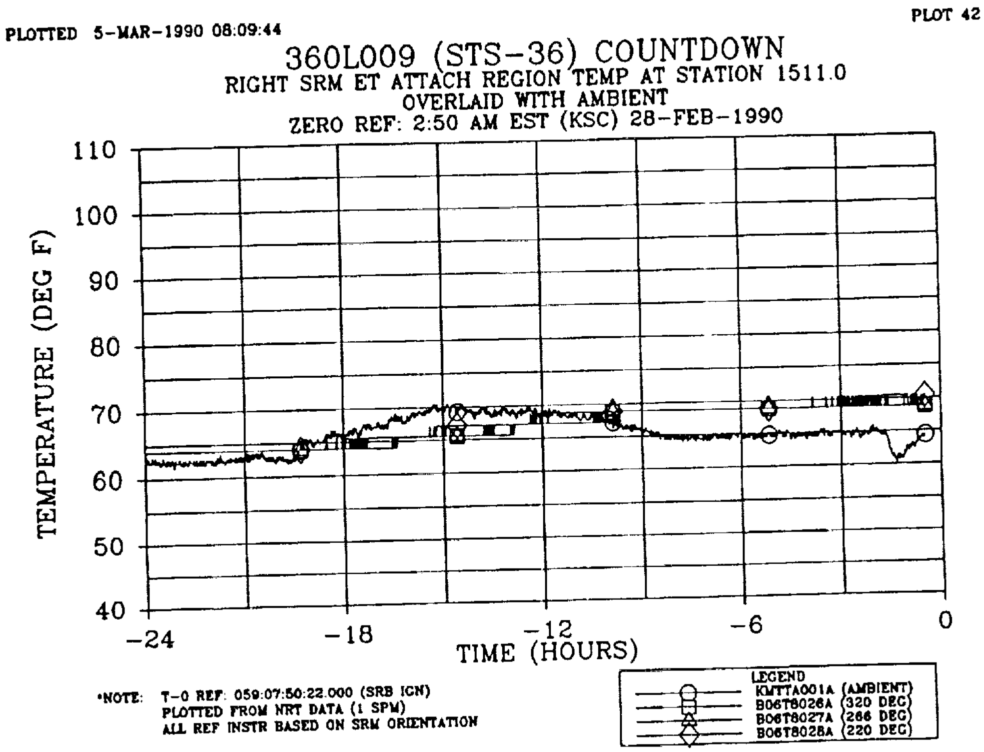

Figure 4.8-77 Countdown RH ET Attach Region Temperatures at Station 1511.0

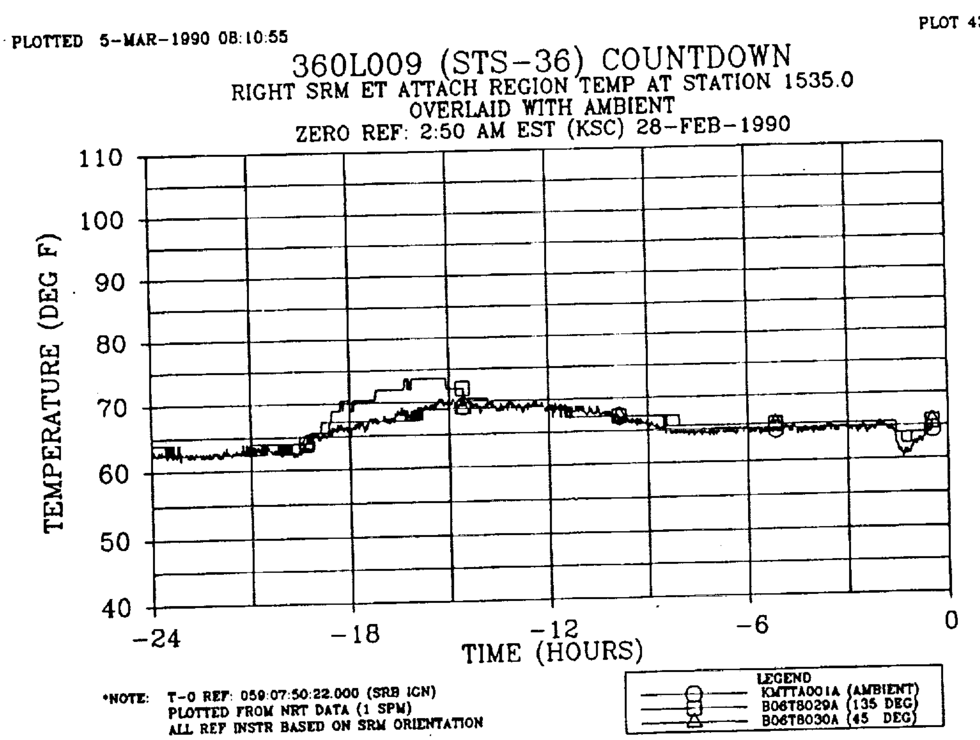

Figure 4.8-78 Countdown RH ET Attach Region Temperatures at Station 1535.0

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PLOT 44

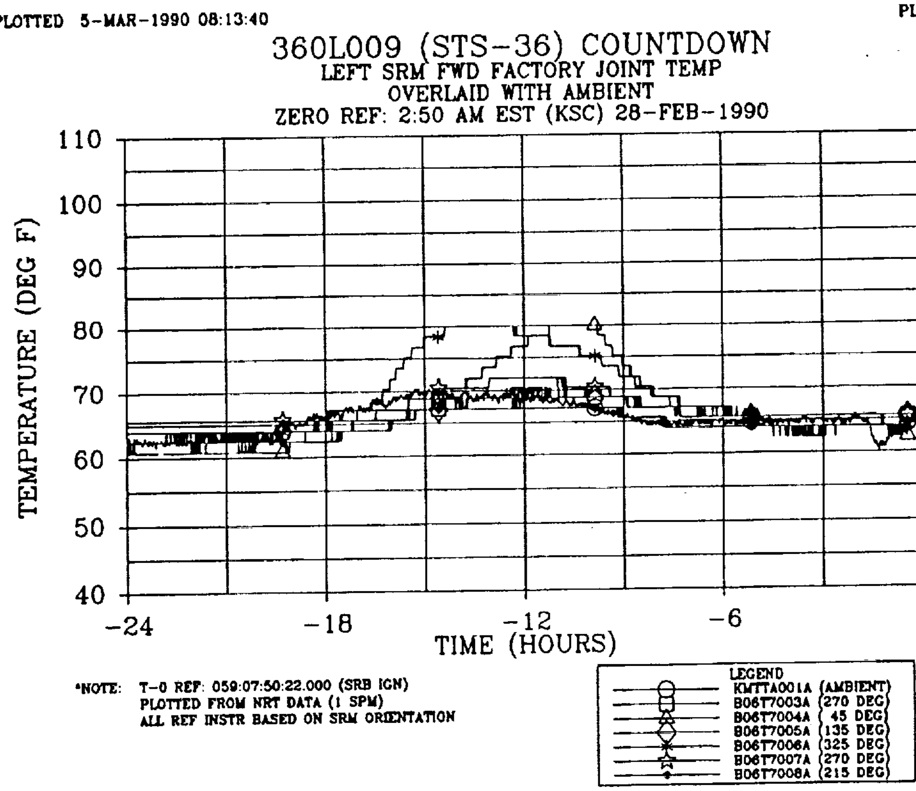

Figure 4.8-79 Countdown LH Forward Factory Joint Temperatures

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PLOT 45

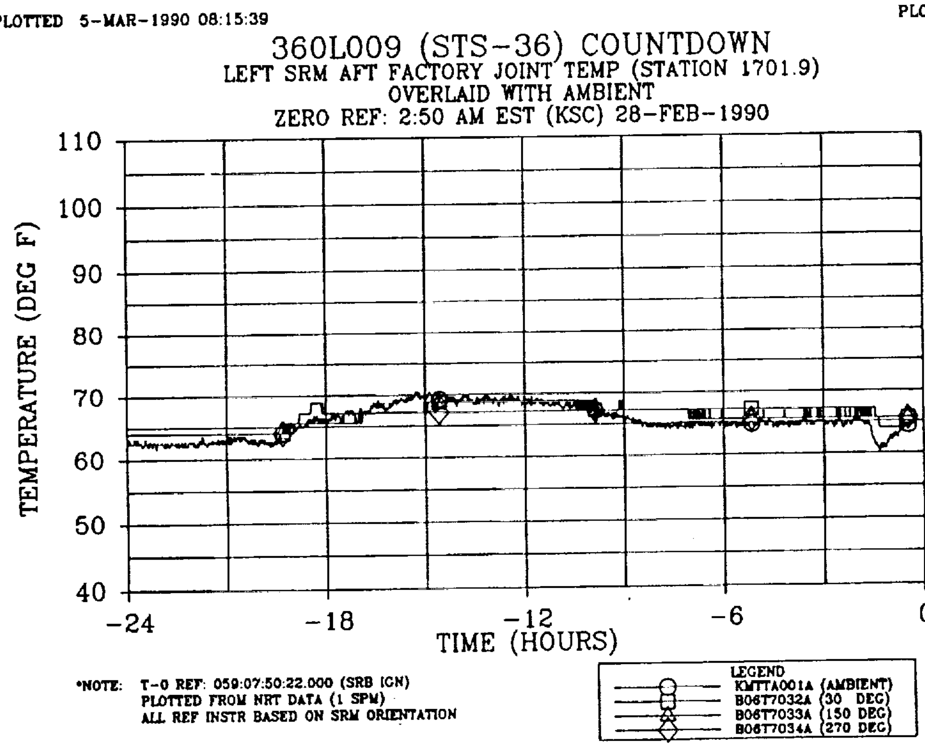


Figure 4.8-80 Countdown LH Aft Factory Joint Temperatures at Station 1701.9

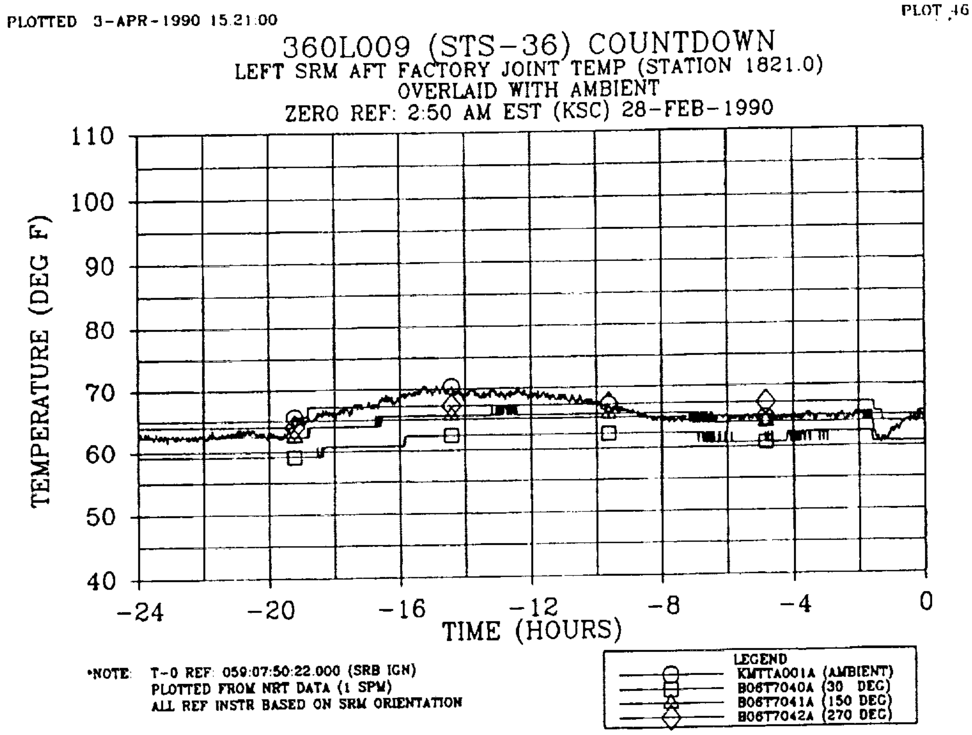


Figure 4.8-81 Countdown LH Aft Factory Joint Temperatures at Station 1821.0

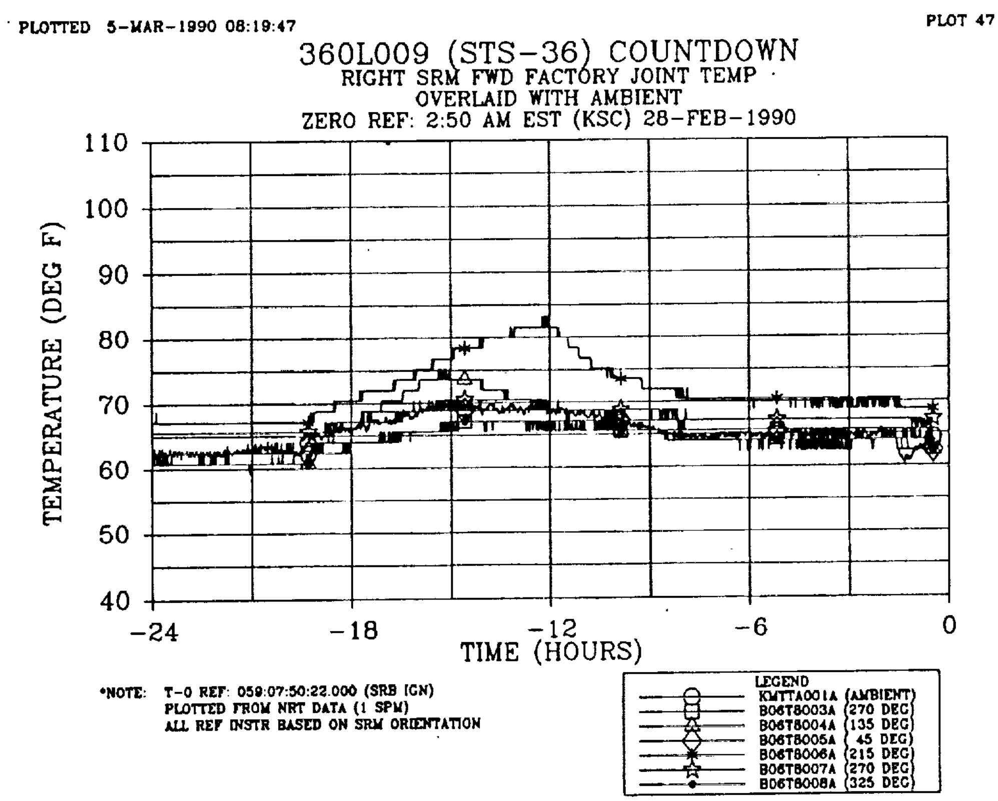


Figure 4.8-82 Countdown RH Forward Factory Joint Temperatures

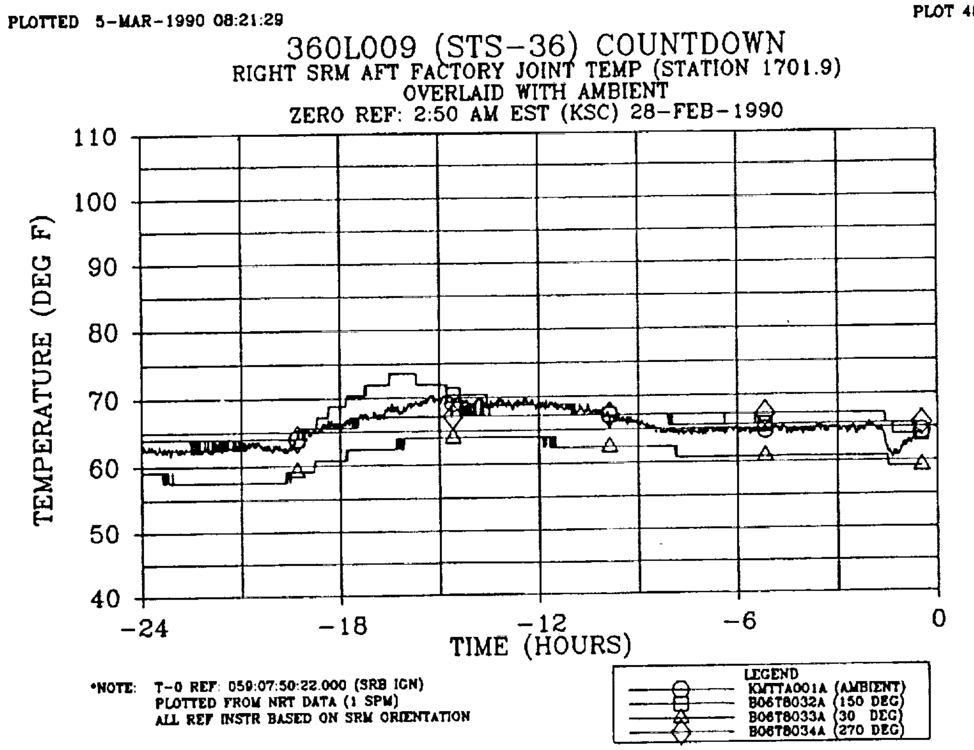


Figure 4.8-83 Countdown RH Aft Factory Joint Temperatures at Station 1701.9

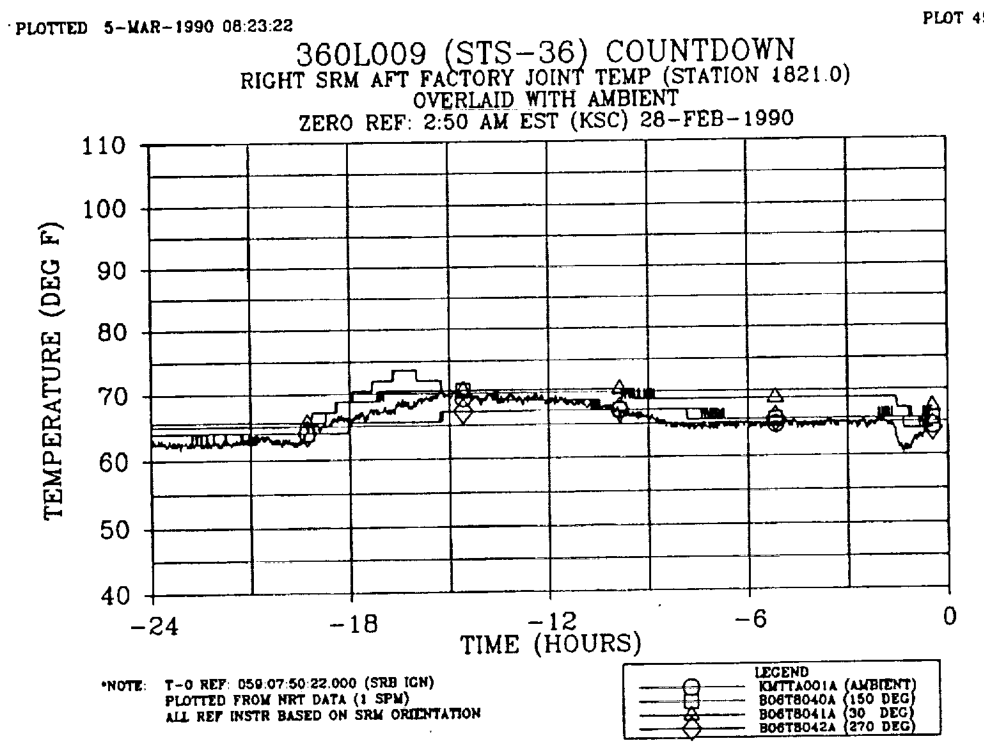
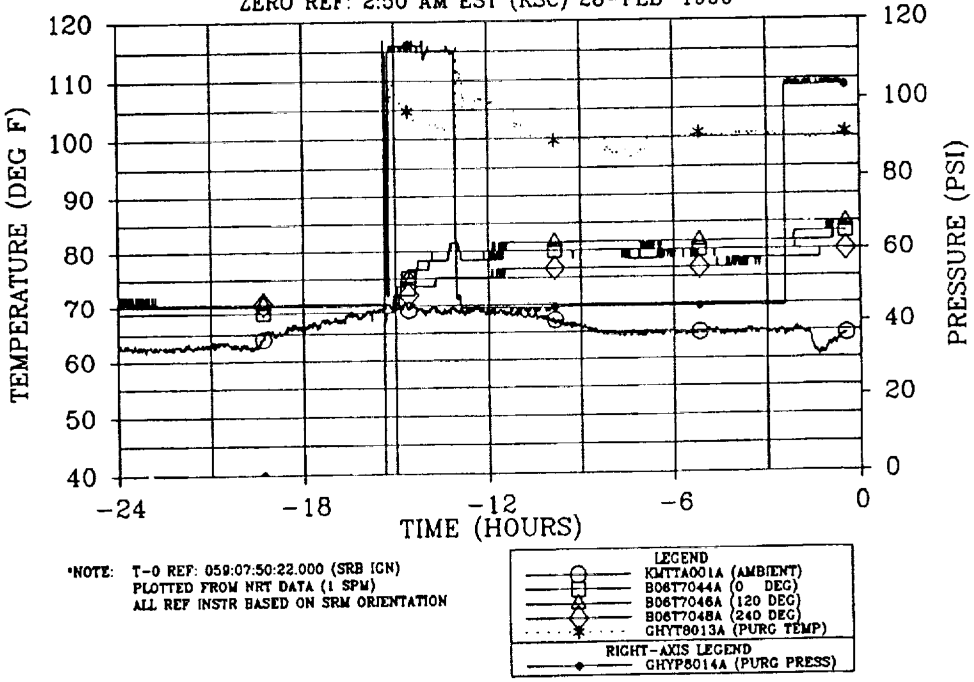


Figure 4.8-84 Countdown RH Aft Factory Joint Temperatures at Station 1821.0

PLOTTED 5-MAR-1990 15:00:21 PLOT 50

360L009 (STS-36) COUNTDOWN
LEFT SRM NOZZLE REGION TEMP AT STATION 1845.0
OVERLAID WITH AMBIENT
ZERO REF: 2:50 AM EST (KSC) 28-FEB-1990

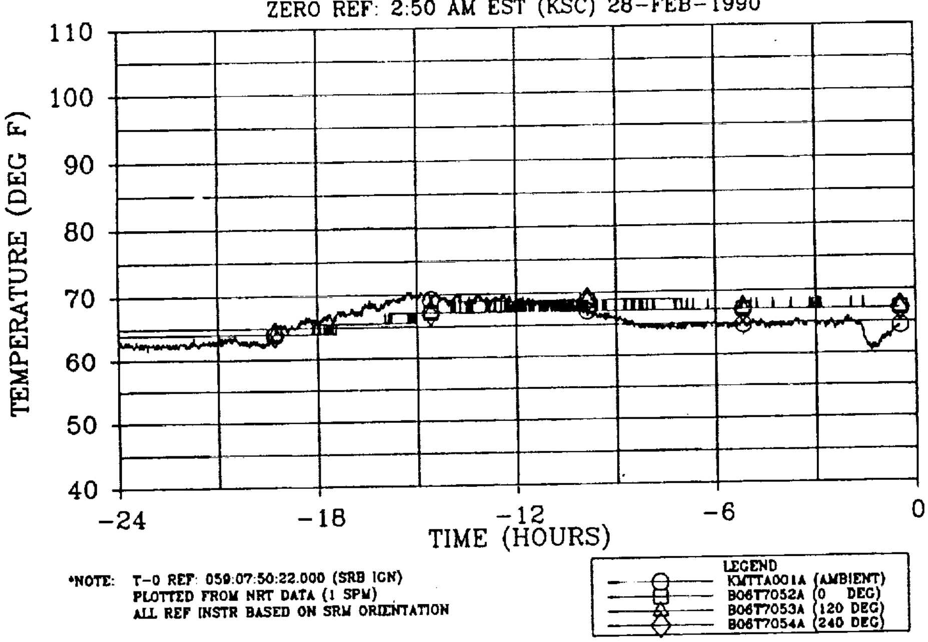


*NOTE: T-0 REF: 059:07:50:22.000 (SRB IGN)
PLOTTED FROM NRT DATA (1 SPM)
ALL REF INSTR BASED ON SRM ORIENTATION

Figure 4.8-85 Countdown LH Nozzle Region Temperatures at Station 1845.0

PLOTTED 5-MAR-1990 15:01:48 PLOT 51

360L009 (STS-36) COUNTDOWN
LEFT SRM NOZZLE REGION TEMP AT STATION 1950.0
OVERLAID WITH AMBIENT
ZERO REF: 2:50 AM EST (KSC) 28-FEB-1990



*NOTE: T-0 REF: 059:07:50:22.000 (SRB IGN)
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ALL REF INSTR BASED ON SRM ORIENTATION

Figure 4.8-86 Countdown LH Nozzle Region Temperatures at Station 1950.0

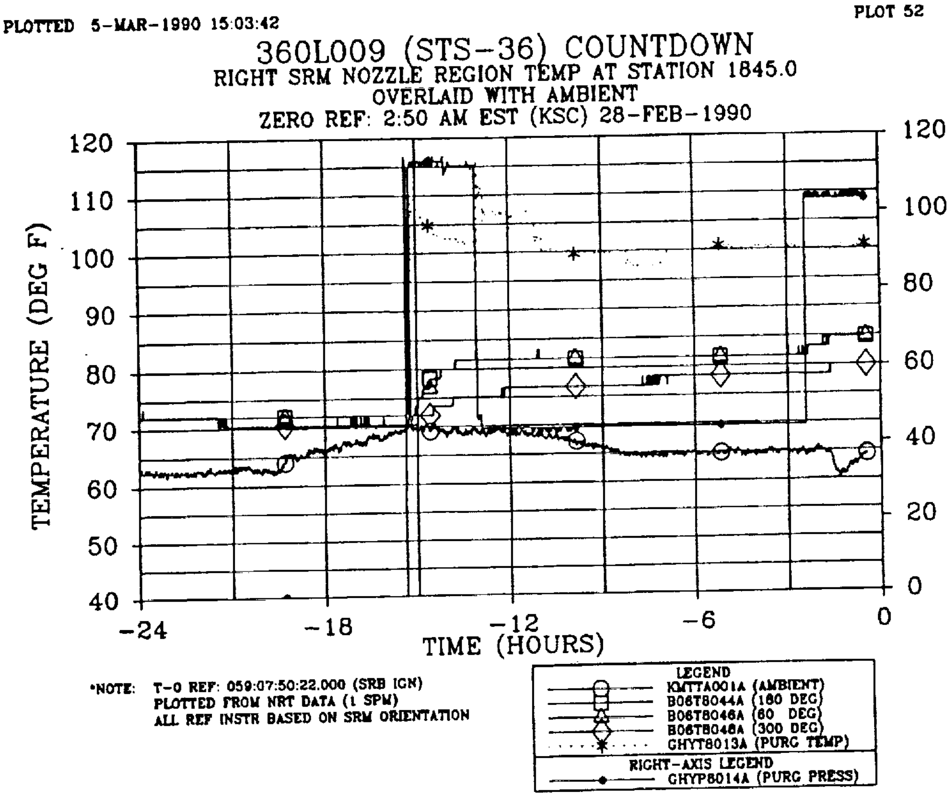

Figure 4.8-87 Countdown RH Nozzle Region Temperatures at Station 1845.0

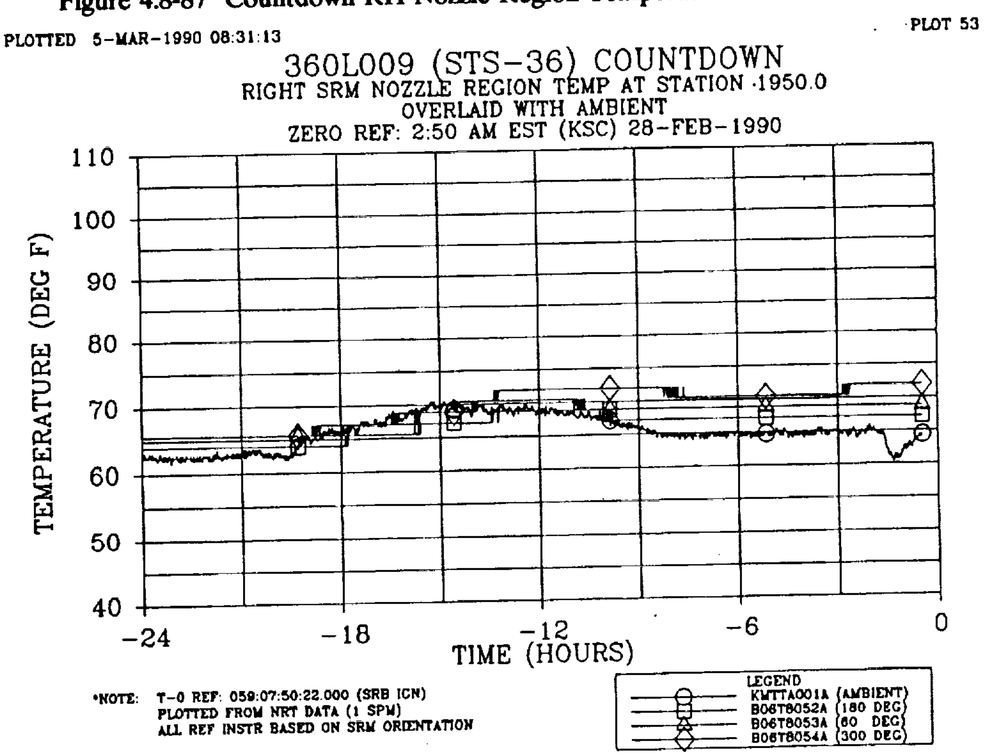

Figure 4.8-88 Countdown RH Nozzle Region Temperatures at Station 1950.0

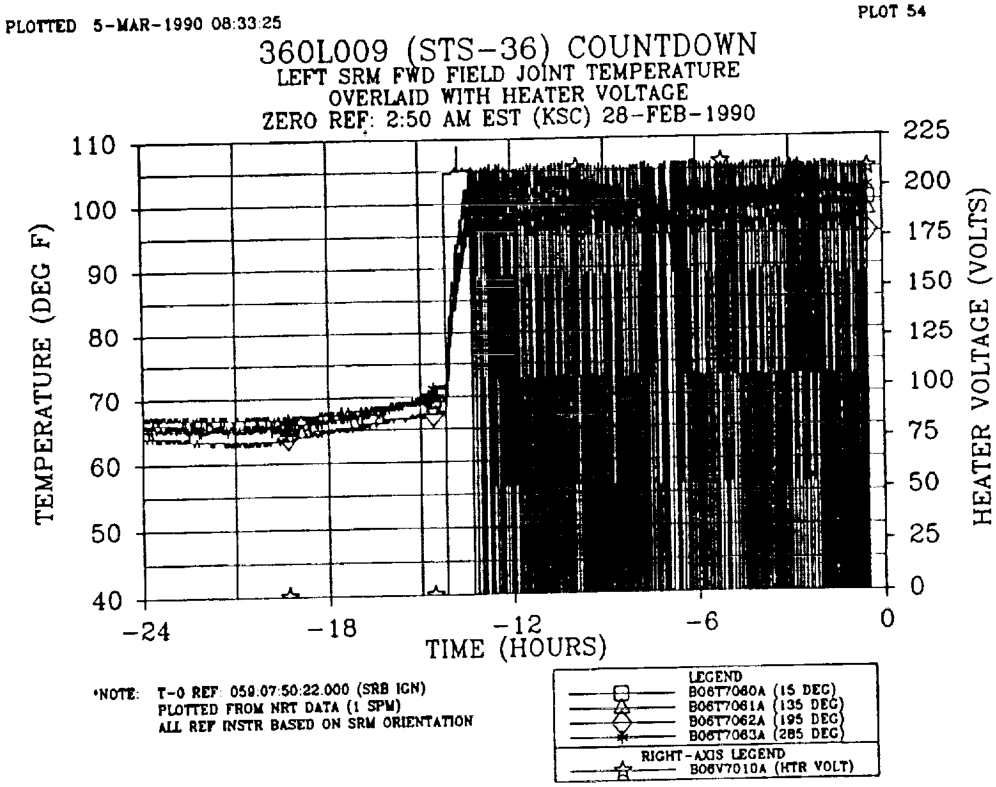

Figure 4.8-89 Countdown LH Forward Field Joint Temperatures

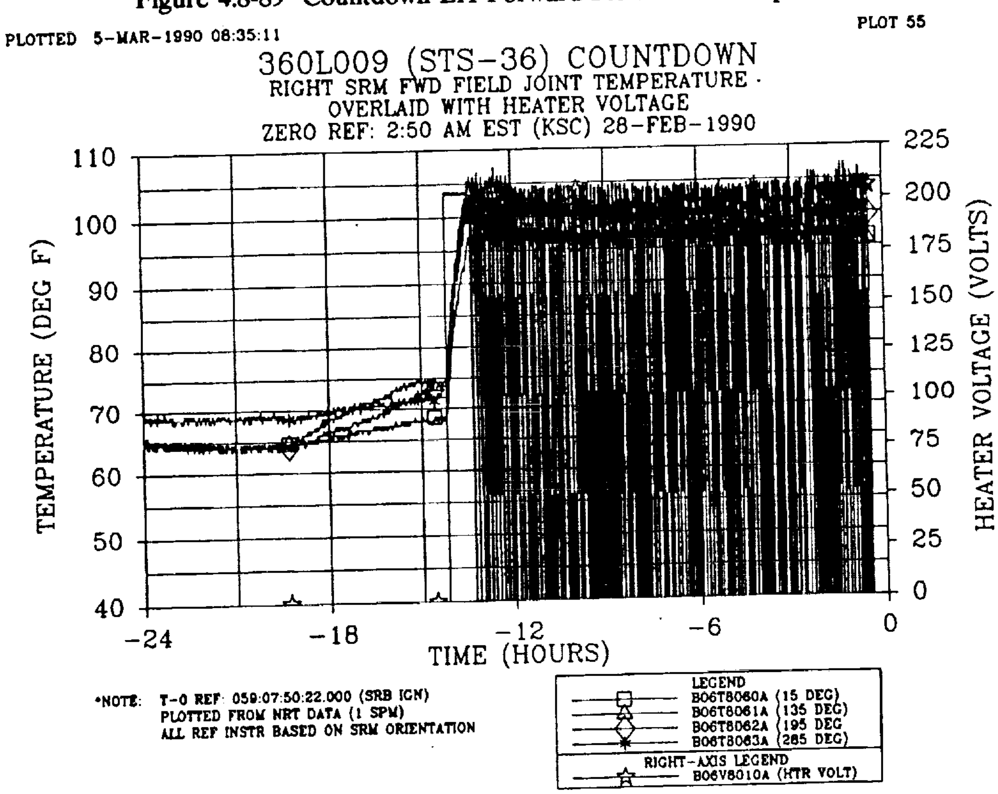

Figure 4.8-90 Countdown RH Forward Field Joint Temperatures

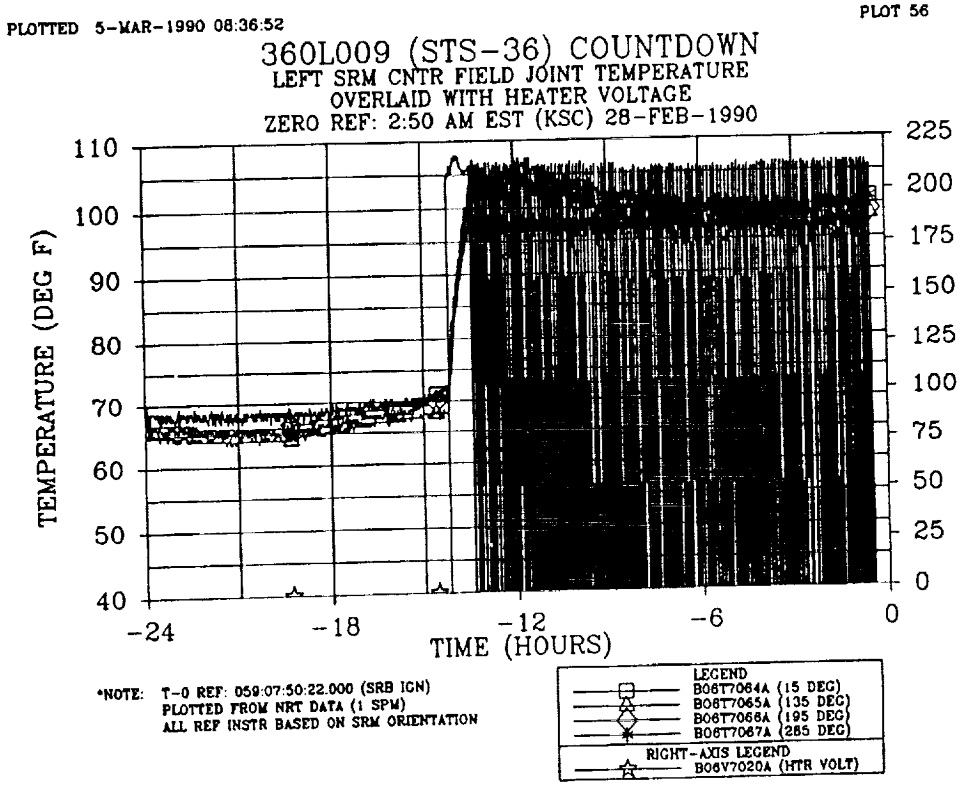

Figure 4.8-91 Countdown LH Center Field Joint Temperatures

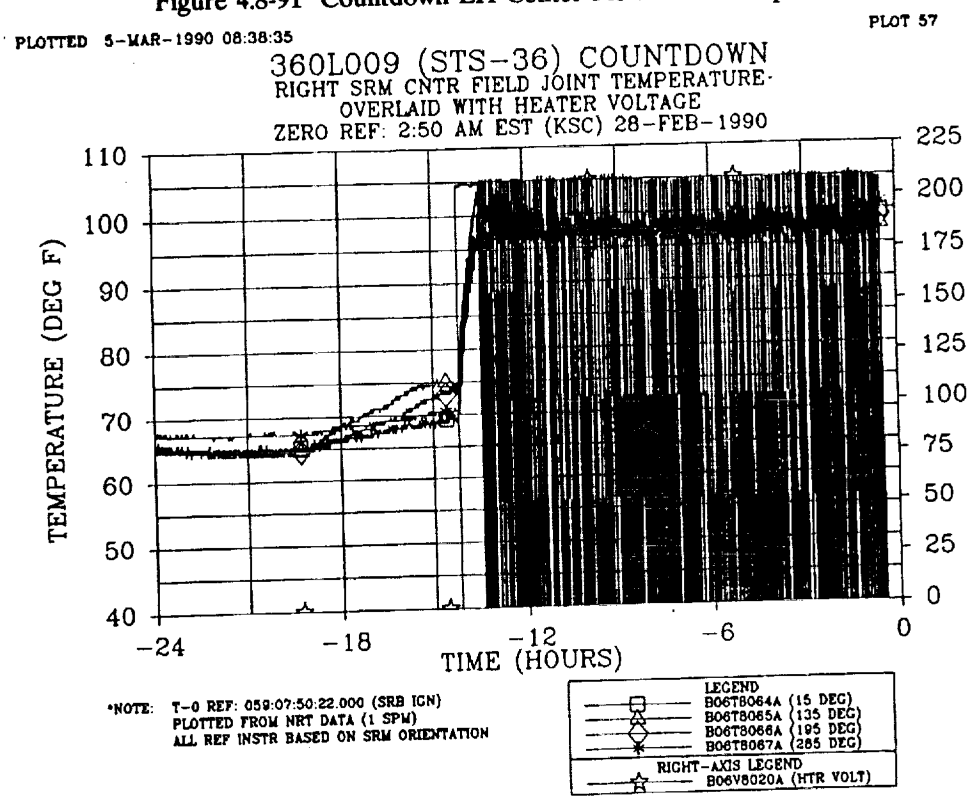

Figure 4.8-92 Countdown RH Center Field Joint Temperatures

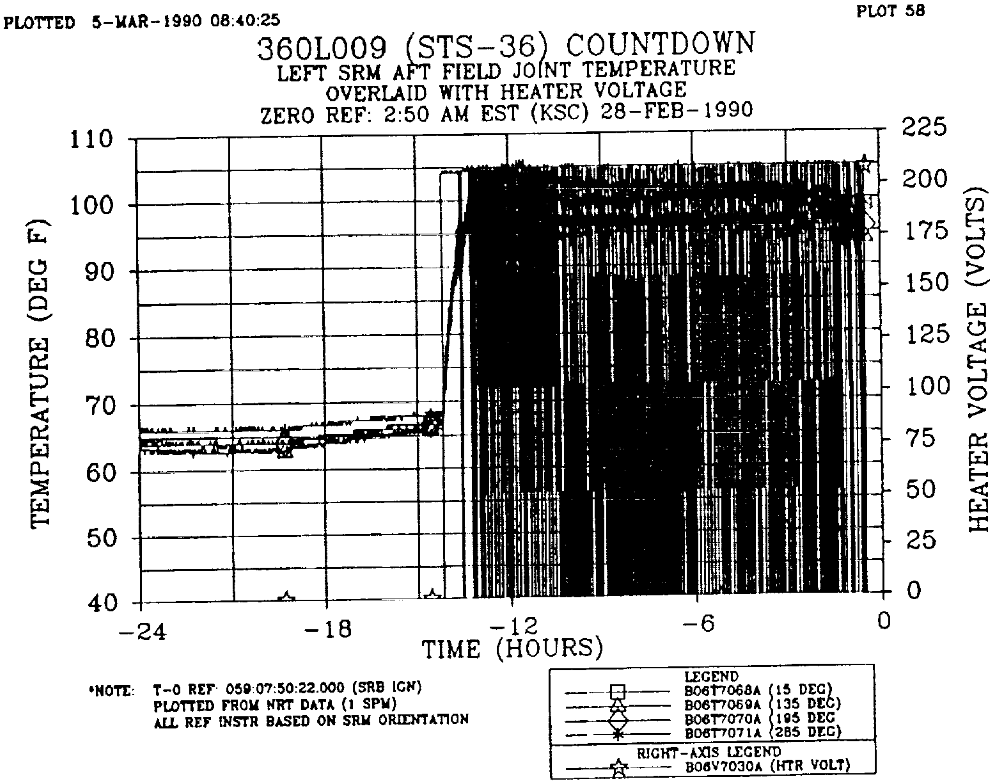

Figure 4.8-93 Countdown LH Aft Field Joint Temperatures

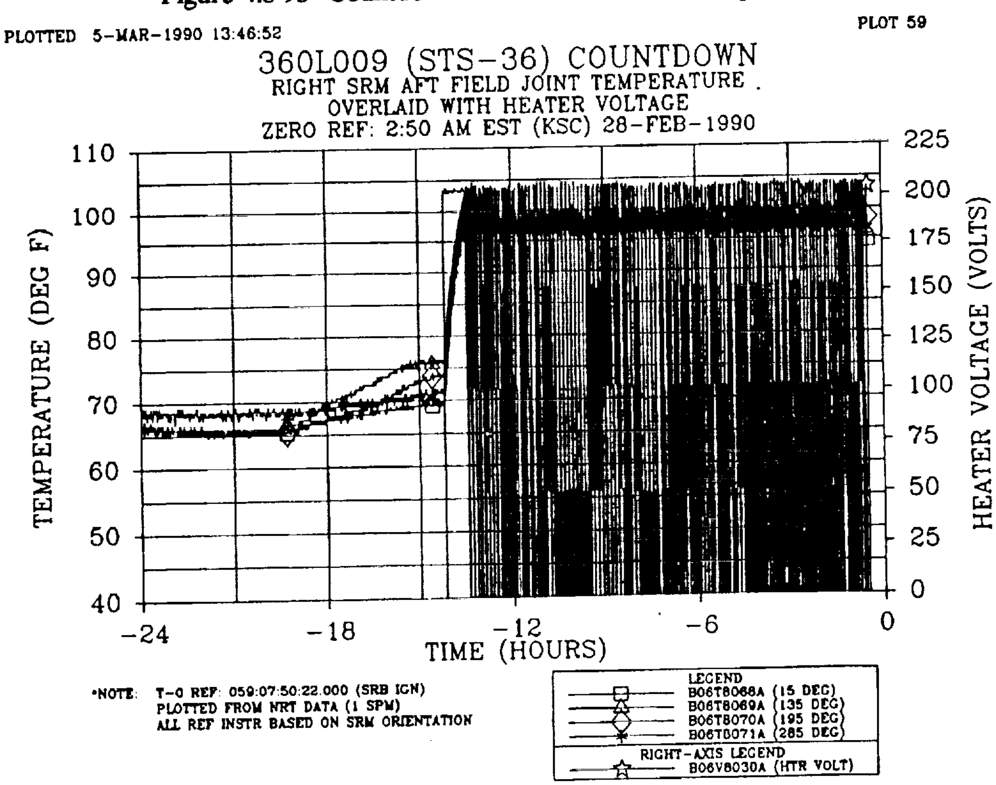

Figure 4.8-94 Countdown RH Aft Field Joint Temperatures

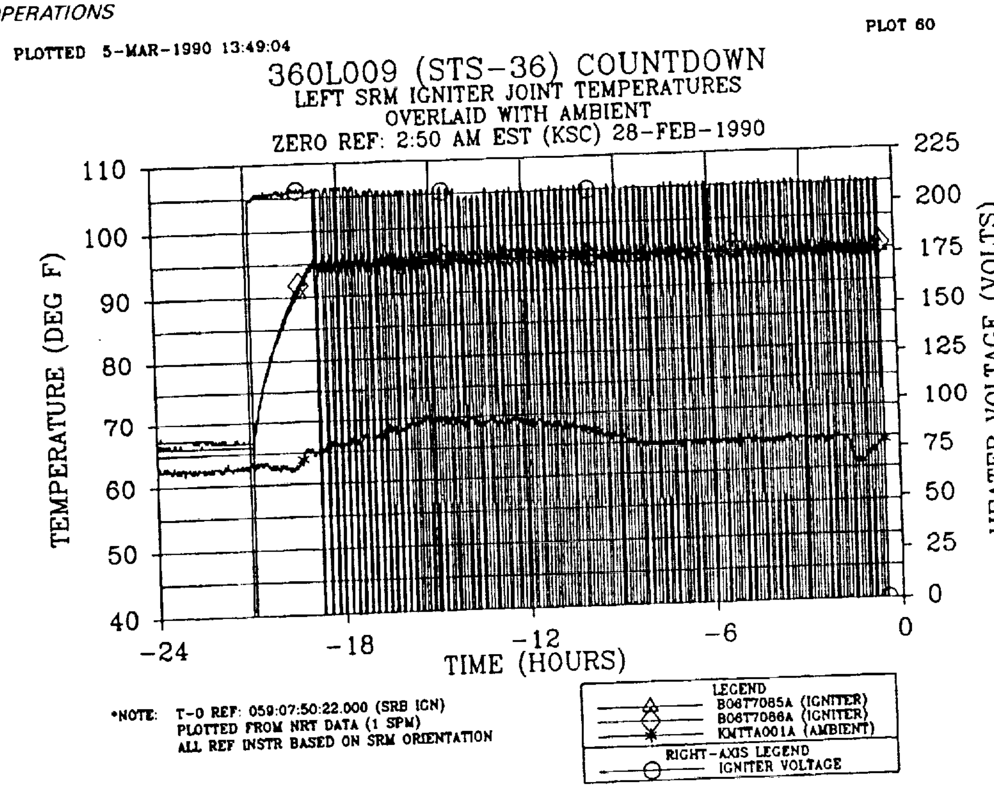

Figure 4.8-95 Countdown LH Igniter Joint Temperatures

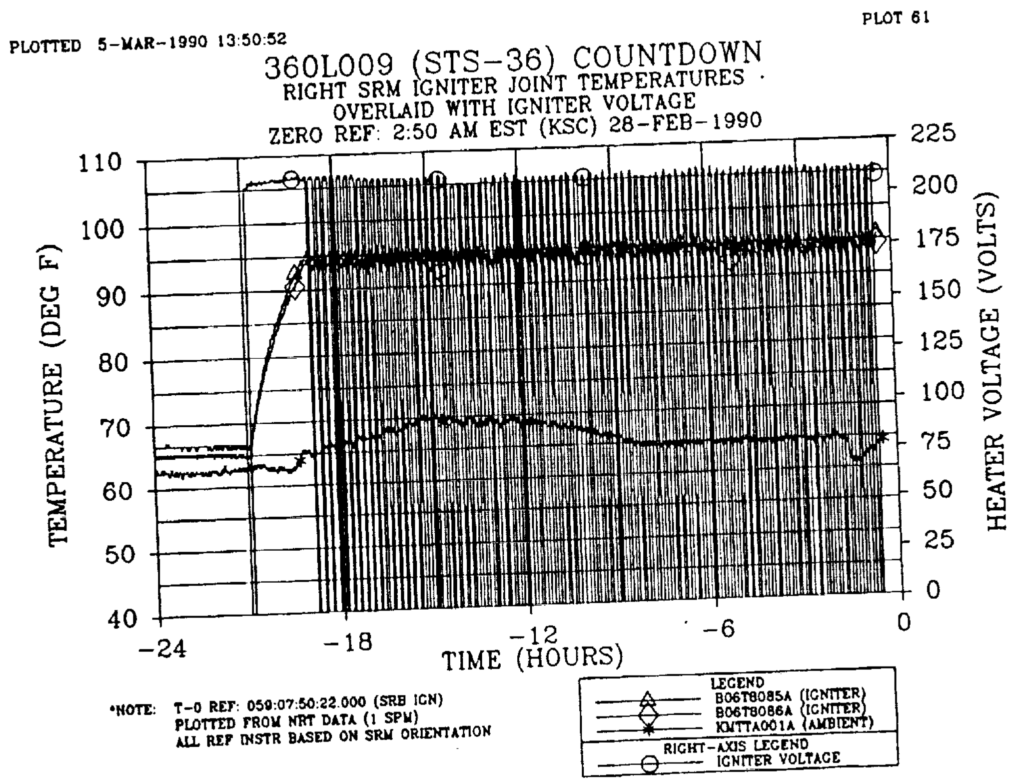

Figure 4.8-96 Countdown RH Igniter Joint Temperatures

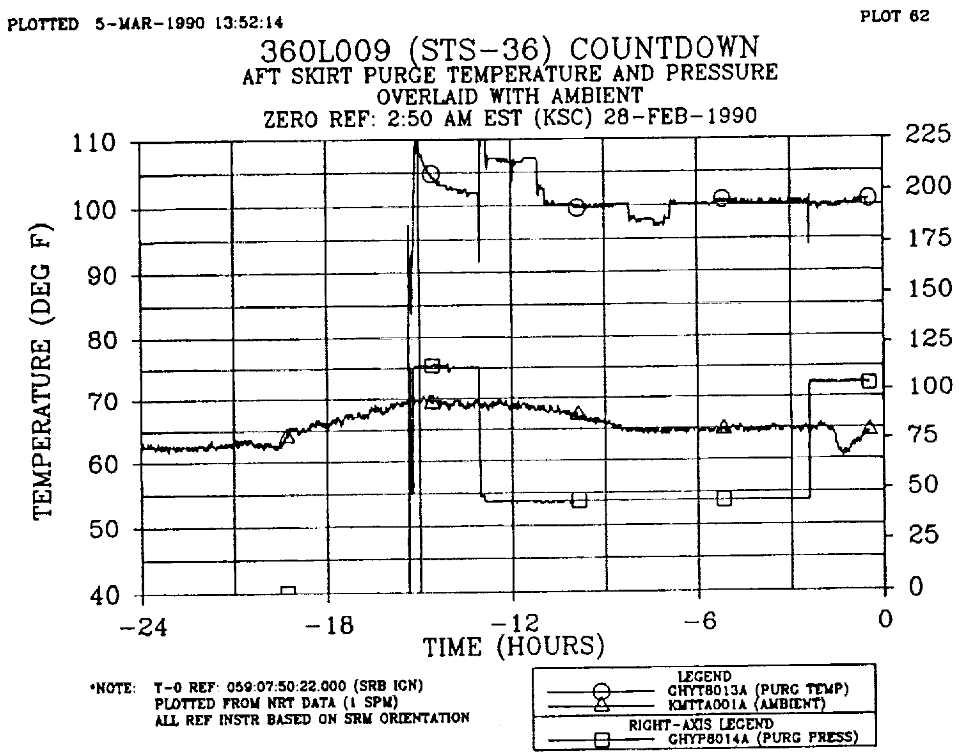

Figure 4.8-97 Countdown Aft Skirt Purge Temperature and Pressure

except for the actual case-to-nozzle joint, flex bearing aft end ring, and case acreage temperatures, which were 2° to 13°F higher than the historical predictions (Table 4.8-6). The L-12 hour predictions of launch time conditions, which incorporate an environmental update for the last 24 hours prior to launch, were in good agreement with the GEI.

Postflight reconstructed predictions of GEI and igniter/field joint heater response were performed using the actual environmental data from the 24 hours prior to launch. A few examples of the predictions, compared with actual measured sensor data, are found in Figures 4.8-98 through 4.8-113. Reasonable agreement is apparent in all areas except the ET attach ring, case acreage, and the left SRB systems tunnel. In the future, modeling improvements (environment and detail) need to be made in these regions.

Figure 4.8-114 shows the postflight FBMBT prediction created from reconstructed ambient temperature and aft skirt purge data.

4.8.4 Conclusions and Recommendations

A summary of these recommendations was presented in Section 3.3; a more detailed explanation is provided here.

4.8.4.1 Postflight Hardware Inspection. Based on the quick-look external inspection, the SRM TPS performed adequately on STS-36. No unexpected heating effects were noted. The SRM TPS design, from a thermal perspective, continues to suggest that the worst-case flight design environments of the IVBC-3 and SRB reentry are, for the most part, overly conservative. An exception to this is the environment in the nozzle base region during reentry, when hydrazine fires and excessive nozzle flame heating are present (see TWR-17542, STS-29R Final Report, Vol I). Updated thermal environments have been received from USBI and are currently being evaluated (Remtech Technical Note RTN 163-55, "Hydrazine Fire Environments-SRB Internal Aft Skirt," and the Appendixes from Remtech Technical Note RTN 173-02-A, which provide technical background information used for the determination of the hydrazine fire effects.)

4.8.4.2 Debris. No SRM violations of NSTS debris criteria were noted. All TPS cork pieces (generally small) are due to nozzle severance debris, splashdown loads, and debris or handling scrapes.

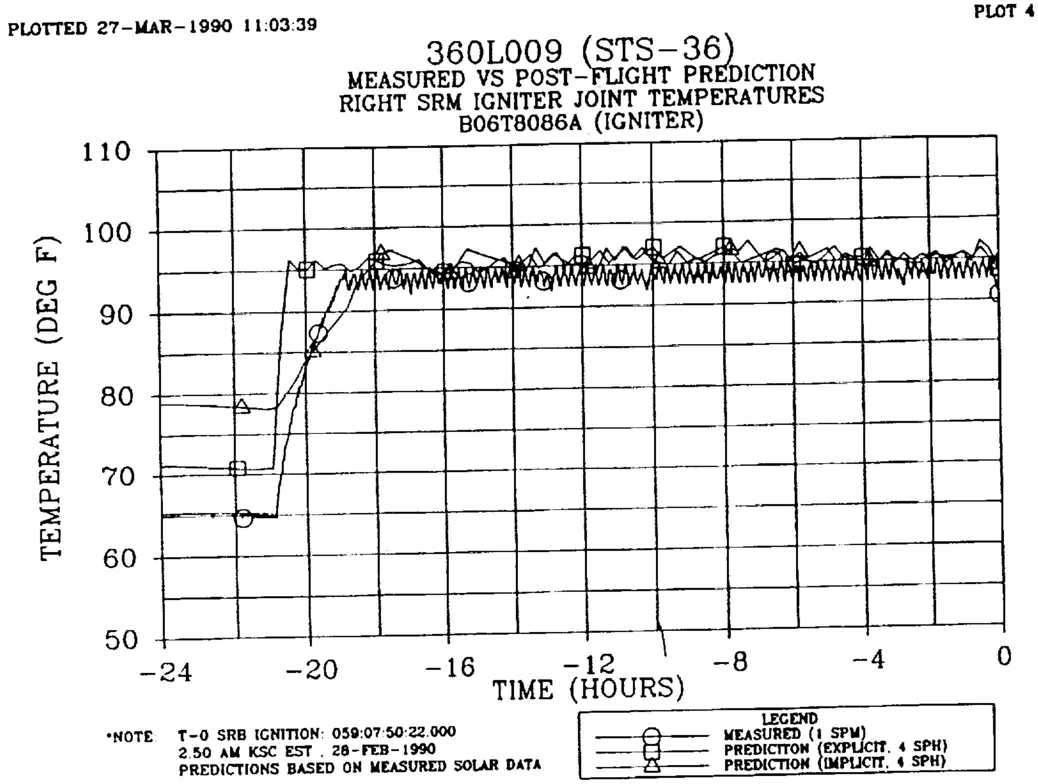

Figure 4.8-98 Measured Versus Postflight Prediction — RH Igniter Joint Temperatures

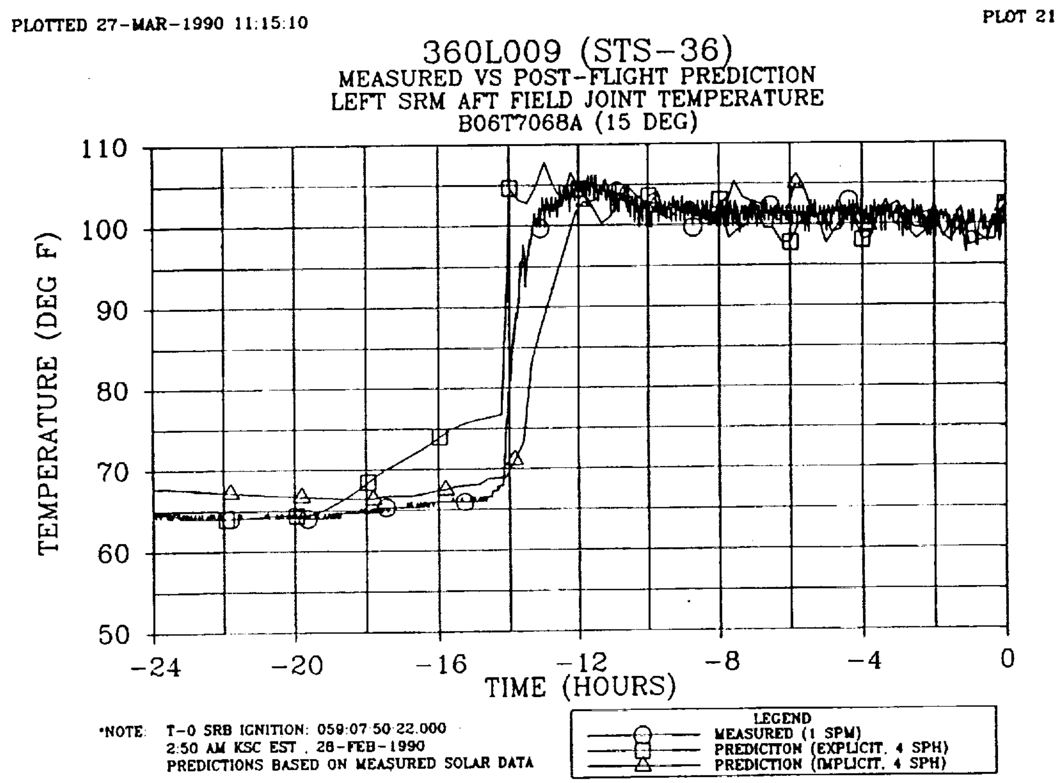

Figure 4.8-99 Measured Versus Postflight Prediction—LH Aft Field Joint (15 deg) Temperatures

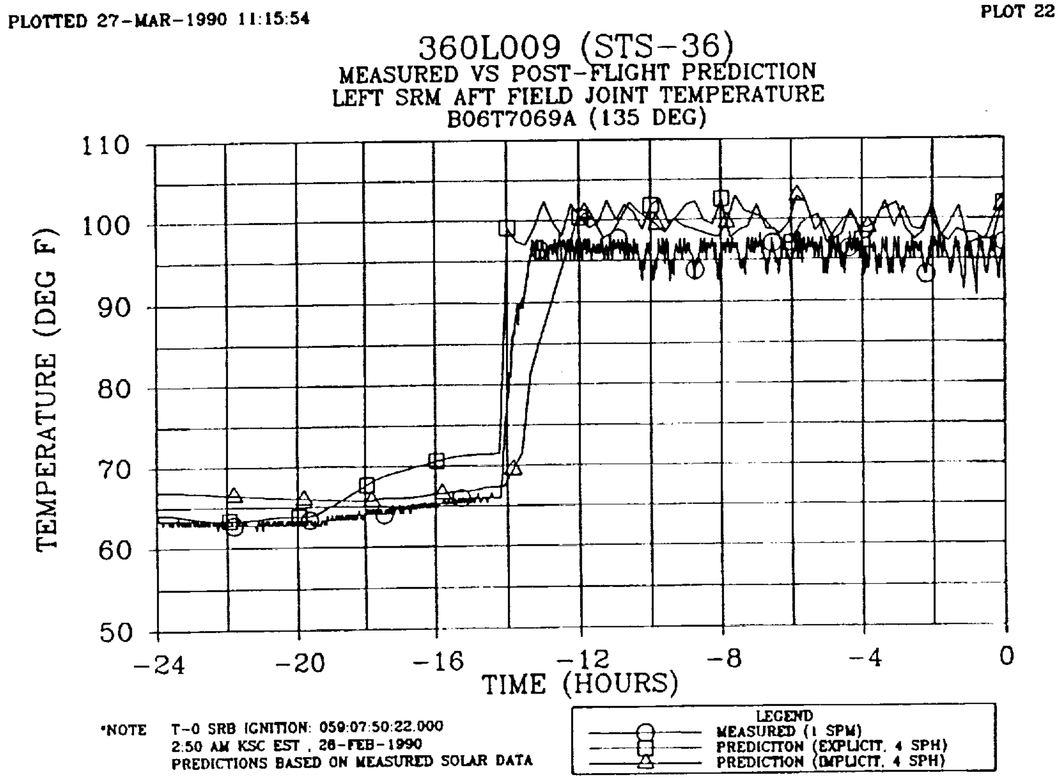

Figure 4.8-100 Measured Versus Postflight Prediction—LH Aft Field Joint (135 deg) Temperatures

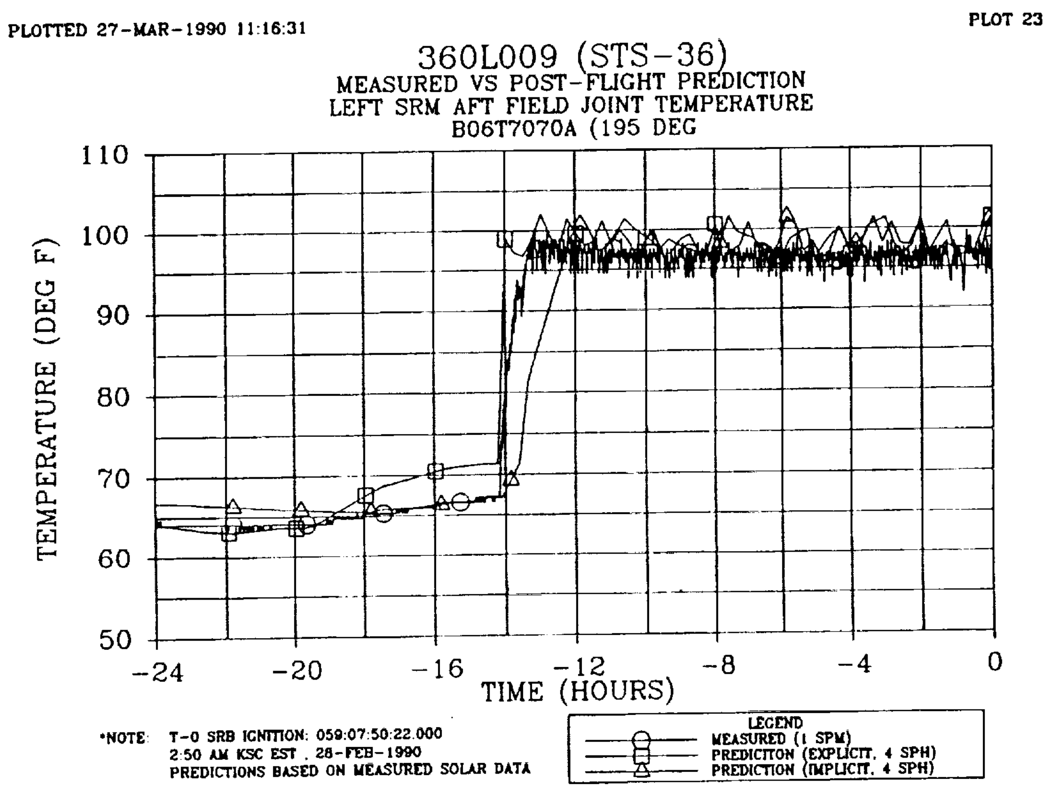

Figure 4.8-101 Measured Versus Postflight Prediction—LH Aft Field Joint (195 deg) Temperatures

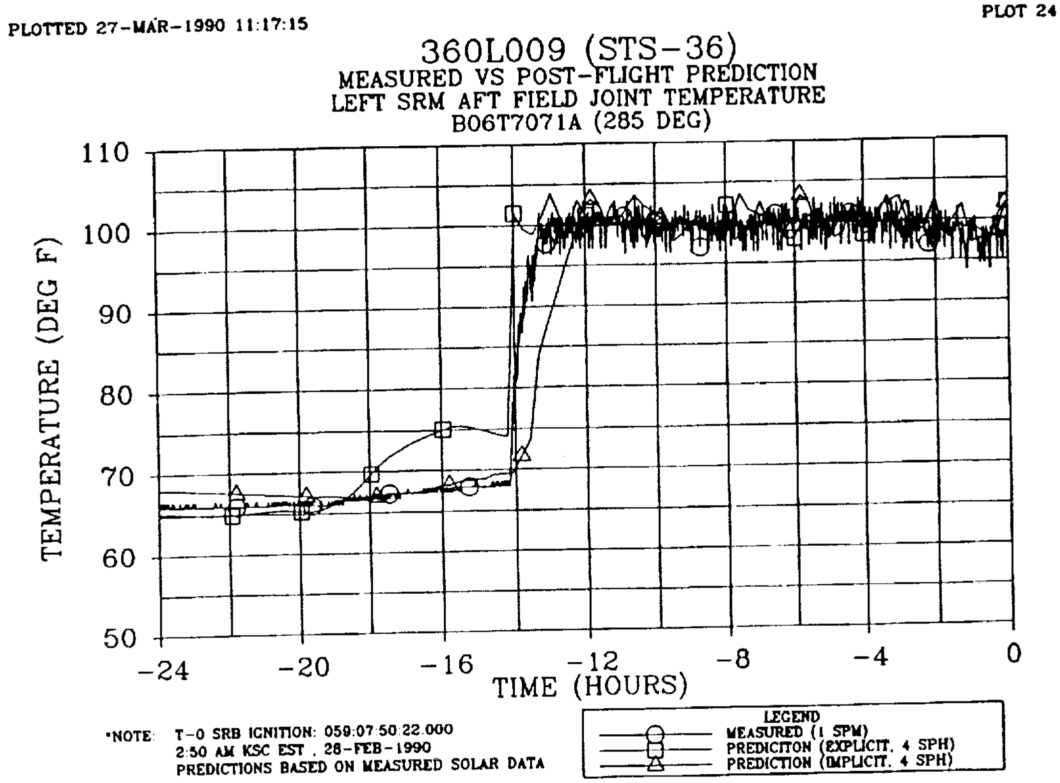

Figure 4.8-102 Measured Versus Postflight Prediction—LH Aft Field Joint (285 deg) Temperatures

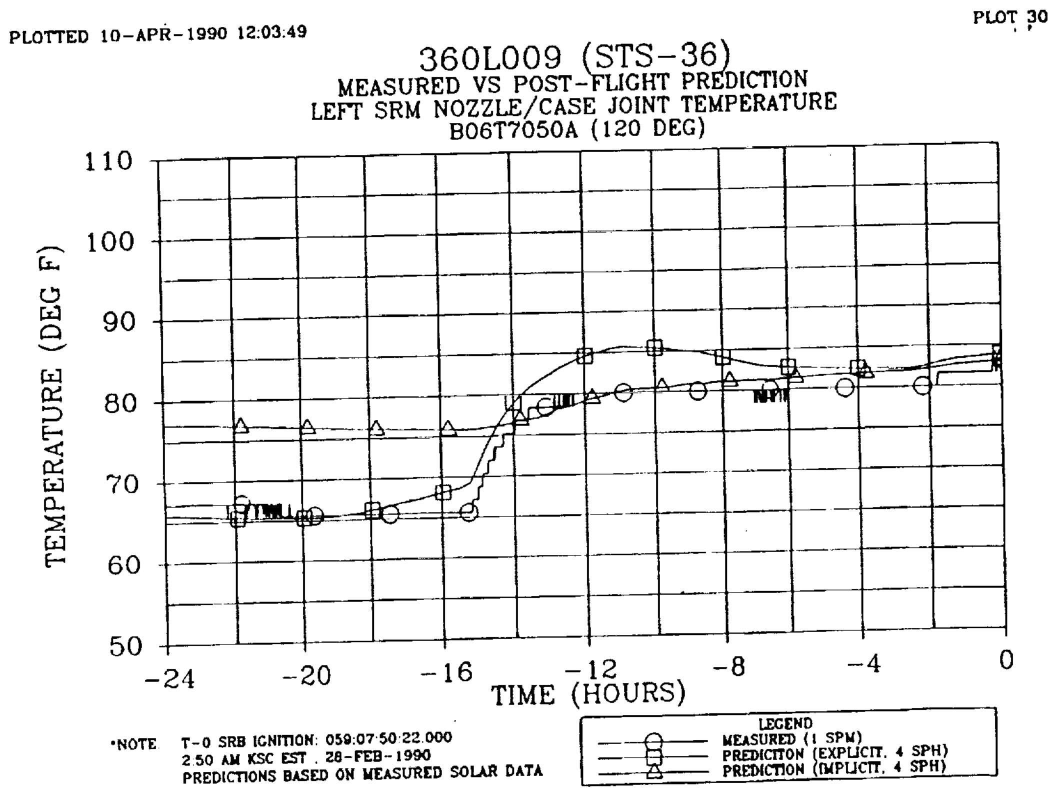

Figure 4.8-103 Measured Versus Postflight Prediction—LH Case-to-Nozzle Joint (120 deg) Temperatures

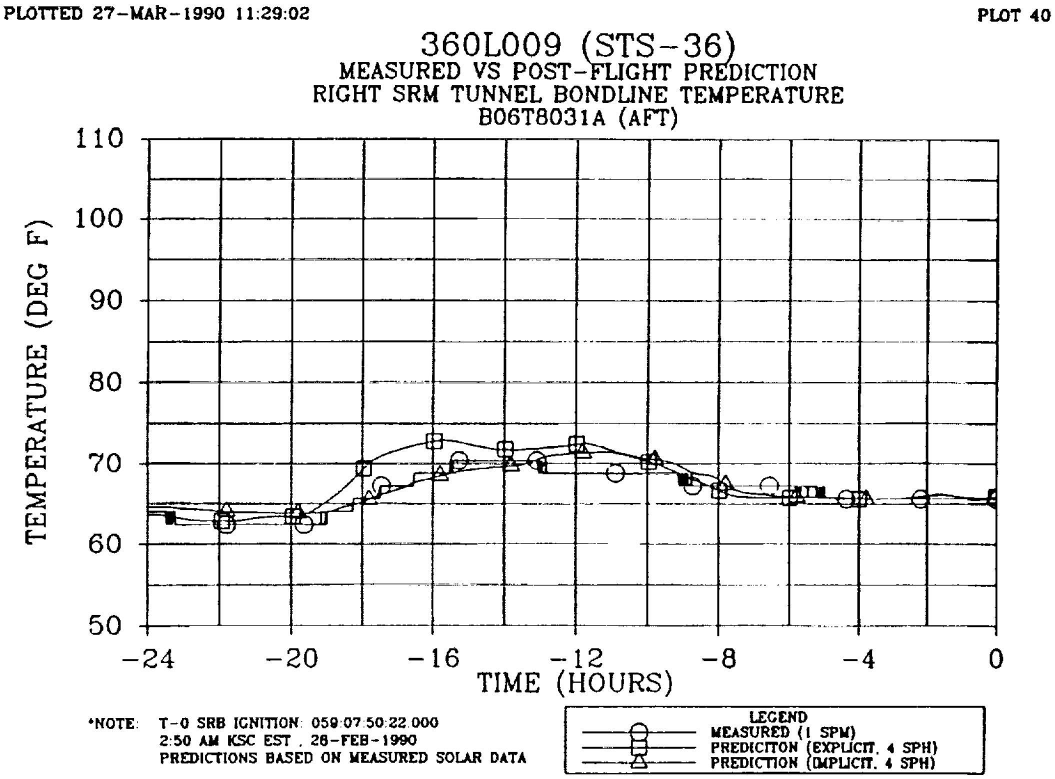

Figure 4.8-104 Measured Versus Postflight Prediction—RH Tunnel Bondline (aft) Temperatures

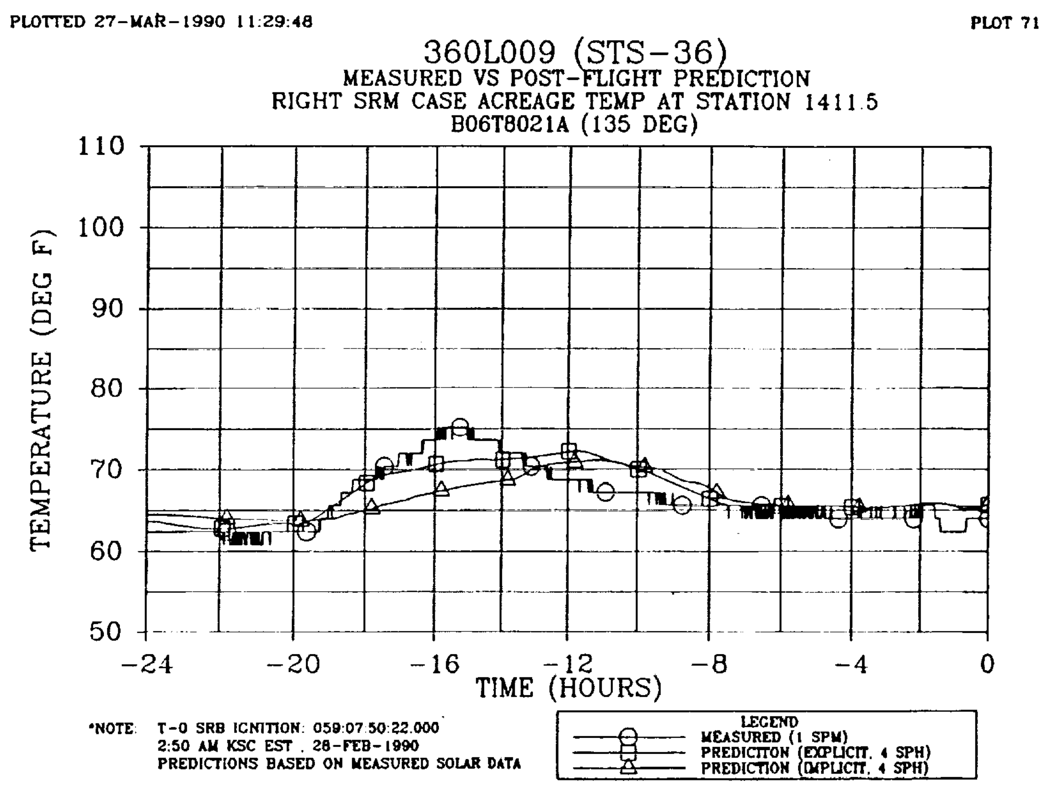

Figure 4.8-105 Measured Versus Postflight Prediction—RH Case Acreage Temperatures at Station 1411.5 (135 deg)

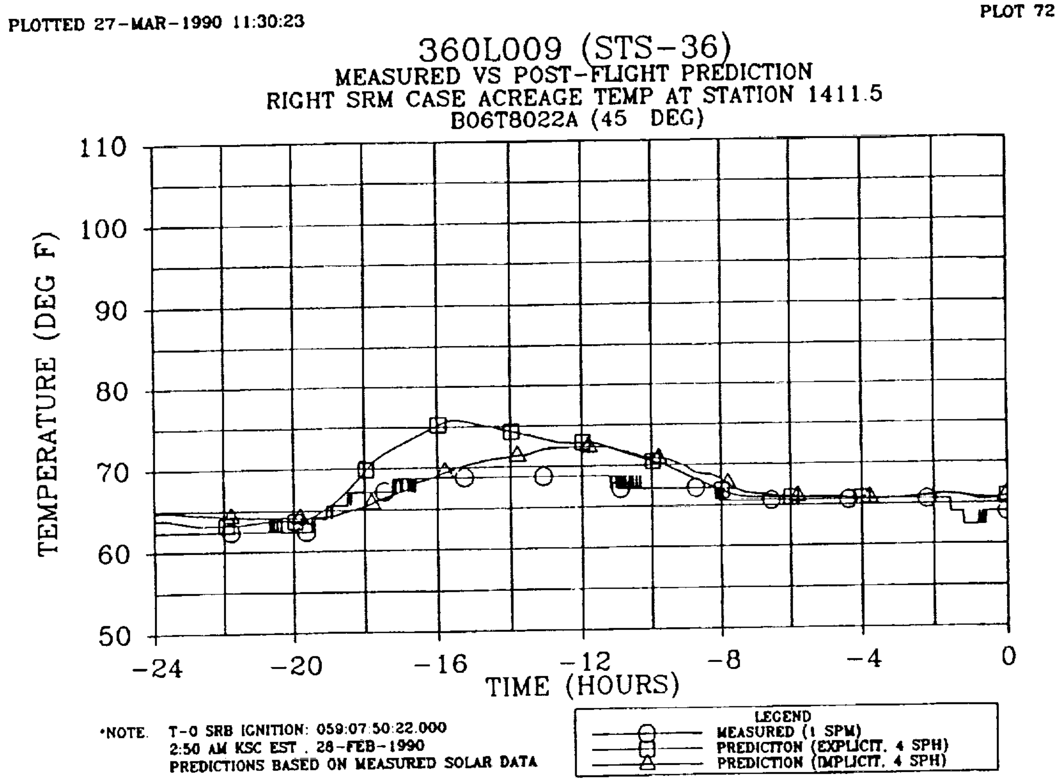

Figure 4.8-106 Measured Versus Postflight Prediction—RH Case Acreage Temperatures at Station 1411.5 (45 deg)

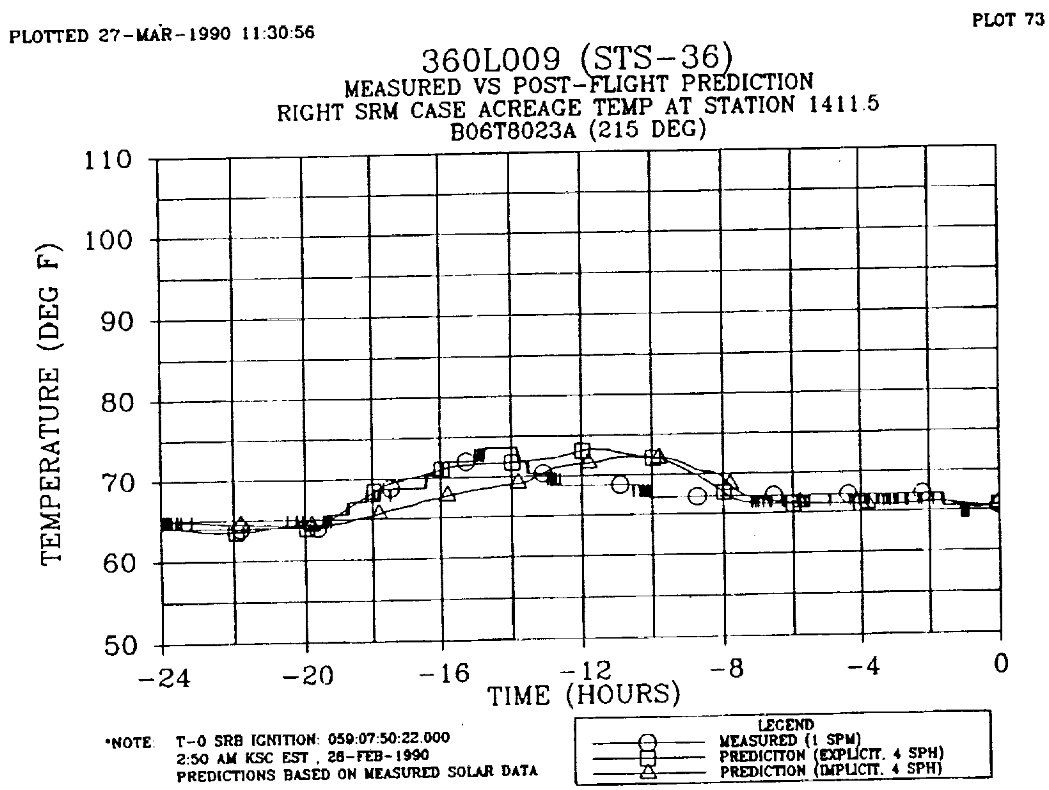

Figure 4.8-107 Measured Versus Postflight Prediction—RH Case Acreage Temperatures at Station 1411.5 (215 deg)

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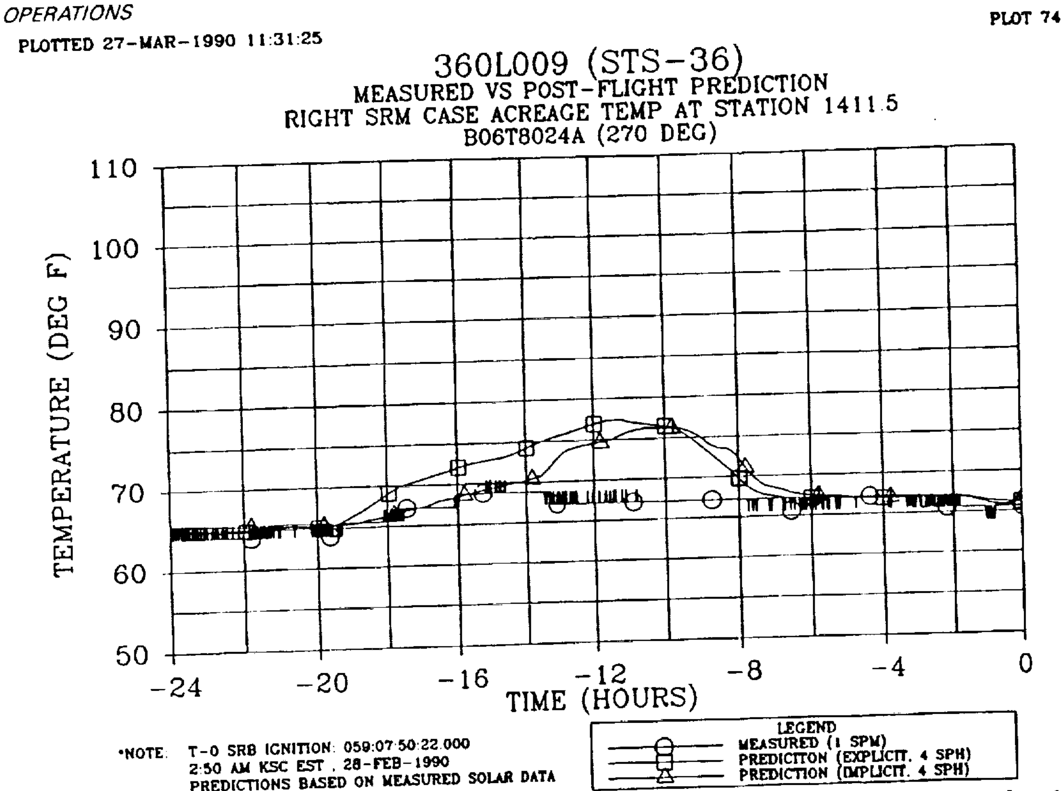

Figure 4.8-108 Measured Versus Postflight Prediction—RH Case Acreage Temperatures at Station 1411.5 (270 deg)

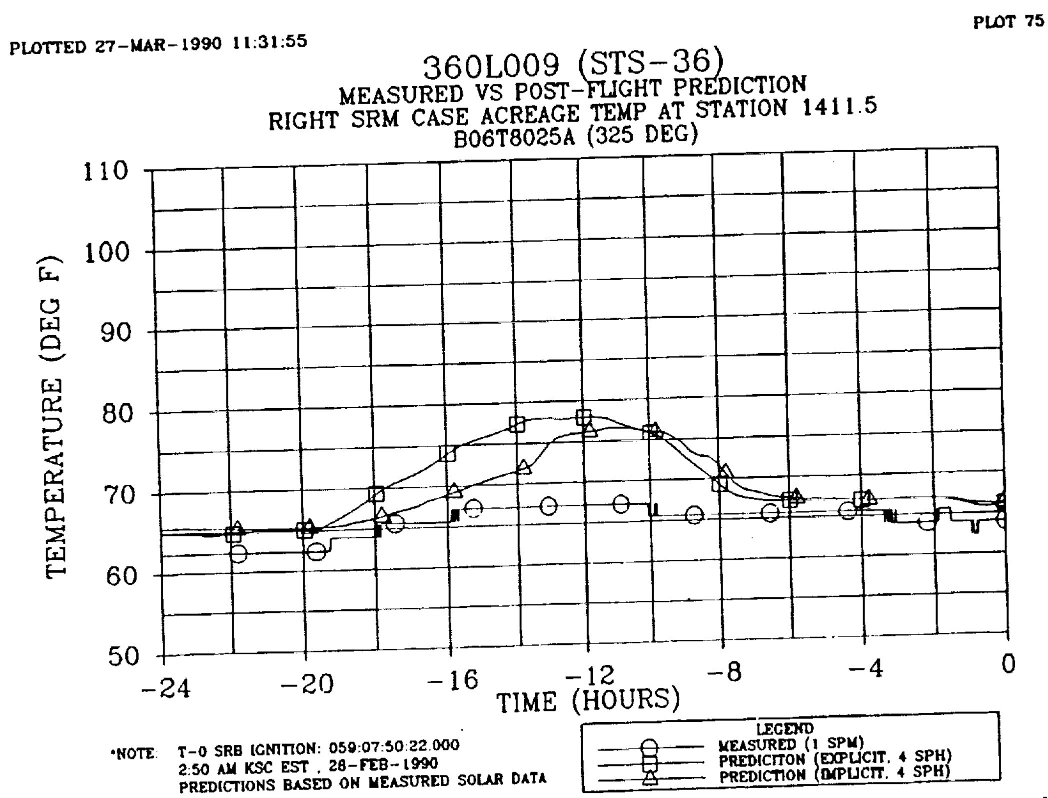

Figure 4.8-109 Measured Versus Postflight Prediction—RH Case Acreage Temperatures at Station 1411.5 (325 deg)

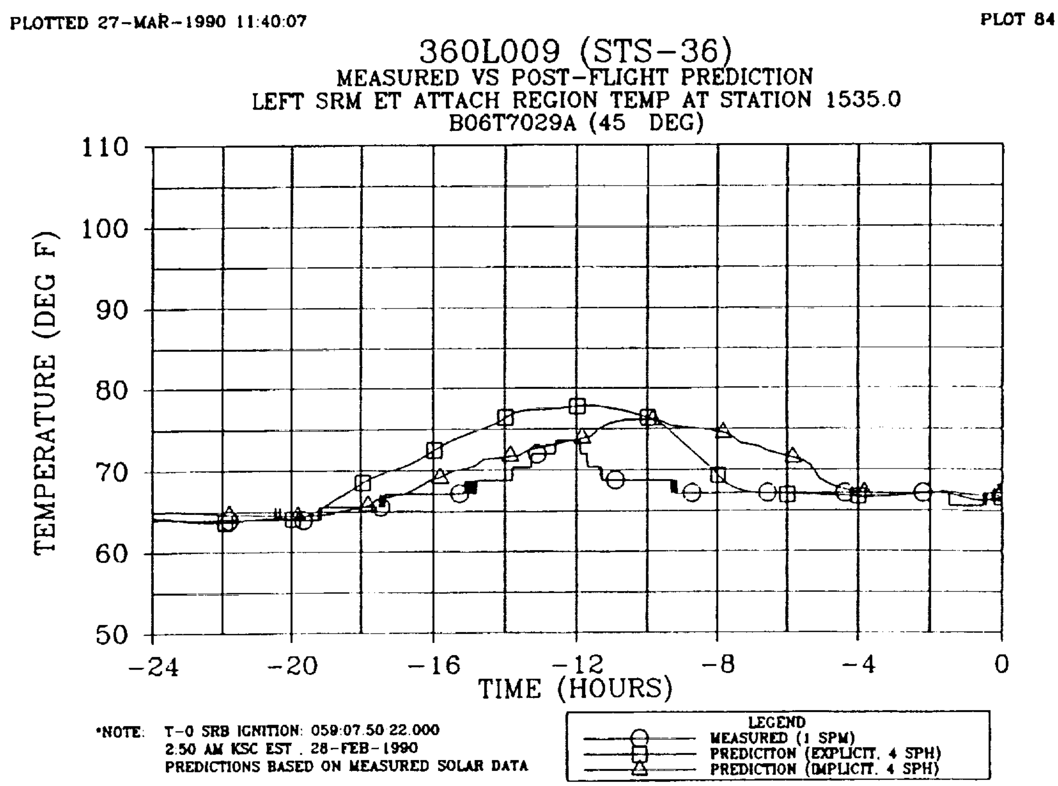

Figure 4.8-110 Measured Versus Postflight Prediction—LH ET Attach Region Temperatures at Station 1535.0 (45 deg)

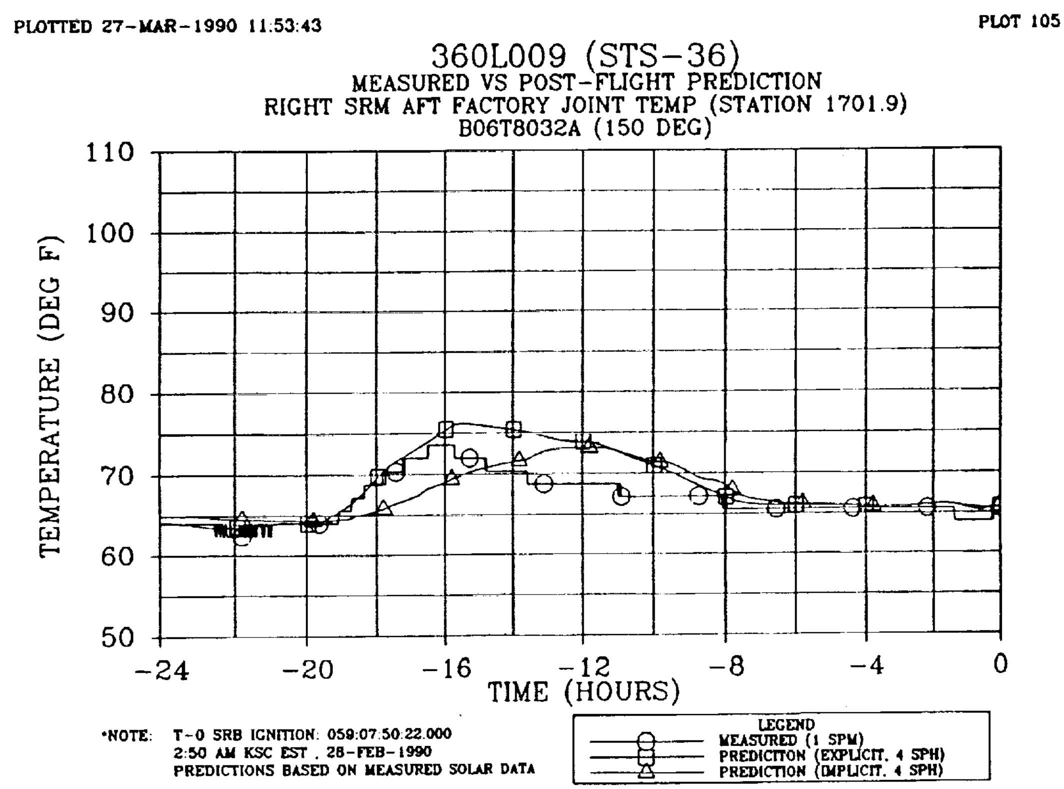

Figure 4.8-111 Measured Versus Postflight Prediction—RH Aft Factory Joint Temperatures at Station 1701.9 (150 deg)

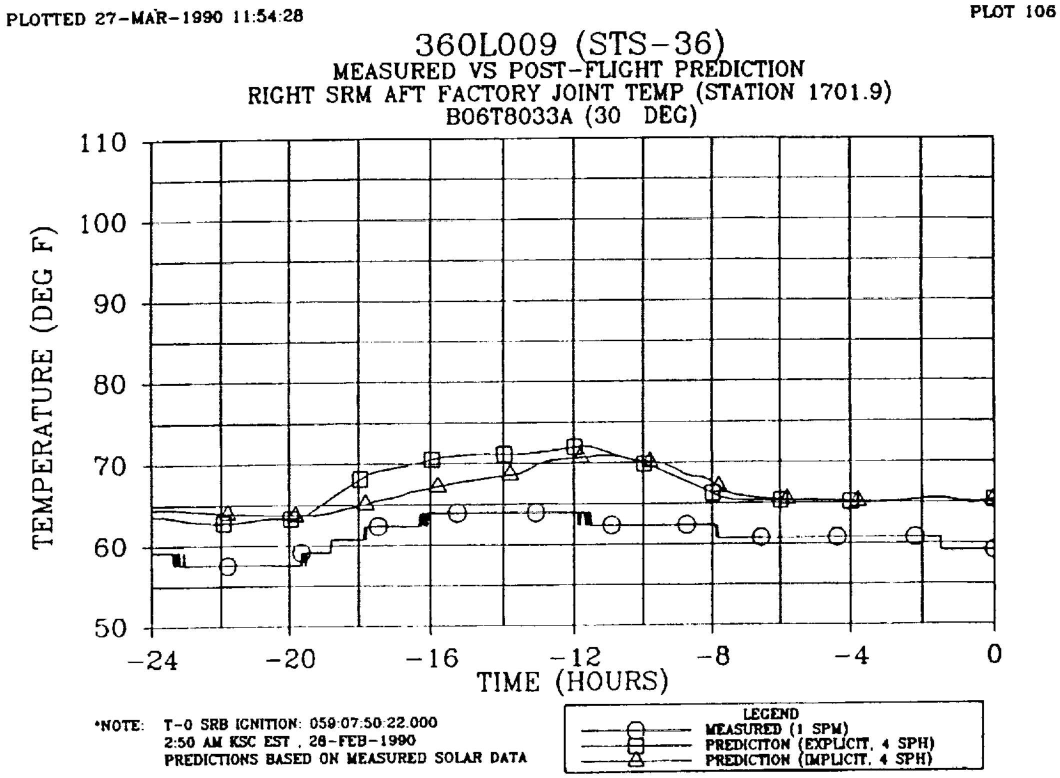

Figure 4.8-112 Measured Versus Postflight Prediction—RH Aft Factory Joint Temperatures at Station 1701.9 (30 deg)

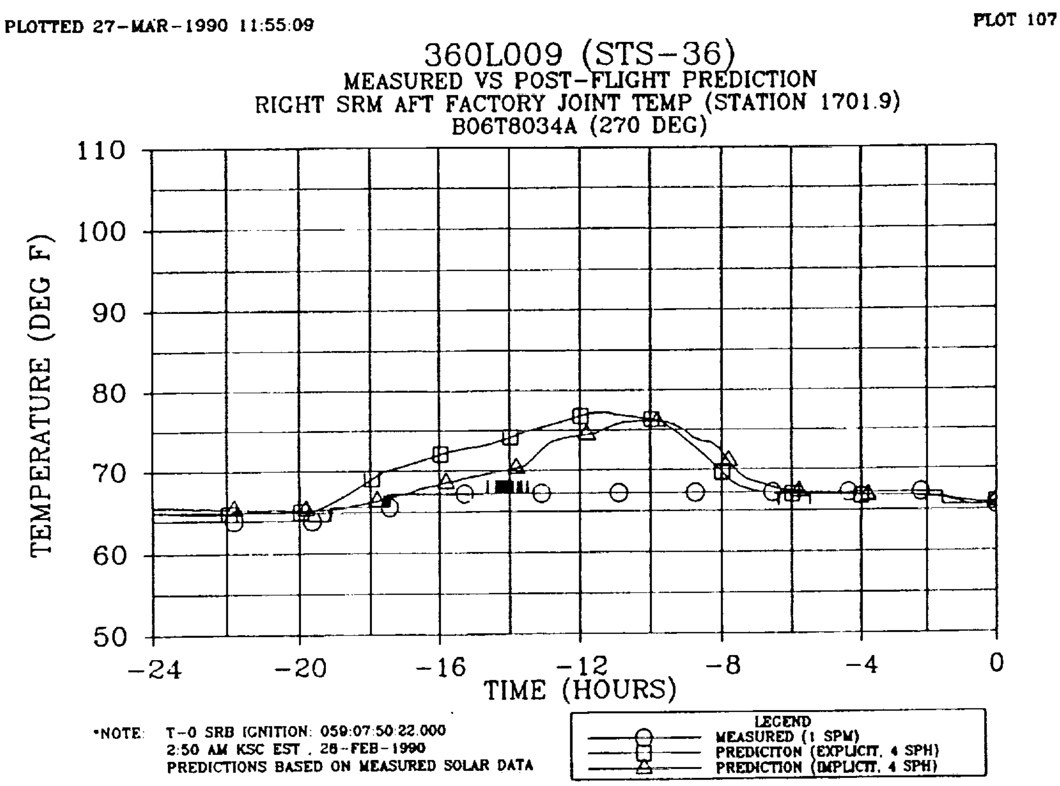

Figure 4.8-113 Measured Versus Postflight Prediction—RH Aft Factory Joint Temperatures at Station 1701.9 (270 deg)

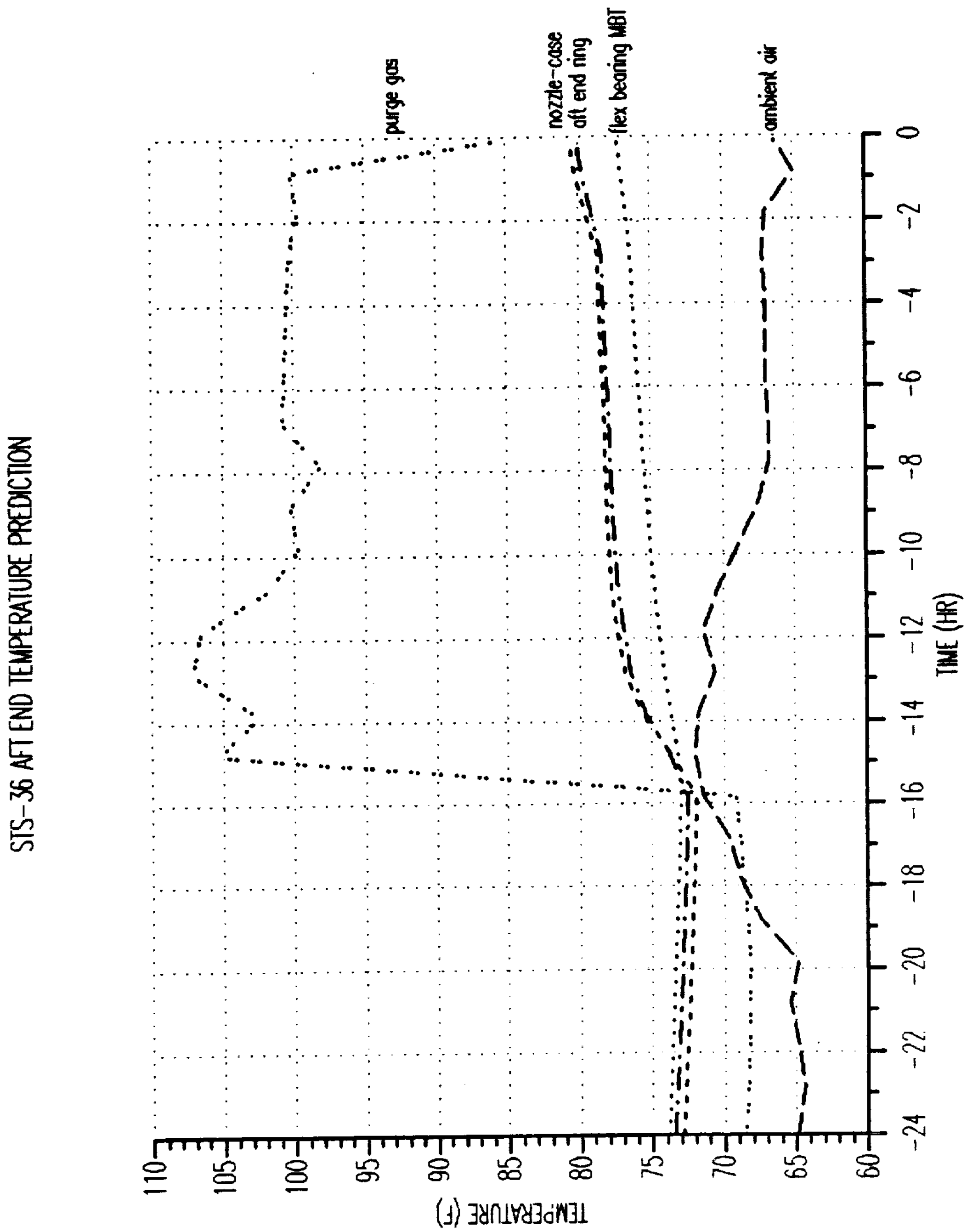

Figure 4.8-114 Aft End Temperature Prediction

4.8.4.3 GEI Prediction. Additional model enhancement is recommended to improve predictions for certain motor regions. It should be noted, however, that the attainment of actual solar radiation data for recent STS flights has improved postflight predictions significantly. Submodel development effort for the areas of the ET attach ring, field joint, factory joint, systems tunnel, igniter, and nozzle regions is anticipated. These tasks would be encompassed by the global model. It is recommended that the nodes be made smaller to refine the model. It is also recommended that all these models, including the 3-D SRM model, be made available for use at MSFC. This would allow Thiokol thermal personnel to support launch countdowns at the HOSC with prediction update capability. Thiokol could then extend these modeling capabilities to MSFC thermal personnel counterparts.

4.8.4.4 Aft Skirt Purge Operation. During the early stages of the STS-36 purge operation, up to a 5°F circumferential temperature differential existed between the case-to-nozzle joint sensors and between the aft end ring sensors. This occurred under high flow and temperature conditions. This represents a good data point from which to base a 3-D skirt region flow analysis. This effort would be of special value if the GN_2 heating system fails and a GN_2 cold purge is required in the last stages of the count.

4.8.4.5 GEI Accuracy. Gage range has been reduced on all field joint and igniter heater sensors, resulting in better data resolution. It is recommended that the data collection accuracy of all GEI be increased by reducing the gage range and increasing the digital word length. The real fidelity of the KSC GSE could then be quantified, and could conceivably be replaced if determined to be inadequate.

4.8.4.6 Local Chilling. Based on data from the launch attempt on 25 Feb 1990, STS-28 (360H005), STS-29R (360L003) and STS-30R (360L004), local cooling does occur. When comparing this flight with the three previously mentioned, based on similar wind conditions, cooling should have occurred on 360L008 (STS-32R), but it did not. In a joint effort between MSFC and Thiokol, methods are currently being developed to accurately quantify and predict the chill effect.

4.8.4.7 Infrared Measurements. STI data continues to be much more reliable than IR gun measurements. Comparisons with GEI are within acceptable margins for STI data, but are questionable and unpredictable for IR gun data. Future efforts should be made in specifying locations for additional stationary STI cameras to assist in the eventual replacement of the outboard GEI (inboard GEI will need to be maintained since the STI cannot reach these blind regions).

4.8.4.8 Ice/Debris Team Support. Thiokol provided a formal response to the Ice/Debris team concerning debris particles coming out of the SRM nozzle prior to and following separation. It was concluded that the particles were not insulation, but slag particles ejected due to pressure reduction at motor burnout.

4.8.4.9 SRM Hardware Thermal Assessment. The SRM TPS design, from a thermal perspective, continues to suggest that the worst-case flight design environments of the IVBC-3 and SRB reentry are, for the most part, overly conservative. An exception to this is the environment in the nozzle base region during reentry when excessive nozzle flame heating and hydrazine fires are present (see TWR-17542, STS-29R Final Report, Vol I). Updated thermal environments have been received from USBI and are currently being evaluated (Remtech Technical Note RTN 163-55, "Hydrazine Fire Environments-SRB Internal Aft Skirt," and the Appendixes from Remtech Technical Note RTN 173-02-A, which provide technical background information used for the determination of the hydrazine fire effects).

4.9 MEASUREMENT SYSTEM PERFORMANCE (DFI) (FEWG REPORT PARA 2.9.5)

DFI has been eliminated on STS-30R (360L004) and subsequent flights. This section is reserved pending any future motors that incorporate DFI.

4.10 MEASUREMENT SYSTEM PERFORMANCE (FEWG REPORT PARA 2.9.7)

4.10.1 Instrumentation Summary

Table 4.10-1 shows the location and number of 360L009 (STS-36) instrumentation. Note that the igniter heater sensors are classified as GEI, whereas the field joint heater sensors are listed under a separate category. The OFI consists of the three OPTs which are used to determine the SRB separation time.

Table 4.10-1. STS-36 Instrumentation

Parameter	LH OFI	LH GEI	LH HTR	RH OFI	RH GEI	RH HTR	Total
Pressure	3			3			6
Temperature		54*	12		54*	12	132
							138

*Includes igniter heater sensors

4.10.2 GEI/OFI Performance

The GEI instrumentation on Flight Motor Set 360L009 consisted of 108 temperature sensors, RTDs which monitor motor case temperature while the motor is on the pad. OFI consists of three OPTs on each forward dome. All GEI gages were functioning and all were within the allowable variation before launch, with the exceptions of seven case acreage temperature sensors which read higher or lower than surrounding sensors. Tables 4.10-2 and 4.10-3 are the GEI instrumentation lists and include gages which consistently read differently from surrounding gages. All GEI are disconnected by breakaway umbilicals at SRB ignition and are not operative during flight. Figures 4.8-6 and 4.8-8 through 4.8-10 show GEI/OFI locations.

The OFI consists of three OPTs on each forward dome. The results of the 75 percent calibration verified readings (performed at T-1.5 hours) were well within the 740- to 804-psia allowable range:

360L009A (LH)		360L009B (RH)	
Gage	Reading	Gage	Reading
B47P1300C	763.8	B47P2300C	763.8
B47P1301C	769.8	B47P2301C	761.8
B47P1302C	763.8	B47P2302C	765.8

4.10.3 Heater Sensor Performance

Evaluation of the field joint heaters and heater sensor performance was discussed previously in Section 4.8.3. Table 4.10-4 and Figure 4.8-7 list the joint heater sensors and show the gage locations, respectively.

4.10.4 S&A Device Rotation Times

Table 4.10-5 includes the arm and safe delta times for the S&A functional test performed prior to the 360L009 (STS-36) countdown. Table 4.10-6 lists the arm and safe times during the actual launch sequence (at T-5 minutes). As with the functional test, all values are less than 2.0 seconds.

Table 4.10-2. GEI List for 360L009A (LH)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location	Comments
B06T7003A	270	534.5	±200	Forward segment	
B06T7004A	45	694.5	±200	Forward segment	
B06T7005A	135	694.5	±200	Forward segment	
B06T7006A	325	694.5	±200	Forward segment	
B06T7007A	270	694.5	±200	Forward segment	
B06T7008A	215	694.5	±200	Forward segment	
B06T7009A	90	778.98	±200	Forward segment (systems tunnel)	
B06T7010A	45	931.48	±200	Forward center segment	
B06T7011A	135	931.48	±200	Forward center segment	
B06T7012A	325	931.48	±200	Forward center segment	
B06T7013A	270	931.48	±200	Forward center segment	
B06T7014A	215	931.48	±200	Forward center segment	
B06T7015A	45	1091.48	±200	Forward center segment	
B06T7016A	135	1091.48	±200	Forward center segment	
B06T7017A	325	1091.48	±200	Forward center segment	
B06T7018A	270	1091.48	±200	Forward center segment	
B06T7019A	215	1091.48	±200	Forward center segment	
B06T7020A	90	1258.98	±200	Aft center segment (systems tunnel)	
B06T7021A	45	1411.48	±200	Aft center segment	
B06T7022A	135	1411.48	±200	Aft center segment	
B06T7023A	325	1411.48	±200	Aft center segment	
B06T7024A	270	1411.48	±200	Aft center segment	
B06T7025A	215	1411.48	±200	Aft center segment	
B06T7026A	220	1511	±200	ET attach ring	Reads 2°-4°F higher than surrounding stations
B06T7027A	274	1511	±200	ET attach ring	
B06T7028A	320	1511	±200	ET attach ring	
B06T7029A	45	1535	±200	Aft segment	
B06T7030A	135	1535	±200	Aft segment	
B06T7031A	90	1565	±200	Aft segment (systems tunnel)	
B06T7032A	30	1701.86	±200	Aft segment	
B06T7033A	150	1701.86	±200	Aft segment	
B06T7034A	270	1701.86	±200	Aft segment	
B06T7035A	45	1751.5	±200	Aft segment	
B06T7036A	135	1751.5	±200	Aft segment	
B06T7037A	325	1751.5	±200	Aft segment	
B06T7038A	270	1751.5	±200	Aft segment	
B06T7039A	215	1751.5	±200	Aft segment	
B06T7040A	30	1821	±200	Aft segment	
B06T7041A	150	1821	±200	Aft segment	
B06T7042A	270	1821	±200	Aft segment	
B06T7043A	0	1847	±200	Flex bearing	
B06T7044A	0	1845	±200	Nozzle throat	
B06T7045A	120	1847	±200	Flex bearing	
B06T7046A	120	1845	±200	Nozzle throat	
B06T7047A	240	1847	±200	Flex bearing	
B06T7048A	240	1845	±200	Nozzle throat	

Table 4.10-2. GEI List for 360L009A (LH) (cont)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location	Comments
B06T7049A	0	1876.6	±200	Case-to-nozzle joint	
B06T7050A	120	1876.6	±200	Case-to-nozzle joint	
B06T7051A	240	1876.6	±200	Case-to-nozzle joint	
B06T7052A	0	1950	±200	Exit cone	
B06T7053A	120	1950	±200	Exit cone	
B06T7054A	240	1950	±200	Exit cone	
B06T7085A	184.5	486.4	-4 to 158	Igniter	
B06T7086A	355.5	486.4	-4 to 158	Igniter	

Table 4.10-3. GEI List for 360L009B (RH)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location	Comments
B06T8003A	270	534.5	±200	Forward segment	
B06T8004A	135	694.5	±200	Forward segment	
B06T8005A	45	694.5	±200	Forward segment	
B06T8006A	215	694.5	±200	Forward segment	
B06T8007A	270	694.5	±200	Forward segment	
B06T8008A	325	694.5	±200	Forward segment	
B06T8009A	90	778.98	±200	Forward segment (systems tunnel)	
B06T8010A	135	931.48	±200	Forward center segment	
B06T8011A	45	931.48	±200	Forward center segment	
B06T8012A	215	931.48	±200	Forward center segment	
B06T8013A	270	931.48	±200	Forward center segment	
B06T8014A	325	931.48	±200	Forward center segment	
B06T8015A	135	1091.48	±200	Forward center segment	
B06T8016A	45	1091.48	±200	Forward center segment	
B06T8017A	215	1091.48	±200	Forward center segment	
B06T8018A	270	1091.48	±200	Forward center segment	
B06T8019A	325	1091.48	±200	Forward center segment	
B06T8020A	90	1258.98	±200	Aft center segment (systems tunnel)	
B06T8021A	135	1411.48	±200	Aft center segment	
B06T8022A	45	1411.48	±200	Aft center segment	
B06T8023A	215	1411.48	±200	Aft center segment	
B06T8024A	270	1411.48	±200	Aft center segment	
B06T8025A	325	1411.48	±200	Aft center segment	
B06T8026A	320	1511	±200	ET attach ring	Reads 2°-4°F higher than surrounding stations
B06T8027A	266	1511	±200	ET attach ring	
B06T8028A	220	1511	±200	ET attach ring	
B06T8029A	135	1535	±200	Aft segment	
B06T8030A	45	1535	±200	Aft segment	
B06T8031A	90	1565	±200	Aft segment (systems tunnel)	
B06T8032A	150	1701.86	±200	Aft segment	
B06T8033A	30	1701.86	±200	Aft segment	
B06T8034A	270	1701.86	±200	Aft segment	
B06T8035A	135	1701.86	±200	Aft segment	Reads approx 4°-8°F lower than adjacent sensors
B06T8036A	45	1751.5	±200	Aft segment	
B06T8037A	215	1751.5	±200	Aft segment	
B06T8038A	270	1751.5	±200	Aft segment	
B06T8039A	325	1751.5	±200	Aft segment	
B06T8040A	150	1821	±200	Aft segment	
B06T8041A	30	1821	±200	Aft segment	
B06T8042A	270	1821	±200	Aft segment	
B06T8043A	180	1847	±200	Flex bearing	
B06T8044A	180	1845	±200	Nozzle throat	
B06T8045A	60	1847	±200	Flex bearing	
B06T8046A	60	1845	±200	Nozzle throat	
B06T8047A	300	1847	±200	Flex bearing	
B06T8048A	300	1845	±200	Nozzle throat	

Table 4.10-3. GEI List for 360L009B (RH) (cont)

Instrument No.	Location (deg)	Station	Range (°F)	Case Location	Comments
B06T8049A	180	1876.6	±200	Case-to-nozzle joint	
B06T8050A	60	1876.6	±200	Case-to-nozzle joint	
B06T8051A	300	1876.6	±200	Case-to-nozzle joint	
B06T8052A	180	1950	±200	Exit cone	
B06T8053A	60	1950	±200	Exit cone	
B06T8054A	300	1950	±200	Exit cone	
B06T8085A	355.5	486.4	-4 to 158	Igniter	
B06T8086A	184.5	486.4	-4 to 158	Igniter	

Table 4.10-4. Field Joint Heater Temperature Sensor Lists (LH and RH)

Instrument No.	Location (deg)	Station	Range (°F)	Required Accuracy (%)	Digital*	Remarks	Comments
LH RSRM Heater Temperature Sensor List							
B07T7060	15	851.5	-4 to 158	±1	1	Forward heater	
B07T7061	135	851.5	-4 to 158	±1	1	Forward heater	
B07T7062	195	851.5	-4 to 158	±1	1	Forward heater	
B07T7063	285	851.5	-4 to 158	±1	1	Forward heater	
B07T7064	15	1171.5	-4 to 158	±1	1	Center heater	
B07T7065	135	1171.5	-4 to 158	±1	1	Center heater	
B07T7066	195	1171.5	-4 to 158	±1	1	Center heater	
B07T7067	285	1171.5	-4 to 158	±1	1	Center heater	
B07T7068	15	1491.5	-4 to 158	±1	1	Aft heater	
B07T7069	135	1491.5	-4 to 158	±1	1	Aft heater	
B07T7070	195	1491.5	-4 to 158	±1	1	Aft heater	
B07T7071	285	1491.5	-4 to 158	±1	1	Aft heater	
RH RSRM Heater Temperature Sensor List							
B07T8060	15	851.5	-4 to 158	±1	1	Forward heater	
B07T8061	135	851.5	-4 to 158	±1	1	Forward heater	
B07T8062	195	851.5	-4 to 158	±1	1	Forward heater	
B07T8063	285	851.5	-4 to 158	±1	1	Forward heater	
B07T8064	15	1171.5	-4 to 158	±1	1	Center heater	
B07T8065	135	1171.5	-4 to 158	±1	1	Center heater	
B07T8066	195	1171.5	-4 to 158	±1	1	Center heater	
B07T8067	285	1171.5	-4 to 158	±1	1	Center heater	
B07T8068	15	1491.5	-4 to 158	±1	1	Aft heater	
B07T8069	135	1491.5	-4 to 158	±1	1	Aft heater	
B07T8070	195	1491.5	-4 to 158	±1	1	Aft heater	
B07T8071	285	1491.5	-4 to 158	±1	1	Aft heater	

*Sampling rate is given in samples per minute (SPM).

90537-7.7

Table 4.10-5. Delta Times for S&A Functional Test

SRB IGNITION S&A ROTATION - STS-36
(847588.070 - IGNITION S&A FUNCTIONAL TEST)

ROTATE #	GMT	COMMAND	GMT	RESPONSE	DELTA	ARM LEFT	ARM RIGHT	SAFE LEFT	SAFE RIGHT
1	185429.723	B55K3000X1-LH ARM	185430.749	B55X1842X1-LH ARM	1.026	1.026			
	185429.963	B55K4000X1-RH ARM	185431.669	B55X2842X1-RH ARM	1.706		1.706		
	185438.243	B55K3001X1-LH SAFE	185439.149	B55X1843X1-LH SAFE	0.906			0.906	
	185438.483	B55K4001X1-RH SAFE	185439.469	B55X2843X1-RH SAFE	0.986				0.986
2	185539.003	B55K3000X1-LH ARM	185539.949	B55X1842X1-LH ARM	0.946	0.946			
	185539.323	B55K4000X1-RH ARM	185540.469	B55X2842X1-RH ARM	1.146		1.146		
	185547.003	B55K3001X1-LH SAFE	185547.949	B55X1843X1-LH SAFE	0.946			0.946	
	185547.283	B55K4001X1-RH SAFE	185548.269	B55X2843X1-RH SAFE	0.986				0.986
3	185627.722	B55K3000X1-LH ARM	185628.749	B55X1842X1-LH ARM	1.026	1.026			
	185627.963	B55K4000X1-RH ARM	185628.869	B55X2842X1-RH ARM	0.906		0.906		
	185635.402	B55K3001X1-LH SAFE	185636.349	B55X1843X1-LH SAFE	0.947			0.947	
	185635.642	B55K4001X1-RH SAFE	185636.469	B55X2843X1-RH SAFE	0.827				0.827
4	185721.682	B55K3000X1-LH ARM	185722.749	B55X1842X1-LH ARM	1.067	1.067			
	185721.922	B55K4000X1-RH ARM	185722.869	B55X2842X1-RH ARM	0.947		0.947		
	185729.323	B55K3001X1-LH SAFE	185730.149	B55X1843X1-LH SAFE	0.826			0.826	
	185729.563	B55K4001X1-RH SAFE	185730.469	B55X2843X1-RH SAFE	0.906				0.906
5	185758.323	B55K3000X1-LH ARM	185759.349	B55X1842X1-LH ARM	1.026	1.026			
	185758.563	B55K4000X1-RH ARM	185759.469	B55X2842X1-RH ARM	0.906		0.906		
	185806.003	B55K3001X1-LH SAFE	185806.949	B55X1843X1-LH SAFE	0.946			0.946	
	185806.243	B55K4001X1-RH SAFE	185807.069	B55X2843X1-RH SAFE	0.826				0.826
6	185830.963	B55K3000X1-LH ARM	185831.949	B55X1842X1-LH ARM	0.986	0.986			
	185831.203	B55K4000X1-RH ARM	185832.069	B55X2842X1-RH ARM	0.866		0.866		
	185838.603	B55K3001X1-LH SAFE	185839.549	B55X1843X1-LH SAFE	0.946			0.946	
	185838.843	B55K4001X1-RH SAFE	185839.669	B55X2843X1-RH SAFE	0.826				0.826
7	185917.843	B55K3000X1-LH ARM	185918.749	B55X1842X1-LH ARM	0.906	0.906			
	185918.083	B55K4000X1-RH ARM	185918.869	B55X2842X1-RH ARM	0.786		0.786		
	185925.323	B55K3001X1-LH SAFE	185926.149	B55X1843X1-LH SAFE	0.826			0.826	
	185925.563	B55K4001X1-RH SAFE	185926.469	B55X2843X1-RH SAFE	0.906				0.906
8	185949.843	B55K3000X1-LH ARM	185950.749	B55X1842X1-LH ARM	0.906	0.906			
	185950.083	B55K4000X1-RH ARM	185950.869	B55X2842X1-RH ARM	0.786		0.786		
	185957.283	B55K3001X1-LH SAFE	185958.149	B55X1843X1-LH SAFE	0.866			0.866	
	185957.563	B55K4001X1-RH SAFE	185958.469	B55X2843X1-RH SAFE	0.906				0.906
9	190017.203	B55K3000X1-LH ARM	190018.149	B55X1842X1-LH ARM	0.946	0.946			
	190017.523	B55K4000X1-RH ARM	190018.469	B55X2842X1-RH ARM	0.946		0.946		
	190024.923	B55K3001X1-LH SAFE	190025.749	B55X1843X1-LH SAFE	0.826			0.826	
	190025.163	B55K4001X1-RH SAFE	190026.069	B55X2843X1-RH SAFE	0.906				0.906
10	190042.563	B55K3000X1-LH ARM	190043.549	B55X1842X1-LH ARM	0.986	0.986			
	190042.803	B55K4000X1-RH ARM	190043.669	B55X2842X1-RH ARM	0.866		0.866		
	190050.123	B55K3001X1-LH SAFE	190050.949	B55X1843X1-LH SAFE	0.826			0.826	
	190050.363	B55K4001X1-RH SAFE	190051.269	B55X2843X1-RH SAFE	0.906				0.906
				AVERAGE		0.982	0.906	0.886	0.898

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Table 4.10-6. S&A Device Activity Times for 360L009

28 Feb 1990 (at T-5 minutes)

Rotation times (sec)	LH	1.048*
(arm command to arm indiction)	RH	1.327*

*The data sample rate is five times per second; therefore, actual rotation times could be ±0.200 sec sooner

4.11 RSRM HARDWARE ASSESSMENT (FEWG REPORT PARAGRAPH 2.11.2)

4.11.1 Insulation Performance

4.11.1.1 Summary. No gas paths through the case-to-nozzle joint polysulfide adhesive or any other anomalous joint conditions were identified. The internal insulation in all six of the case field joints also performed as designed, with no anomalous conditions. There were no recordable (over 0.1 in.) clevis edge separations. No evidence of hot gas penetration through any of the acreage insulation or severe erosion patterns were identified. Complete insulation performance evaluation is in Volume III of this report.

4.11.1.2 External Insulation

Factory Joint Weatherseals. Three of the fourteen factory joint weatherseals exhibited aft edge unbonds. No forward edge unbonds were found on any weatherseal.

One aft edge unbond was found on the RH forward center segment factory joint weatherseal at 250 deg, 1.0 in. circumferentially by 0.08 in. maximum depth. This unbond exhibited adhesive failure between the case and Chemlok 205.

Two aft edge unbonds were found on the LH forward center segment factory joint weatherseal at 135 and 180 deg. The largest unbond, measuring 1.0 in. circumferentially by 0.08 in. deep, was found at the 135-deg location. These unbonds exhibited adhesive failure between the case and Chemlok 205.

Six unbonds were found on the aft edge of the LH aft center segment weatherseal. Two unbonds (one at 5 deg, 0.2 in. circumferentially at a depth of 0.20 in.; the second at 340 deg, 0.1 in. circumferentially at a depth of 0.30 in.) did not violate the postflight engineering evaluation plan (PEEP) requirement. The remaining four unbonds extended to the pin retainer band. These unbonds were located at 160 deg, covering 2.0 in. circumferentially, 330 deg covering 2.8 in. circumferentially, 53 to 58 deg, covering 7.0 in. circumferentially, and 60 to 70 deg, covering 13.0 in. circumferentially. All unbonds exhibited Chemlok 205-to-case failure. Evident moisture under the four unbonds extended to the pin retainer band, resulting in corrosion on the case surface. A sample was taken from the 60- to 70-deg location for Fourier Transform Infrared (FTIR) analysis.

Some intermittent small-debris impact damage from reentry was evident on the aft edges of the weatherseals. Normal heat effects and discoloration were evident on both aft segment weatherseals. No significant areas of missing EPDM insulation were noted.

Stiffener Stubs and Rings. The insulation over the stiffener stubs and rings was in good condition. Normal heat effects and discoloration were evident on all surfaces in the 200- to 340-deg region. There were no significant areas of missing material. The EPDM was well bonded to the stiffener stubs and appeared to be well bonded to the stiffener rings. Three separations were identified in the forward stub insulation of the RH motor near 210 deg. The separations were located 0.06 in. from the top of the stub to a depth of 0.20 in. and ranged from 0.2 to 0.4 in. in length. No heat effects were identified in the separations. Missing material from the top of the stub was identified at 200 deg and measured 0.06 in. deep by 3.0 in. circumferentially over the width of the stub (~0.6 in.). No heat effects were identified within the region of the separations or missing material.

4.11.1.3 Case-to-Nozzle Joints. Based on the visual evaluation, both case-to-nozzle joints performed well. No gas paths through the polysulfide adhesive were identified. The disassembled joints showed the failure mode was 95 percent cohesive in the LH polysulfide bondline; the RH motor failure mode was 90 percent cohesive in the polysulfide bondline. Several small voids were identified in the polysulfide adhesive on the LH case-to-nozzle joint. The largest, located at 57 deg, measured 0.17 in. on the aft edge of the ramp and 0.25 in. on the forward edge of the ramp at a circumferential length of 0.30 inch. Several small voids were also found on the RH joint. The largest, located at 302 deg, measured 0.40 in. axially by 0.18 in. circumferentially, 0.55 in. aft of the step region. Slight porosity was evident on both joints in the step region. The polysulfide vent slot fill was 44 percent on the LH motor and 34 percent on the RH motor.

4.11.1.4 Field Joints. The internal insulation in all six field joints performed as designed, and no anomalous conditions were noted. J-leg tip contact was evident full circumference at each joint with the minimum contact identified on the RH aft segment where the bondline contact measured 0.65 inch. Wet soot deposits extending down the bondline were noted on all of the field joints, generally to a depth of 0.2 to 0.4 in. radially into the bondline (outboard from the remaining material). The maximum depth of the wet soot was 0.60 in. on the LH aft field joint. No heat effects were evident under the soot. Similar wet sooting has been noted on previous RSRM joints and is believed to occur at reentry or splashdown during joint flexing.

There were no recordable (over 0.10 in. deep) clevis edge separations.

4.11.1.5 Ignition System Insulation. The igniter chamber insulation and the igniter-to-case joint insulation, for both igniter joints, showed normal erosion.

A gas path through the putty was found in the RH igniter-to-case joint at 175 deg. The blowhole measured 2.5 in. wide at the aft edge of the putty and 0.30 in. wide at the adapter aft face. The igniter adapter-to-igniter chamber joint had a blowhole measuring 1.35 in. circumferentially through the putty at 90-deg.

There were no blowholes in the LH igniter joints. During removal of the LH igniter, the inner bolts were removed first, allowing the igniter chamber to fall into the forward segment. A careful examination of the igniter and case insulation showed no evidence of damage to either component. The putty in all joints exhibited a constant light olive green color, nominal tack, and 100 percent cohesive failure.

4.11.1.6 Internal Acreage Insulation. The acreage insulation, including the internal insulation over each of the factory joints, appeared in good condition. No evidence of hot gas penetration through the insulation was identified. Minor debris damage was evident in the RH aft and aft center segments.

Forward Segments. The stress relief flap was present full circumference on both forward segments but was heat affected and eroded. The castable inhibitors were completely missing full circumference. The flaps had a scalloped appearance similar to that seen on previous RSRM flight forward segment flaps. The acreage insulation was in normal condition. The 11-point star pattern was easily distinguishable in the liner.

Both forward domes near the igniter boss were extensively inspected for excessive erosion and thin insulation. No gas paths or areas of abnormal erosion were identified. Preliminary insulation thickness measurements indicated adequate thermal safety factors near the igniter boss: LH -- 2.15, RH -- 2.21. The insulation in this area was also removed; on the LH sample, four folds in the insulation next to the case were found to have a maximum depth of 0.08 in. On the RH, nine folds were found to have a maximum depth of 0.14 inch.

A final evaluation of the thermal performance of the insulation will be accomplished after internal thicknesses are measured at the Clearfield, UT, H-7 facility.

Center Segments. The NBR inhibitors on the RH and LH center and aft segments showed normal erosion/heat effects. Sixteen tears exceeding 3.0 in. in length were identified on the RH forward center segment. Of the sixteen tears, three circumferential tears occurred between 108 and 146 deg. Eight tears on the LH forward center segment and one tear on the aft center segment exceeded 3.0 in. in length. All tears had sharp corners and showed no evidence of erosion within the tears.

The flap and acreage insulation exhibited normal erosion. The castable inhibitor was completely missing on all four center segments. The flap and capture feature (CF)/EPDM was completely eroded to the flap bulb on the aft center segments and partially eroded on the forward center segments.

Aft Segments. The aft segment NBR inhibitor stubs exhibited scalloped erosion around the circumference. These areas had a very short inhibitor stub with intermittent inhibitor pieces taller than adjacent areas. This condition has been noted on all previous flight RSRM aft segments and does not represent a problem. There were no tears in either inhibitor. The aft segment acreage insulation was in normal condition. No CF/EPDM blisters were found in either of the aft domes.

4.11.2 Case Component Performance

4.11.2.1 Summary. Evaluation of the steel case indicated that the hardware performed as expected during flight. There was no increase in fretting magnitude in the previously fretted hardware, but new frets were found at the edge of repair areas on the LH aft field joint. Complete case evaluation results are included in Volume II of this report.

4.11.2.2 Stiffener Stubs, Stiffener Rings, and ETA Stubs. Typical postflight stiffener ring and stub damage on both motors. The RH center stiffener had an outer ligament crack. A crack in the aft stiffener stub outer ligament at 196 deg was found at Clearfield after grit blast. There is some feeling that this crack should have been found at KSC during the postflight evaluation. However, researching the evaluations performed on this stub revealed no evidence of the crack. The cavity collapse centerline was at 190 deg and all holes in that region were evaluated visually and with a knife blade by the case/seals personnel. The holes between 190 and 202 deg were deformed (see PFOR B-24 in appendix of TWR-17436, KSC Ten-Day Postflight Hardware Evaluation Report 360L009) and were looked at very closely by two Postfire Hardware Evaluation, one reliability, and one NASA/Marshall engineering personnel. A crack at 196 deg was neither observed nor felt. Flight Motor Set 360T004 had the last outer ligament crack seen. The ET stubs were nominal.

The LH center stiffener had 12 bolts missing between 172 through 194 degrees. The LH aft stiffener had 8 bolts missing between 202 through 208 deg and 212 through 218 deg, and 7 bolts missing between 182 through 194 deg. The stub bolt holes between 174 through 180 deg and 190 through 202 deg were deformed.

The LH center stiffener ring web was cracked at 196 deg and buckled at 182 deg. The LH aft stiffener ring web was cracked at 194 deg, buckled with missing web at 181 deg, and buckled at 219 deg.

The RH center stiffener had 25 bolts missing between 160 through 208 deg. An outer ligament crack was observed at 210 deg. The RH aft stiffener ring had 10 bolts missing between 190 through 208 deg, and 9 bolts were missing between 162 through 178 deg.

The RH center stiffener ring web was cracked between 178 through 188 deg and the web buckled at 159 deg. The RH aft stiffener ring web was cracked at 180 and 188 deg. The web was buckled at 162 and 204 deg.

Based on missing Insta-foam, the cavity collapse load centerline for the RH and LH motors was estimated to be at 190 deg for each.

4.11.2.3 Field Joints. The case field joint surface conditions were as expected. Fretting ranged from light to heavy. All joints had some fretting. The LH center and aft field joints had the worst fretting, with pits from 0.008 to 0.011 in. deep; the RH center field joint had a 0.009 in. deep fret. The LH center and aft field joints and the RH center field joint had previously been fretted. No new frets were found in the old fret indications, but new frets were found at the edge of repair areas on the LH aft field joint. Figure 4.11-1 provides a subjective summary of the fretting.

4.11.2.4 Case-to-Nozzle Joint. The case-to-nozzle joint on both motors was in nominal condition. There were no signs of metal damage to any of the sealing surfaces, bolt holes or heat-affected metal, corrosion, or damaged bolts.

4.11.2.5 Igniter-to-Forward Dome. The RH igniter-to-forward dome joint surfaces had a corrosion pit at 175 deg on the dome through hole and the igniter chamber flange outside diameter (OD). The LH igniter-to-forward dome surfaces had two areas of medium corrosion at 285 and 324 deg.

4.11.2.6 Factory Joint External Surface. Medium corrosion was observed on the RH center aft factory joint. No pitting was observed. The other factory joints were nominal.

4.11.2.7 Miscellaneous Case Surfaces. All cork, K5NA, cables, and gages associated with the GEI were removed at Hangar AF, KSC, because of corrosion pits observed on previous case segments from an instrumentation spot band. These spot bands are for lightning protection and use silver-filled epoxy (Eccobond 56C). The instrumentation is then covered with K5NA and Hypalon® paint. During SRB reentry, the Hypalon paint blisters, allowing seawater to soak into the K5NA, producing a galvanic cell between the case and the silver-filled epoxy. Some of the case surfaces under the removed GEI runs had light corrosion, but no pits were observed at any of the GEI spot bond locations.

4.11.2.8 OPTs, Special Bolts, and Special Bolt Plugs. There was no evidence of any gas leakage past the primary seals on any of the OPTs. The LH and RH primary seals saw pressure. Soot deposits were observed on the threads on the tip of the OPTs and up to the primary seals, but not past the primary. All of the seals performed nominally. The physical condition of the OPTs was excellent.

The special bolt primary seals and special bolt plug seals were in excellent condition and performed as expected. All LH and RH igniter special bolts

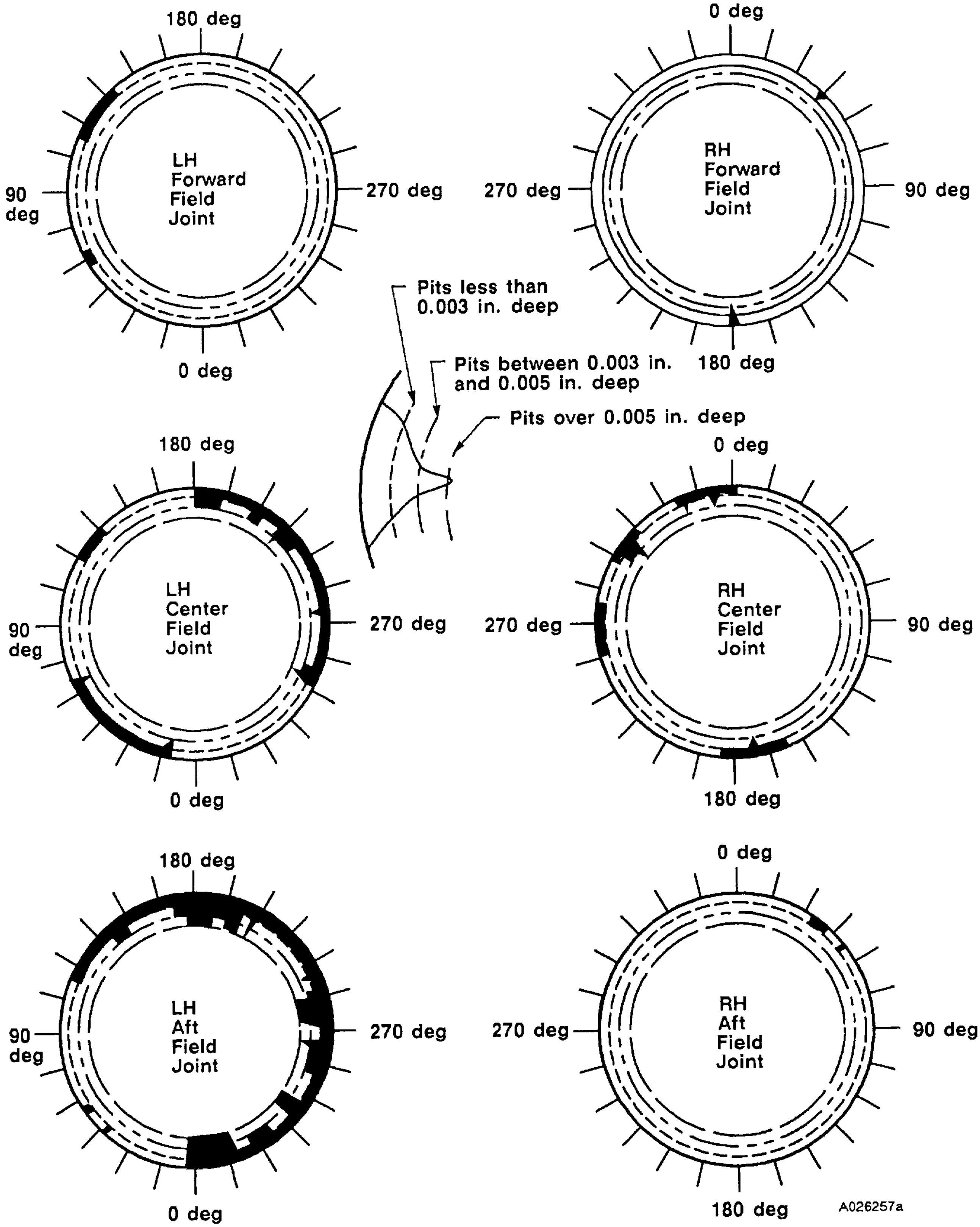

Figure 4.11-1. Flight Motor Set 360L009 Field Joint Fretting

experienced typical light sooting up to the primary O-ring and on the end of the special bolts.

4.11.2.9 Vent Port and Leak Check Port Plugs. The metal surfaces of the plugs were free of soot, debris, and corrosion.

4.11.2.10 Joint Heaters. Both RH and LH igniter heaters were evaluated before and after removal. No discoloration or warping was noted, indicating proper installation and nominal performance.

4.11.3 Seals Performance

4.11.3.1 Summary. Evaluation of the field and factory joints indicated that the internal seals performed as expected during flight. All internal seals, including the redesigned field joint seals and case-to-nozzle joint seals, appear to have performed well with no hot gas leakage evident. A complete evaluation is included in Volume II of this report.

4.11.3.2 Exit Cone Field Joint. There was no evidence of pressure to the primary O-ring on either LH or RH exit cone joint. There is no seal or seal surface damage on the joint.

Light to medium corrosion of the aft exit cone shell was found intermittently on both LH and RH motors at the ID and OD of the shell. This is caused during splashdown when sea water enters the joint through the bondline separations.

4.11.3.3 Case Field Joint. Inspection of the field joint seals revealed no anomalous conditions. All motor pressure was contained by the insulation J-joint. No corrosion or damage was found on any of the O-ring sealing surfaces. The V_2 filler was also found to be in excellent condition. None of the vent ports were obstructed by the V_2 filler. The grease application was nominal. There was typical light to medium corrosion.

4.11.3.4 OPT, Special Bolts, and Special Bolt Plug Seals. There was no evidence of gas leakage past the primary seals on any of the OPTs. The LH and RH primary seals saw pressure. Soot deposits were observed from the tips of the transducer threads to the primary seals. All of the seals performed nominally.

Special bolt primary seals were in excellent condition and performed as expected. Special bolt plug seals were also in excellent condition. All LH and RH igniter special bolts experienced typical light soot up to the primary O-ring and on the end of the special bolts.

4.11.3.5 Ignition System Joint. The igniter removal on this flight set was the third to use dynamometers and guide pins to monitor the loads involved and minimize the putty disturbance during disassembly. The LH igniter inner bolts were removed before the outer bolts, causing the igniter chamber to fall into the forward segment. There was no damage found in the forward dome ID area or on the igniter chamber. The chamber rotated downward as the putty let go, shearing some metal from the inner gasket retainer. There was no damage to the seal.

The seals of the S&A, igniter outer, and igniter inner gaskets revealed no erosion or heat effect.

The LH S&A gasket was in nominal condition, with soot on the ID edge of the retainer. The LH outer gasket had a raised area on the forward face outboard cushion of the primary seal at 173 deg. The dimensions were 0.005 in. in diameter by 0.002 in. in height. Two areas of medium corrosion were found on the igniter through hole of the LH forward dome boss at 285 and 324 deg.

The aft face of the LH inner gasket metal retainer was damaged at the 270-deg location when the inner bolts were removed and the igniter chamber fell into the forward segment. Metal was sheared off the retainer at this location. Light corrosion was found on the chamber sealing surfaces from the igniter chamber falling into the sea water in the forward segment, but there was no other damage. No blowholes through the putty were found on the LH motor.

The RH S&A had typical sooting of the ID edge of the retainer. A rework area was found on the forward primary seal at 207 deg (this area is noted on DR 156334 as Defect 19). The environmental seal was torn (1.35 in. maximum) on the forward face at 100 and 288 deg.

The RH igniter adapter-to-forward dome joint had a blowhole in the putty at 175 deg. Soot was found on the ID edge of the outer gasket retainer from 18 to 342 deg, on the OD of the inner gasket retainer from 60 to 340 deg, and within 0.1 in. of the seal cushion at 175 deg on the inner gasket. Cadmium plating measuring 1.5 in. circumferentially by 0.15 in. radially was missing at the 175-deg location on the aft face. Heavy corrosion was found on the forward dome through hole and on the igniter chamber at the 175-deg location. This corrosion had been determined to be caused by combustion by-products and/or sea water.

The RH igniter adapter-to-igniter chamber joint had a blowhole at 90 deg. Soot was found on the ID of the retainer from 88 to 96 deg.

4.11.3.6 Case-to-Nozzle Joint. The overall joint condition was excellent on both motors. Motor pressure was halted at the polysulfide adhesive, leaving the fluorocarbon O-rings untouched. No disassembly damage was noted on the primary or wiper O-rings. No radial bolt hole plugs were damaged.

The LH and RH case-to-nozzle joint Stat-O-Seals were in good condition, with no disassembly damage.

4.11.3.7 Vent Port Plugs. The case field joint and case-to-nozzle joint vent port plugs and seals on each motor were in excellent condition. Typical extrusion damage was found on the primary O-rings. The vent port plug O-rings showed no evidence of heat effect. The fluorocarbon O-rings, glands, and metal surfaces of the plugs were free of soot, debris, and corrosion.

4.11.3.8 Leak Check Port Plugs. The leak check port plugs and seals on the LH and RH motors in the case field joints, case-to-nozzle joints, aft exit cone joints, and the ignition system joints were in good condition. None of the leak check port plug O-rings showed any evidence of heat effect. Disassembly damage was found on the ID of the LH case-to-nozzle O-ring and the RH forward field joint O-ring. The fluorocarbon O-rings, glands, and metal surfaces of the plugs were free of soot, debris, and corrosion.

4.11.3.9 Igniter Leak Check Plugs and O-rings. No anomalous conditions were found on the plugs or O-rings. Typical ID circumferential cuts were found on both igniter adapter-to-forward dome joint leak check plug O-rings and also on the LH igniter adapter-to-igniter chamber joint leak check plug O-ring. No soot or damage to the plugs was observed.

4.11.3.10 Igniter OPTs and O-rings. No anomalous conditions were found on the OPTs or the O-rings. No damage was found on the primary O-rings. Each secondary O-ring had typical puncture marks caused by the removal tool. No damage to the transducer threads or sealing surfaces was found.

4.11.3.11 Igniter Special Bolts and O-rings. No damage was found on the primary O-rings and no damage to the bolts threads or sealing surfaces was observed.

4.11.3.12 Igniter Stat-O-Seals. No anomalous conditions were found on the Stat-O-Seals. The LH joint had disassembly damage on 22 out of 36 Stat-O-Seals. The RH joint had disassembly damage on 11 out of 36 Stat-O-Seals. No damage was found to the metal retainers.

4.11.3.13 IPT Port Plugs and O-rings. The secondary O-ring on the LH IPT port plug had a material separation on the ID of dual seal plug secondary O-ring (0.7 in. long by 0.45 in. deep). The dual seal plug groove had excessive grease in the secondary groove. Testing with excessive grease in the groove indicated that the separation was caused by the grease overfilling the groove, causing the O-ring to be cut between the edge of the dovetail and the igniter adapter. Testing of the 360L009 O-ring and plug verified that the separation damage still sealed at igniter maximum expected operating pressure (MEOP) (2,159 psi) for the full time duration of motor firing.

4.11.4 Nozzle Performance

4.11.4.1 Summary. Postflight evaluation indicated that both nozzles performed as expected during flight. Phenolic erosion was smooth and normal. Complete evaluation is included in Volume V of this report.

4.11.4.2 LH Nozzle

Aft Exit Cone: The aft exit cone was severed by the LSC during parachute descent. The radial cut through the glass cloth phenolic (GCP) appeared nominal, with no anomalies observed. The carbon cloth phenolic (CCP) liner was totally missing. These are typical postflight observations, and occur during exit cone severance and at splashdown. The aft exit cone had exposed metal from approximately 320 through 0 to 10 deg. The axial length of the exposed region varied from 2 to 7 inches. The exposed metal and GCP plies showed no signs of heat effect.

Light to medium oxidation was found on the gland between the O-ring grooves on the aft exit cone from 26 to 49 deg. Light to medium oxidation was also found on the OD edge of the flange on the aft exit cone from 112 to 117 deg. There were no voids in the polysulfide. The polysulfide shrank a maximum of 0.08 inch. No separations were observed between the polysulfide and the aft exit cone shell.

The actuator brackets showed only minor paint scratches, scrapes and chips due to actuator removal. The primer remained intact and no metal damage or loose bolts were observed. The 45-deg actuator bracket had a bearing pulled out 0.210 in. during actuator removal.

Forward Exit Cone Assembly: The forward 26 in. (approximately 75 percent) of the CCP liner was missing due to splashdown. There was typical dimpled erosion on the aft end, approximately 0.1 in. deep radially.

Throat Assembly: The throat assembly had smooth erosion on the throat inlet and the forward 11 in. of the throat ring, with typical rippled erosion on the aft 5 in. measuring a maximum of 0.05 in. deep. There was a postburn wedgeout in the forward end of the throat inlet ring from 10 to 90 deg. The wedgeout measured 0.7 in. axially by 0.6 in. deep radially.

The aft 4 to 5 in. of the throat ring had numerous postburn impact marks, the largest measuring 1.5 in. axially by 0.7 in. circumferentially by 0.15 in. radially. These marks appear to be caused by the insertion of the diver-operated plug (DOP).

Nose Inlet Assembly: The forward nose and aft inlet rings eroded smoothly. No wash areas were observed. The forward nose ring had postburn intermittent impact marks with a maximum depth of 0.2 in. and a maximum diameter of 0.5 in.

Nose Cap: The nose cap had smooth erosion with typical minor wash areas measuring approximately 0.2 in. deep radially on the forward 8 inches. Slag deposits were noted on the forward 8 to 10 in. of the nose cap. Postburn wedgeouts of charred CCP were found on the aft 2 in. from 68 to 160 deg, 250 to 280 deg, and 328 to 348 deg. Postburn popped-up CCP was found on the aft 2 in. at 10, 175, and 202 deg.

Cowl Ring: The cowl ring showed typical minor wash areas (0.15 in. deep) on most of the ring. One postburn wedgeout of charred CCP was observed on the aft 2 in. from 357 to 0 to 250 deg.

Outer Boot Ring (OBR): The OBR had postburn pop-ups on the forward 2 in. of the ring intermittently around the circumference. There were typical postburn delaminations in the aft end along the 35-deg ply wraps. These were 1.0 to 1.5 in. deep axially. The aft tip adjacent to the flex boot was typically fractured and wedged out the full circumference. There were 1-in.-deep postburn wedgeouts on the forward 2 in. from 108 to 112 deg and from 158 to 188 deg.

Fixed Housing Assembly: The fixed housing insulation erosion was smooth and uniform. The forward 2 in. of the fixed housing showed typical postburn wedgeouts of charred CCP intermittently around the circumference with some slag deposits on exposed plies. The maximum radial depth of the wedgeouts was 0.8 inch.

4.11.4.3 RH Nozzle

Aft Exit Cone: The aft exit cone was severed by the LSC during parachute descent. The radial cut through the GCP appeared nominal, with no anomalies observed. The CCP liner was totally missing. These are typical postflight observations, and occur during exit cone severance and at splashdown. The GCP plies showed no signs of heat effect.

Light to medium oxidation was found on the gland between the O-ring grooves on the aft exit cone from 135 to 153 deg. Light to medium oxidation was also found on the OD edge of the flange on the aft exit cone from 97 to 130 deg and from 265 to 300 deg. There were no voids in the polysulfide. The polysulfide shrank a maximum of 0.05 inch. No separations were observed between the polysulfide and the aft exit cone shell.

The actuator brackets showed only minor paint scratches, scrapes, and chips due to actuator removal. The primer remained intact and no metal damage or loose bolts were observed.

Forward Exit Cone Assembly: The center 19 in. (approximately 60 percent) of the CCP liner was missing due to splashdown. There was typical dimpled erosion on the aft end, approximately 0.1 in. deep radially. The forward 8 to 13 in. eroded smoothly.

Throat Assembly: The throat assembly had smooth erosion on the throat inlet and the forward 8 in. of the throat, with typical rippled erosion (0.08 in. radial depth) on the aft 8 in. of the throat ring. There were postburn wedgeouts on the forward

1.5 in. of the throat inlet ring from 30 to 90 deg, 160 to 170 deg, and 240 to 275 deg.

The aft 4 to 5 in. of the throat ring had numerous postburn impact marks, the largest measuring 1.5 in. axially by 0.7 in. circumferentially by 0.15 in. radially. These marks appear to be caused by the insertion of the DOP.

Nose Inlet Assembly: The 503 and 504 rings eroded smoothly. No wash areas were observed. The 504 ring had intermittent postburn impact marks with a maximum depth of 0.2 in. and a maximum diameter of 0.5 inch.

Nose Cap: The nose cap had smooth erosion with typical minor wash areas on the forward 8 in. measuring approximately 0.1 in. deep radially. Popped-up CCP was found on the aft 2 in. intermittently around the circumference. There were no wedgeouts.

Cowl Ring: The cowl ring showed typical minor wash areas (0.1 in. deep) on the forward 5 in. of the ring. Postburn wedgeouts of charred CCP, measuring 0.7 in. deep radially, were observed on the aft 3 in. intermittently around the circumference.

OBR: The OBR had popped plies on the forward 1.5 in. intermittently around the circumference. No wedgeouts were noted. There were typical postburn delaminations, measuring 1.5 in. deep axially, in the aft end along the 35-deg ply wraps. The aft tip adjacent to the flex boot was fractured off (postburn) from 228 to 275 deg, 288 to 310 deg, and 318 to 0 to 90 deg.

Fixed Housing Assembly: The fixed housing insulation erosion was smooth and uniform. The forward 2 in. of the fixed housing showed typical postburn wedgeouts (maximum 0.8 in. deep radially) of charred CCP intermittently around the circumference with some slag deposits on exposed plies.

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