

REMTECH

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SRB ENVIRONMENT
EVALUATION AND ANALYSIS
FINAL REPORT

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VOLUME III: ASRB PLUME
INDUCED ENVIRONMENTS

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FOREWORD

This Technical Report documents the results of the analyses done on the redesigned Solid Rocket Booster (SRB) performed by REMTECH inc., under NASA/MSFC Contract NAS8-37891, Mr. L. D. Foster, ED33, COTR. This report is presented in three volumes:

- Volume I: Redesigned SRB Flight Heating Evaluation
- Volume II: RSRB Joint Filling Test/Analysis Improvements
- Volume III: ASRB Plume Induced Environments

Volume III documents analyses and technical support related to model and full-scale radiation measurement tests, design cycle environment generation, development flight instrumentation, and ASRB Thermal Panel participation over the time period from December 1989 through September 1991.

ABSTRACT

Contract NAS8-37891 was expanded in late 1989 to initiate analysis of Shuttle plume induced environments as a result of the substitution of the Advanced Solid Rocket Booster (ASRB) for the Redesigned Solid Rocket Booster (RSRB). To support this analysis, REMTECH became involved in subscale and full-scale solid rocket motor test programs which further expanded the scope of work. Later contract modifications included additional tasks to produce initial design cycle environments and to specify development flight instrumentation. Volume III of the final report describes these analyses and contains a summary of reports resulting from various studies. This work was performed under the direction of Mr. Peter Sulyma of MSFC's Induced Environment Branch, ED33.

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Section 1 SUMMARY

The scope of work for contract NAS8-37891 was expanded in late 1989 to initiate analysis of Shuttle plume induced environments as a result of the substitution of the Advanced Solid Rocket Booster (ASRB) for the Redesigned Solid Rocket Booster (RSRB). To support this analysis, REMTECH became involved in subscale and full-scale solid rocket motor test programs which further expanded the scope of work. Later contract modifications included additional tasks to produce initial design cycle environments and to specify development flight instrumentation. An overview of these analyses and a summary of reports resulting from these studies is presented in Section 2. The following discussion highlights the various contract modifications, their objectives, and REMTECH's accomplishments.

1.1 Contract Modification Chronology

The efforts reported in Volume III of the final report began with Modification 5 to the contract which was initiated December 14, 1989. The next three modifications (6, 7, and 8) followed closely after Modification 5 to involve REMTECH in the purchase and implementation of radiometers to support the various test programs. Modifications 6, 7, and 8 were activated in December 1989 and March 1990, respectively. Modification 9 in August 1990 began the work directed toward producing the ASRB Cycle 1 design base heating environments which were published in February 1991. Modification 10 was an interim cost adjustment initiated in October 1990.

Following completion of the Cycle 1 environments in February 1991, work to update the methodology and initiate the Cycle 1.5 environment determination was begun under Modification 11 in April 1991. This effort was continued through September 1991 under Modification 12. The total period of performance spanned approximately 22 months and involved, in total, 8 separate contract modifications.

1.2 Objectives

The primary objective of these contract extensions was to involve REMTECH and its subcontractor, SECA, Inc. in the early phases of the assessment of changes in the National Space Transportation System (Space Shuttle) ascent aerothermal environments resulting from the substitution of the ASRB for the RSRB. The focus was on identifying and specifying the plume induced environments by defining the ASRB plumes and resulting impact of the different (from RSRB) plumes on Shuttle element base heating. To accomplish this objective, a variety of tasks and individual analyses were performed. These various tasks fell into three general categories.

1. Empirical Data Base Support
2. Base Heating Methodology Development

3. Design Cycle Environment Specification.

These individual efforts were pursued simultaneously, in most cases, and generally complemented each other.

Section 2

ACCOMPLISHMENTS

REMTECH and SECA's efforts through the 22 months of performance on this phase of the contract produced a variety of reports, schematics and test support information, instrumentation lists, environment packages, and handout materials which were distributed to the ASRB Thermal Panel. Much of this information was not formally documented by REMTECH or SECA, but was introduced into the ASRB program generically as MSFC ED33 input. Therefore, to address our accomplishments on the contract requires discussion of our individual efforts from inception to completion with specific output and deliveries noted as they occurred.

This work has been separated into four major categories with discussion plus a listing of reports provided for each category. Originally, our support to the development flight instrumentation specification and ASRB Thermal Panel was expected to be minimal. However, these studies ultimately consumed a substantial part of our total effort and were, therefore, selected as separate categories.

2.1 Radiation Measurement Test Support

Experimental radiation work included three motor test programs: the 48-inch (case diameter) MNASA motor tests at MSFC, full-scale RSRM motor firings at the Thiokol facility in Utah, and the full-scale ASRM tests at Stennis Space Center. The tasks in this work included: selection and purchasing of instrumentation, instrument custodial services (shipping to tests, procurement of calibrations and record keeping), preparation of test requirements indicating instrument type and locations, coordination of measurements by others, and evaluation of the test results. The instrumentation responsibilities and accomplishments on the test programs will be described below. A summary of all contract reports pertinent to radiation measurement test support is provided in Table 2 at the end of this subsection.

2.1.1 Radiometers

Initially, a range of radiometer designs were selected to provide a set capable of performing a range of measurement functions, but as the test requirements became more precisely defined, the type of radiometers procured became more specific. Most of the radiometers procured near the end of the work were narrow-view units with a 4-degree (included angle) field of view designed to view a source with an emission range of up to 100 BTU/ft²-sec. The radiometers procured are listed in Table 1 with notes to indicate the number of tests each was used on and its current condition.

As each instrument is procured, it is entered into a data base which is used to track the instrument location, to record tests it has been used on, and to provide a history of the calibration results. After each use, the instrument is sent to the manufacturer for

Table 1: Radiometers Purchased on the Contract

MEDTHERM Model Number	Field of View (Degree)	Sapphire Window	Serial Number	Test ** Firings	Current Condition
NVRW-100-4-20246	4	Yes *	64801	A,D,F,G,H	Calibration
NVRW-100-4-20246	4	Yes *	64802	A,B,D,F,G,H	Calibration
NVRW-100-4-20246	4	Yes *	64803	A,D,F,G,H	Calibration
NVRW-100-4-20246	4	Yes *	64804	A,D,F,G,H	Calibration
NVRW-100-4-20246	4	Yes *	64805	A,B,D,F,G,H	Calibration
NVRW-100-4-20246	4	Yes *	64806	A,D,F	Bad
NVRW-100-4-20246	4	Yes *	64807	A,D,F,G,H	Calibration
NVRW-100-4-20246	4	Yes *	64808	A,D,F,G,H	Calibration
NVRW-056-4-20430	4	Yes *	64809	D,E,F,G,H	Calibration
NVRW-056-4-20430	4	Yes *	648010	D,E,F,G,H	Calibration
NVRW-056-4-20430	4	Yes *	648011	D,E,F,G,H	Calibration
NVRW-056-4-20430	4	Yes *	648012	D,E,F,G,H	Calibration
NVRW-056-4-20430	4	Yes *	648013	D,E,F,G,H	Calibration
NVRW-056-4-20430	4	No	648014	D,E	Bad
NVRW-056-4-20430	4	No	648015	D,E	Bad
NVRW-056-4-20430	4	No	648016	D,E,F	Bad
NVRW-100-7/30-20430	7, 15, 30	No	648017	0	Good
NVRW-100-7/30-20430	7, 15, 30	No	648018	0	Good
NVRW-100-7/30-20430	7, 15, 30	No	648019	0	Good
NVRW-100-7/30-20430	7, 15, 30	No	648020	0	Good
NVRW-100-7/30-20430	7, 15, 30	No	648021	0	Good

* Radiometer Retrofitted with Sapphire Window

** Key to Test Firings

A - FSM-1
B - TEM-7

C - TEM-8
D - MNASA-2

E - MNASA-3
F - MNASA-4

G - MNASA-5
H - MNASA-6

Table 1: (concluded) Radiometers Purchased on the Contract

MEDTHERM Model Number	Field of View (Degree)	Sapphire Window	Serial Number	Test * Firings	Current Condition
64-40-20494	180	No	648022	0	Good
64-40-20494	180	No	648023	0	Good
64-40-20494	180	No	648024	0	Good
64-10-20494	180	No	648025	D,E,F,G,H	Calibration
64-10-20494	180	No	648026	D,E,F,G,H	Calibration
64-10-20494	180	No	648027	D,E,F,G,H	Calibration
64-10-20494	180	No	648029	D,E,F,G,H	Calibration
64-10-20494	180	No	648030	D,E,F,G,H	Calibration
NVRW-100-4-20969	4	Yes	68351	B,C,E,G,H	Calibration
NVRW-100-4-20969	4	Yes	68352	B,C,E,G,H	Calibration
NVRW-100-4-20969	4	Yes	68353	B,C,E,G,H	Calibration
NVRW-100-4-20969	4	Yes	68354	B,C,E,G,H	Calibration
NVRW-100-4-20969	4	Yes	68355	B,C,E	Calibration
NVRW-100-4-20969	4	Yes	68356	B,C,E	Calibration
NVRW-100-4-20969	4	Yes	68357	B,C,E	Calibration
NVRW-100-4-20969	4	Yes	68358	B,C,E	Calibration
NVRW-100-4-20969	4	Yes	68359	B,C	Calibration
NVRW-100-4-20969	4	Yes	683510	B,C	Calibration
NVRW-100-6-20364	6	Yes	683511	B,C	Calibration
NVRW-100-6-20364	6	Yes	683512	B,C	Calibration
NVRW-100-6-20364	6	Yes	683513	B,C	Calibration
NVRW-100-6-20364	6	Yes	683514	B,C	Calibration
NVRW-100-6-20364	6	Yes	683515	B,C	Calibration
NVRW-100-6-20364	6	Yes	683516	B,C	Calibration
NVRW-100-4-20969	4	Yes	70961	C	Calibration

* - Key to Test Firings

A - TSM-1
B - TEM-7

C - TEM-8
D - MNASA-2

E - MNASA-3
F - MNASA-4

G - MNASA-5
H - MNASA-6

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calibration, then stored at REMTECH until the next use. The pretest calibration data are furnished to the test facility for use in reducing the data, and the posttest calibration data are used in the test evaluation report to indicate changes in the instrument sensitivity during the test. Experience has indicated that the pretest and posttest calibration generally agree well.

2.1.2 MNASA Motor Tests

The MNASA series of tests use a motor with a 48-inch case diameter with nozzles which approximate a 1/6-scale Shuttle SRM booster. Radiation measurements were planned for these motor tests because it provided the first opportunity to obtain comparative data on the RSRM and ASRM propellants. The first motor firing occurred before radiation measurements were planned, but there have been measurements on five subsequent tests (MNASA 2 through 6) during this contract. The initial test requirements [1] requested 20 measurements by MSFC, but these were eventually supplemented by measurements using personnel and equipment from other sources (CALSPAN, AEDC Plume Diagnostics Group and Stennis Space Center). These additional sources were used to provide thermal imaging and spectrometer measurement capability which could not be provided by MSFC.

The test configurations included both RSRM and ASRM propellants in motors using either a contoured or conical nozzle with a motor configured for either nozzle or case-insulation material testing. In the nozzle tests, a nozzle entry adapter is attached directly to the motor case, while in the insulation tests, a tube approximately 6 feet long is used between the chamber and the nozzle to accommodate case-insulation test specimens. The dates and configurations of the tests during the contract are listed below.

Test	Date	Propellant	Configuration	Nozzle
MNASA 2	9-22-90	RSRM	Nozzle	Conical
MNASA 3	4-10-91	ASRM	Nozzle	Contoured
MNASA 4	7-2-91	RSRM	Insulation	Conical
MNASA 5	8-27-91	ASRM	Insulation	Conical
MNASA 6	9-26-91	ASRM	Nozzle	Contoured

Initial plans called for measurements on only four tests: two nozzle-configuration tests for each of the two propellants. Restriction to the nozzle-test configuration was chosen to avoid uncertainties caused by the insulation-test configuration and possible insulation products in the plume, and two tests for each propellant were selected to allow evaluation of measurement repeatability. However, unexpectedly high radiation levels measured for the ASRM propellant on MNASA 3 led to an expanded test program which includes tests of the insulation configuration to accelerate accumulation of data.

Because the tests use various experimental insulation and nozzle materials, differences in erosion rate and material failures could affect test-to-test comparisons. These differences in performance have occurred, but experience has indicated that data taken early in the test (5 seconds) is remarkably consistent. However, the change from the

contoured nozzle to the slightly lower area ratio conical nozzle between tests MNASA 3 and 5 caused significant changes in some areas of the plume, so data with different nozzle configurations should be compared with caution.

Evaluation of the measurements has included test-to-test comparisons of the radiometer measurements and review of the thermal imaging and spectrometer data. All data appear to be consistent with the ASRM propellant producing significantly higher radiation. Because of the rapid developments in the theoretical prediction techniques, most theoretical prediction comparisons become obsolete before they can be published, but one comparison was published for the MNASA-3 measurements [2].

There has been significant concern that the increases in radiation noted on the small motor tests indicate a greater than predicted increase on the full-scale motors. However, analysis of the differences in scale indicate that the large motors will behave much differently.

2.1.3 Full-Scale SRM Tests

Full-scale measurements have included a preliminary test on the first Flight Safety Motor firing (FSM-1) and two Test and Evaluation Motor firings (TEM-7 and 8). All of these motors have essentially the same propellant and nozzle designs as the current flight motors.

Instrumentation for the FSM-1 firing (8/15/90) consisted of eight narrow-view calorimeters. The detector on these instruments is shielded by a water-cooled tube with a small circular aperture at the end. This shades the detector to provide the restricted field of view. It was expected that this tube would be sufficient to prevent significant convective effects, so no windows were installed over the detector. Use of the instrument without a window allows measurement of the source without the difficulty and uncertainty caused by corrections for the spectral bandpass of a window material, and this method was used successfully in the early MNASA tests. However, the environment at most of the instrument locations on the FSM test was much more severe. Two of the instruments failed and the some of remaining instruments indicated convective cooling which invalidated the measurements. As a result of this experience, sapphire windows were used on the TEM tests, and they have also been gradually installed on the instruments used on the MNASA tests as time permitted.

The TEM-7 and 8 tests were conducted on 12/11/90 and 7/31/91. Instrumentation on the TEM tests consisted of 22 narrow-view radiometers aimed at aspect angles (relative to the forward motor centerline) of 28 to 120 degrees. The results of the two tests were excellent and agreement between the two tests was good. Results for the TEM-7 tests have been reported [3], and the TEM-8 results will be reported along with a comparison of TEM-7 and 8 results as soon as the posttest instrument calibrations are complete.

2.1.4 ASRM Tests

Testing of the ASRM will begin with three demonstration motor (DM) firings in 1994 and 1995. This will be followed by a series of qualification motor (QM) firings. All tests

will be conducted at Stennis Space Center. An intensive measurement program has been planned for the DM firings to provide a large amount of data to verify the plume radiation prediction methodology before the first flight test. After sufficient repeat data are acquired, the number of instruments will be reduced, and the QM motor firing results will be monitored to assure that early changes in the motor design do not affect the plume radiation level. Preliminary test requirements for the ASRM tests [4-5] were prepared as a part of the work on this contract.

Table 2: Report Summary: Radiation Measurement Test Support

Source	Date	Description
REMTECH RTN 213-04	4/90	Plume Radiation Measurements for the 48-inch RSRM and ASRM Motor Tests
REMTECH RTN 213-06	10/90	Preliminary Plume Radiation Measurement Requirements for the ASRM Development Firings at Stennis Space Center
REMTECH RTN 213-17	6/91	Preliminary Radiation Measurement Requirements for the Static Firing of the Advanced Solid Rocket (ASRM) Motor
REMTECH RTN 213-18	6/91	Evaluation of Radiation Measurements on the MNSASA-3 Motor Test
REMTECH RTN 213-20	7/91	Radiation Measurements on the TEM-7 Test of the Space Shuttle Solid Rocket Motor

2.2 ASRB Design Cycle Plume Induced Environments

Throughout the contract, a major effort was directed toward base heating methodology development and production of the design cycle environments. Initially, the objective was the publication of a preliminary environment package to satisfy a March 1990 schedule. The effort became more focused as work progressed toward release of the Cycle 1.0 design environment [6] in February 1991. Our effort has continued since that publication to refine the methodology in preparation for a Cycle 1.5 environment release in January 1992. A summary of pertinent methodology and environment reports published under this contract are provided in Table 3 at the end of this subsection. Details of these efforts are provided in the following discussion.

Methodology used to predict convective and radiative plume induced environments was initiated in December 1989. ASRB plume definitions were generated [7] using a combination of RAMP2 and SPF/2 for over 11 altitudes ranging from sea level to separation. Individual radiation and convection environment prediction codes were

developed and modified based on these flowfield definitions as they evolved according to the latest ASRB propellant and operating characteristics.

Cycle 1 radiation methodology [8-10] specifies for the radiation contribution resulting from the ASRBs to be based on the sea level RSRB plume model scaled to ASRB emissive powers — determined by making prediction of the ratio of emissions with the prototype Monte Carlo code [11]. The SSME radiation contribution utilized is the same as used in the IVBC-3 and Generic Certification environments. Similarly, the convective Cycle 1 methodology [12] was incorporated into a computer code. The SPICE (Shuttle Plume Induced Convective Environment) code, which bases its computations on differences in chamber pressure and time/altitude history as compared with the Shuttle Centaur trajectory used to generate the IVBC-3 environments, was developed to generate the Cycle 1 convective environments in an IVBC-3 compatible format.

Cycle 1 methodology development culminated with the publication of the official ASRM plume induced environment package [6] in January 1991. Tabular environments were provided for a representative set of body points on the SRB, ET, Orbiter, and SSMEs. Normal (no-failure) ascent predictions using the Cycle 1 Low-Loft trajectory for radiation and the Cycle 1 High-Loft trajectory for convection were made for 118 body points. Likewise, RTLS environments were determined for 29 body points for the Cycle 1 RTLS SSME 1 failure trajectory; 41 body points were evaluated assuming SSME 3 failure using the time/altitude data from the Cycle 1 RTLS trajectory and gimbal angles specified for Generic Certification RTLS.

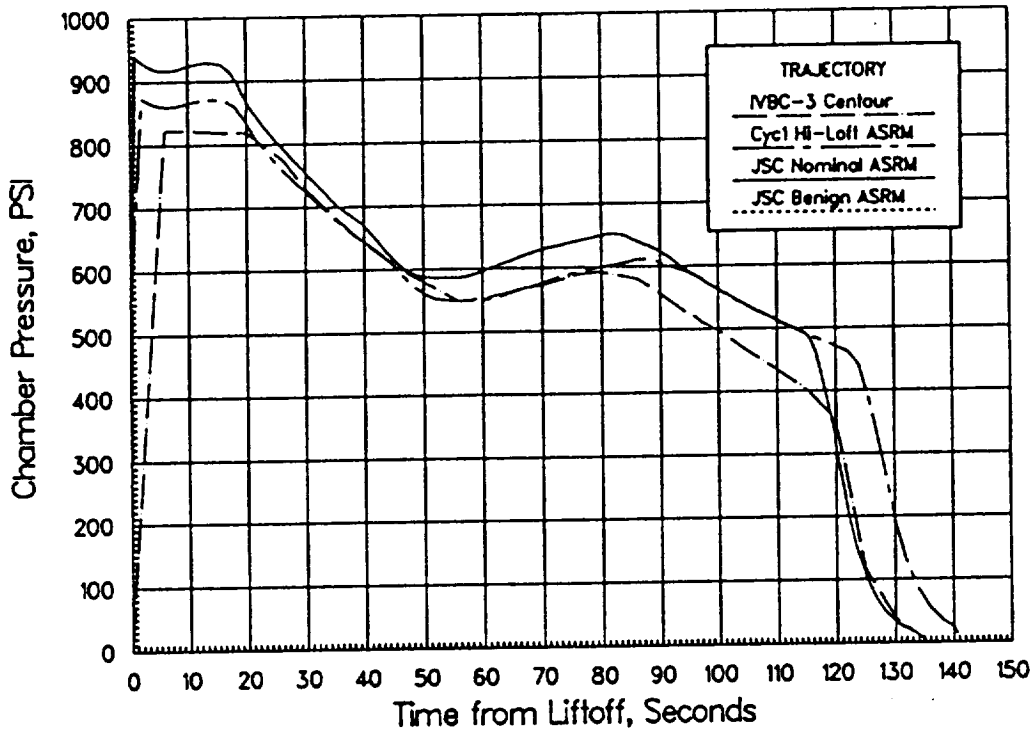
Since the release of the Cycle 1 environments, several studies have been performed to evaluate both the radiative and convective environment with regard to ASRB trajectory sensitivity [13,14]. Beginning in August 1991, JSC requested an evaluation of the radiation and convection environment impact of the nominal and benign ASRM trajectories depicted in Fig. 1. As Fig. 2 exhibits, both the nominal and benign JSC trajectories demonstrate convective heating as high or higher than the ASRM Cycle 1 High-Loft trajectory; no significant increase in radiation was determined. However, this impact to the convective environment was further explored in April 1991 using the RI hot/cold dispersed, winter/summer launch, high-loft trajectories illustrated in Fig. 3. Figure 4 shows that the high-loft, summer launch trajectory dispersed for a hot PMBT provides conditions conducive to a worse case convective heating environment. Likewise, low-loft winter launch trajectory conditions produce the most conservative radiation heating environment. As a result, these conditions will be incorporated into the Cycle 1.5 convective environment trajectory.

Similar to Cycle 1 methodology development, preparations were initiated and are continuing for the Cycle 1.5 vintage environments. Convective environment zones peculiar to the ET were defined and documented [15] in September 1991. Radiation methodology is also maturing with the incorporation of MNASA and TEM test firing data and prototype Monte Carlo code development.

Table 3: Report Summary: ASRB Design Cycle Plume Induced Environments

Source	Date	Description
REMTECH RTN 213-08	1/91	ASRM Cycle 1 Plume Induced Thermal Environments
SECA TR-91-3	2/91	Space Shuttle Advanced Solid Rocket Motor (ASRM) Exhaust Plume Definitions — Sea Level to ASRM Separation
REMTECH RTN 213-09	2/91	ASRM Cycle 1 Plume Radiation Methodology
REMTECH RTN 213-10	2/91	ASRM Cycle 1 Plume Induced Convection Methodology
REMTECH RTN 213-11	2/91	Comparison of Forward and Reverse Monte Carlo Methods
REMTECH RTN 213-12	2/91	ASRM Cycle 1 Plume Radiation Environment Revision
REMTECH RTN 213-13	2/91	Solid Rocket Motor Plume Radiation Methodology Corrections for the Orbiter
REMTECH RTN 213-19	9/91	Evaluation of ET Base Region Zones of Uniform Heating for ASRM Cycle 1.5 Convective Environments
REMTECH RTN 213-24	9/91	Criteria for Selection of the ASRM Cycle 1.5 Plume Radiation Design Trajectory
REMTECH RTN 213-25	9/91	Criteria for Selection of the ASRM Cycle 1.5 Plume Convection Design Trajectory

4-11-91 Chamber Pressure Comparison



4-11-91 Chamber Pressure Comparison

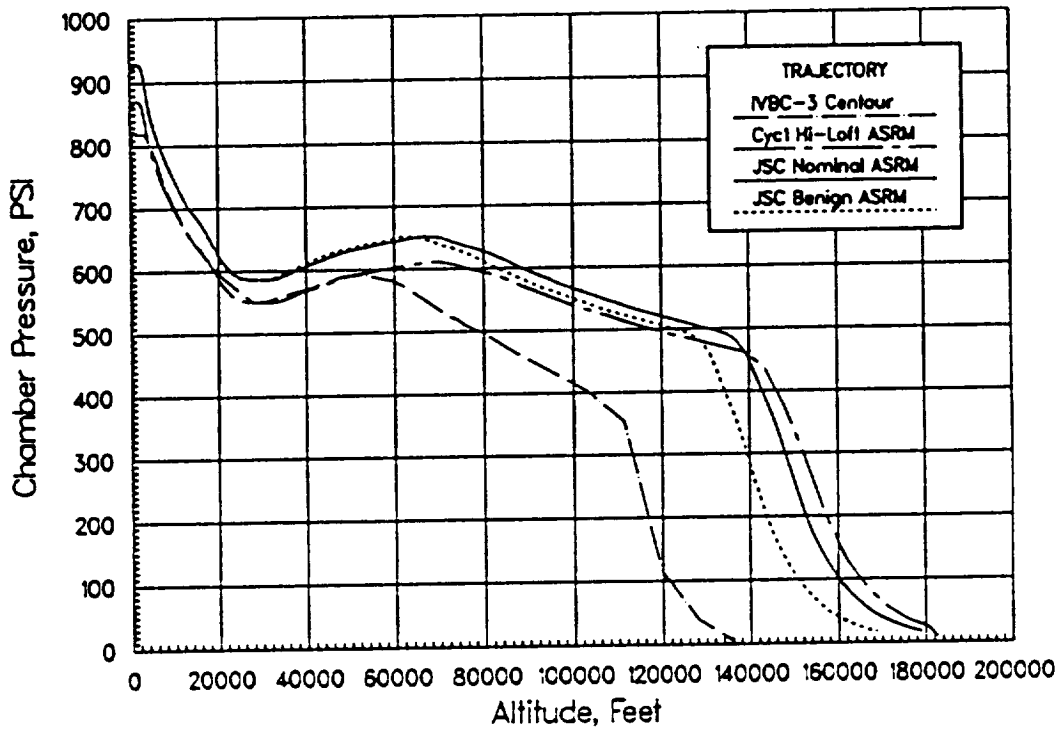


Figure 1: Chamber Pressure Histories Used in 5/91 Plume Induced Heating Trajectory Sensitivity Study

Trajectory Comparison

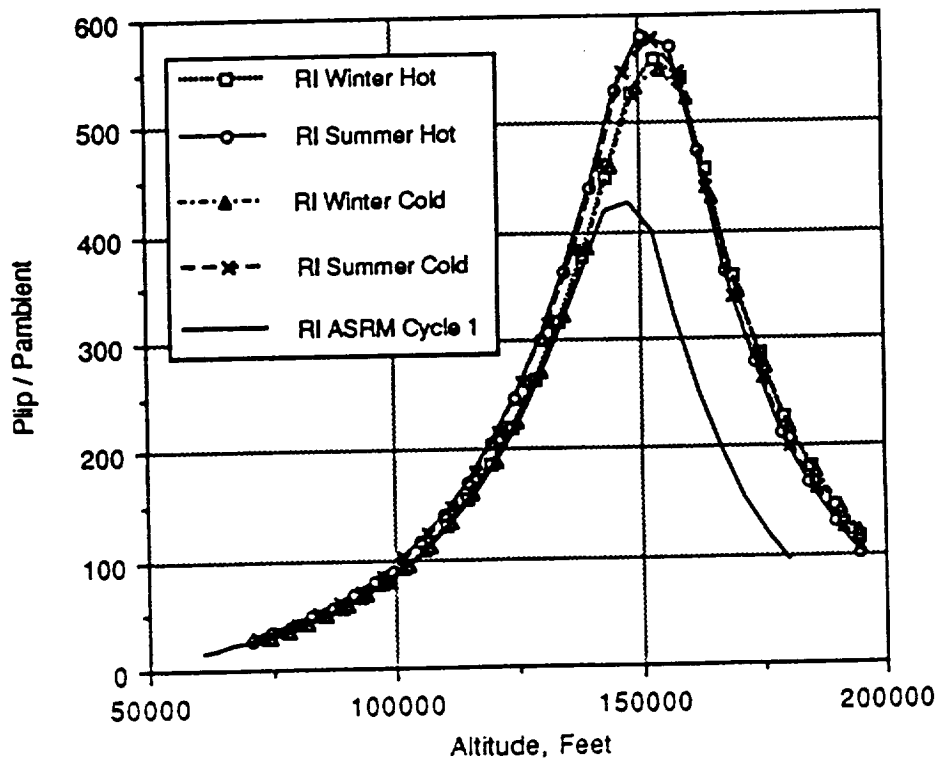
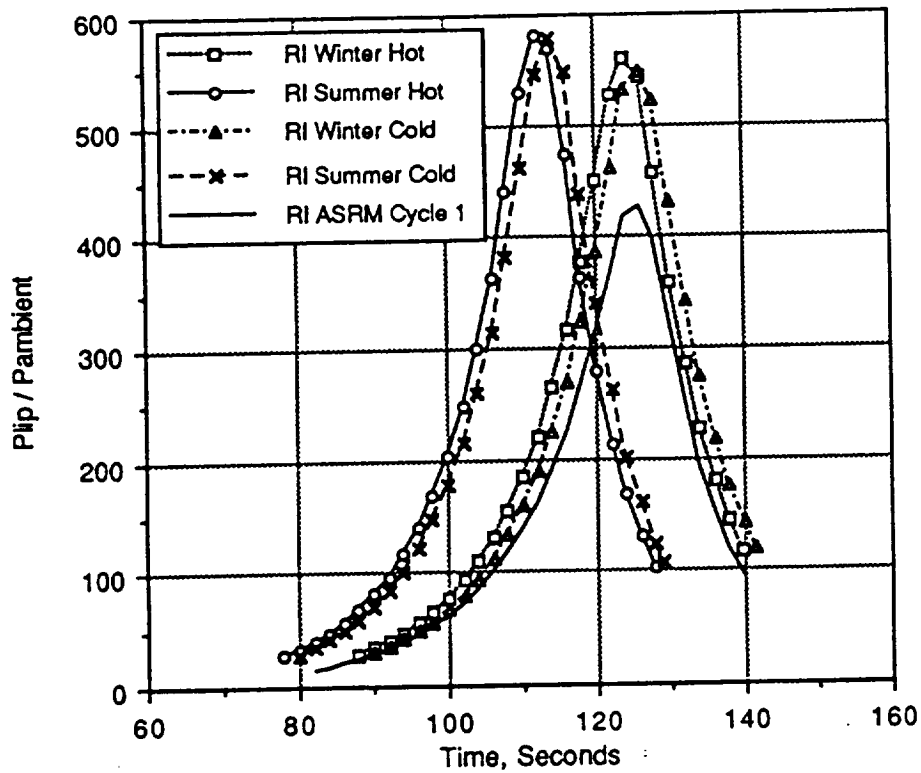


Figure 2: Sensitivity of 5/91 ASRB Convective Base Heating Environments to Trajectory Propulsion and Operational Parameters

Trajectory Comparison for June 18, 1991 Telecon

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Sensitivity of ASRB Convective Base Heating Environments to Trajectory Propulsion and Operational Parameters

Trajectory Parameter	11-12-90 RI Cycle 1 High Loft	4-11-91 JSC Nominal	4-11-91 JSC Benign	4-3-91 Lockheed/Luka Hot, High Loft	4-3-91 Lockheed/Luka Hot, Low Loft	4-3-91 Lockheed/Luka Cold, High Loft	4-3-91 Lockheed/Luka Cold, Low Loft
PMBT - deg F	64 (Dec)	78 (July)	78 (July)	90	90	40	40
Staging Flight Path Angle - deg	24	29	29	32	26	32	26
Maximum Dynamic Pressure - psf	819	690	600	701	731	630	656
Staging Time - sec	141.4	133.3	133.3	131.5	131.5	138.7	138.7
Staging Altitude - kft	184	179	169	185	171	189	175
Onset of Plume Recirculation - sec	90.0	84.7	87.3	83.1	83.1	89.0	89.0
Onset of Plume Recirculation - kft	74	72	72	72	70	74	72
Dispersion	3-sigma for Cold ASRBs	None	None	None	None	None	None
Typical Convective Peak Heating Rate Increase over IVBC 3 Environment at BP 8000 (ET Dome) - percent	22.80	27.94	23.69	30.37	28.41	22.71	20.79
Typical Convective Total Load Increase over IVBC-3 Environment at BP 8000 (ET Dome) - percent	2.43	3.52	3.56	1.47	8.39	-1.71	4.66

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Notes:

- JSC trajectories provided by Curt Wiederhoett; RI Cycle 1 High Loft Trajectory provided by Doug Selfert
- JSC trajectories based on guidelines provided in ASRM Normal Trajectory Design Data Package (TDDP ASRAMA1); RI Cycle 1 trajectory based on preliminary version of TDDP ASRAMA1
- Chamber pressure history most affected by PMBT; RSRM baseline PMBT = 70 deg F, whereas ASRM baseline PMBT = 60 deg F
- RI's 3-sigma dispersion for cold SRBs involves multiplying time table by 1.049, then dividing flow rates and chamber pressure by 1.049---effectively increasing burn time
- RI's high loft criteria involves creating a 3-sigma high change in altitude approximately 10 seconds before staging

Figure 3: 8/91 Trajectory Comparisons Used in Convective Heating Sensitivity Study

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Body Point Locations

Shuttle Component	Body Point	Location/Description
ASRB	2116 11104	Aft Skirt Kick Ring Web TPS
ET	8000 8670	Aft Dome (Zone 2) Aft Dome (Zone 1)

8-20-91 RI ASRM Trajectory Comparison

Body Point	ASRM Trajectory										
		Cycle 1 High-Loft		Summer Cold Disp.		Summer Hot Disp.		Winter Cold Disp.		Winter Hot Disp.	
2116	<i>Peak Rate:</i>	6.35	(114.95)	6.98	(126.48)	7.03	(127.49)	6.39	(115.82)	6.48	(117.44)
	<i>Total Load:</i>	151.29	(113.56)	148.12	(111.18)	152.19	(114.24)	144.41	(108.40)	147.73	(110.89)
11104	<i>Peak Rate:</i>	8.86	(116.03)	9.69	(126.86)	9.83	(128.77)	8.91	(116.62)	9.05	(118.48)
	<i>Total Load:</i>	182.52	(105.51)	177.98	(102.88)	182.97	(105.77)	173.90	(100.52)	177.90	(102.83)
8000	<i>Peak Rate:</i>	8.65	(122.80)	9.35	(132.76)	9.53	(135.37)	8.60	(122.14)	8.76	(124.40)
	<i>Total Load:</i>	199.62	(102.43)	194.58	(99.84)	197.26	(101.21)	190.38	(97.69)	193.70	(99.39)
8670	<i>Peak Rate:</i>	9.84	(123.04)	10.82	(135.23)	10.98	(137.27)	9.90	(123.78)	10.06	(125.75)
	<i>Total Load:</i>	224.87	(99.71)	217.87	(96.61)	221.04	(98.02)	213.37	(94.62)	216.99	(96.22)

- Notes:
- 1) Heating rates and loads are based on $T_{wall} = 540 \text{ R}$
 - 2) Units for peak heating rates are $\text{BTU}/\text{Ft}^2\text{-Sec}$; total heat load are BTU/Ft^2
 - 3) Value in parentheses indicate percent of IVBC-3 operational environment

Figure 4: Summary of Convective Results for 8/20/91 Trajectory Sensitivity Study

2.3 ASRB DFI Planning and Coordination

REMTECH became involved with Development Flight Instrumentation (DFI) in July 1990. At that time REMTECH was asked to develop a list of instrumentation for the Advanced Solid Rocket Boosters which is necessary to perform their mission. This original list, consisting of 104 gages, was combined with requests from USBI, Aerojet, and Rockwell to form a complete list of thermal DFI. This complete list was then examined for overlapping requests. After the duplicate requests were eliminated, the list was still larger than could be accommodated by the proposed data system on the ASRBs. Efforts were then directed toward scrubbing the requests to a level that can be accommodated by the proposed data system. Several iterations were performed where instruments were prioritized and scrubbed by the individual requestors. Since this caused no significant reduction in the number of gages requested, meetings were held with the ASRB and ASRM Chief Engineers so that requestors could justify each gage being requested. The Chief Engineer then decided if the justification warranted the instrumentation requested.

This reduced the number of gages requested, but was not sufficient in the case of the thermal DFI to be accommodated by the proposed data system. The major result of these presentations was the Chief Engineers' awareness of the inadequacy of the proposed data system, particularly in the area of the analog channels required for thermal DFI. As a result, two flight configurations for three flights each are being considered instead of the one flight configuration for six flights originally proposed. This will allow for more varied flight data to be obtained even though the number of flights may be reduced at a particular data location. The last list submitted to USBI for integration indicated the thermal DFI gages requested and the desired flight configuration for each gage.

MSFC/ED33 also requested that REMTECH become involved with the selection of the DFI for the Orbiter, External Tank, and Space Shuttle Main Engines (SSMEs) through our involvement with the Thermal Panel. The Thermal Panel requested that REMTECH keep them abreast of the thermal DFI on the ASRBs in the biweekly telecons. As the thermal DFI on the other elements evolved similar to the instrumentation on the ASRBs, REMTECH became the collection and integration point for the various requests. This resulted in REMTECH preparing justification and rationale charts for all elements using the same format that was used for the presentations to the ASRB and ASRM Chief Engineers. These charts were reviewed with Level II Shuttle integration management. REMTECH is the integration focal point for thermal DFI on all elements and has maintained the "official" list for the Thermal Panel. Additional work was performed by REMTECH in the form of charts, tables, and viewgraphs to support presentations given by Level II.

Two technical notes were also written as a part of REMTECH's DFI effort. The first technical note [16] documents a sensitivity study that was undertaken at the request of the ASRB Chief Engineer. This study looked at the effect of reducing the number of pressure measurements on the circumference of the Forward Motor Segment on the accuracy of the data. It was determined that 12 gages was the minimum number of pressure readings required to keep the percent error at an acceptable level. The

second technical note [17] documents the installation requirements for each proposed REMTECH Gas Temperature Probe (GTP) location. The REMTECH GTP was originally designed to be flown at a specific location on the Orbiter only. Current plans call for five GTP's to fly on each Development Flight; two on the right ASRB, two on the ET, and one on the Orbiter.

A summary of the reports prepared under this contract effort pertinent to DFI is presented in Table 4.

Table 4: Report Summary: ASRB DFI Planning and Coordination

Source	Date	Description
REMTECH RTN 213-5-01	8/91	Evaluation of the Number of Pressure Ports Required for Prediction of Peak Impact Pressure and Roll Orientation of the SRB During Reentry
REMTECH RTN 213-22	9/91	REMTECH Gas Temperature Probe Installation Requirements for ASRB Development Flights

2.4 ASRB Thermal Panel Support

The ASRB Thermal Panel is comprised of representatives from NASA's JSC and MSFC centers, plus Shuttle element and integration contractor teams. The panel is chaired by JSC organization EG3 and has a mandate to coordinate and approve Shuttle with ASRB technical issues in the general technical discipline of aerothermodynamics and induced thermal environments. MSFC organization ED33 is an integral part of the panel, and REMTECH, as a major ASRB contractor to ED33, has been a participating panel member since the panel's inception after the ASRB contract go-ahead.

Throughout the 22-month history of our ASRB contract, REMTECH has provided key inputs to the Thermal Panel, primarily to support the discussion and resolution of issues which were addressed in biweekly teleconferences. Many of these inputs were prepared in viewgraph summary format with supporting tabular and graphical data as necessary to augment the text. Typical issues which have been addressed include:

1. Overviews of base heating methodology.
2. Summaries of solid rocket motor subscale test objectives, procedures, and recorded data.
3. Guidelines, assumptions, and schedules for design cycle environment packages.
4. Justification for ASRB DFI for all elements.
5. Specific technical issues such as trajectory effects on convective base heating.

6. Discussion of relevant code capabilities, including the SIRRM and Monte Carlo plume radiation codes.
7. Body point selection for design environments.
8. Variety of subissues related to issues 1 through 7.

An example of one typical panel discussion input from REMTECH is provided in Figs. 5 through 9.

**SHUTTLE WITH ASRB
INDUCED THERMAL ENVIRONMENTS
AND
DFI REQUIREMENTS REVIEW**

APRIL 10, 1991

Figure 5: Cover Sheet to April 1991 DFI Presentation

SHUTTLE WITH ASRB INDUCED THERMAL ENVIRONMENTS AND DFI REQUIREMENTS

STATUS

CYCLE 1 ENVIRONMENTS

- Defined for all elements (≈ 130 body points)
- Environments released to all element contractors (4/1/91)
- TPS impact assessment in progress

PREDICTION METHODOLOGY

- Improvements and refinements in progress (NAS8 - 37891)
- 48 - inch motor and FSM motor tests in progress
- Code development and plume definitions continuing

DFI REQUIREMENTS

- ASRB DFI - four review iterations completed (Feb. - Mar. 1991)
- DFI for other elements compiled and scrubbed by thermal panel (Mar. 1991)

Figure 6: Shuttle with ASRB Induced Thermal Environments and DFI Requirements — Status

DFI - SHUTTLE WITH ASRB**JUSTIFICATION**

- SUPPORT ANALYSIS OF FLIGHT ANOMALIES
 - Lessons learned: 1) Anomalies will occur
 - 2) DFI will help with resolution
 - 3) New system interfaces create uncertainties
- ASSIST IN IDENTIFYING CORRECTIVE MEASURES FOR SUBSEQUENT FLIGHTS
- ESTABLISH THERMAL MARGINS
- VERIFY ENVIRONMENTS AND PREDICTIVE METHODS
 - Flight measurements are the "anchors" for prediction methodology and the "pointers" for future efforts
 - Methods must be verified to allow design certification and avoid flight-by-flight assessments
 - Environments must be measured under flight conditions to proceed with design evolution
 - TPS assessment
 - Weight reduction
 - Debris prevention
 - Environment estimates are substantially greater than current Shuttle with RSRB and all elements are affected

Figure 7: DFI — Shuttle with ASRB — Justification

NECESSITY OF DFI FOR INITIAL FLIGHTS -- SHUTTLE WITH ASRB

CONCLUSIONS

- No system fixes will eliminate need for DFI
 - Benign structural loads trajectory may increase plume induced environments
 - Design margins uncertain due to lack of verification of new methodology
 - All elements experience increased environments - not just ASRB
- This is an "all-new" vehicle thermally - so first flights require development flight philosophy
- It is always prudent to instrument first flights of any launch vehicle with new major elements and system interfaces
- Some carry-over uncertainties with current Shuttle may benefit from new data, e.g.:
 - Flow fields and environments in ET/Orbiter attach region
 - Forward BSRM plume impingement region
 - Orbiter umbilical door seal environments
 - SSME nozzle entry heating

Figure 8: Necessity of DFI for Initial Flights — Shuttle with ASRB — Conclusions

**INDUCED THERMAL ENVIRONMENTS -
SHUTTLE WITH ASRB**

SUMMARY

ENVIRONMENTS DIFFERENT THAN SHUTTLE WITH RSRB

- ASRB has: 1) Different exhaust thermochemistry due to higher aluminum content (19%)
- 2) Higher chamber pressure final 60 seconds of ascent
- 3) Shock impingement shift
- 4) Longer burn time and higher separation altitude
- 5) Different staging dynamics
- 6) More severe reentry trajectory

CYCLE 1 ENVIRONMENTS COMPARED WITH IVBC-3 DESIGN
FOR SHUTTLE WITH RSRB

- | | |
|-------------------------------|--|
| •Ascent base heating | (Estimated 1.3 x RSRB) |
| •Ascent aeroheating | (Estimated 1.1 x RSRB) |
| •Separation plume impingement | (Analysis pending availability of separation trajectory) |
| •Reentry aeroheating | (Estimated 1.5 x RSRB) |
| ↳Internal aft skirt | (Estimated 1.8 x RSRB) |

Figure 9: Induced Thermal Environments — Shuttle with ASRM — Summary

Section 3 REFERENCES

- [1] Reardon, J. E., "Plume Radiation Measurements for the 48-inch RSRM and ASRM Motor Tests," REMTECH Report RTN 213-04, April 9, 1990.
- [2] Reardon, J. E. and Everson, J. "Evaluation of Radiation Measurements on the MNSASA-3 Motor Test," REMTECH Report RTN 213-18, June 18, 1991.
- [3] Reardon, J. E. and Reardon, C. G. "Radiation Measurements on the TEM-7 Test of the Space Shuttle Solid Rocket Motor," REMTECH Report RTN 213-20, July 31, 1991.
- [4] Reardon, J. E. "Preliminary Plume Radiation Measurement Requirements for the ASRM Development Firings at Stennis Space Center," REMTECH Report RTN 213-06, Oct. 16, 1990.
- [5] Reardon, J. E. "Preliminary Radiation Measurement Requirements for the Static Firing of the Advanced Solid Rocket (ASRM) Motor," REMTECH Report RTN 213-17, June 13, 1991.
- [6] Bender, R. L. and Reardon, J. E., "ASRM Cycle 1 Plume Induced Thermal Environments," REMTECH Report RTN 213-08, Jan. 21, 1991.
- [7] Smith, Sheldon D., "Space Shuttle Advanced Solid Rocket Motor (ASRM) Exhaust Plume Definitions — Sea Level to ASRM Separation," SECA Report TR-91-3, Feb. 1991.
- [8] Reardon, J. E., "ASRM Cycle 1 Plume Radiation Methodology," REMTECH Report RTN 213-09, Feb. 1991.
- [9] Reardon, J. E., "ASRM Cycle 1 Plume Radiation Environment Revision," REMTECH Report RTN 213-12, Feb. 28, 1991.
- [10] Reardon, J. E., "Solid Rocket Motor Plume Radiation Methodology Corrections for the Orbiter," REMTECH Report RTN 213-13, Feb. 8, 1991.
- [11] Everson, John, "Comparison of Forward and Reverse Monte Carlo Methods," REMTECH Report RTN 213-11, Feb. 1991.
- [12] Bender, R. L. and Brown, J. R., "ASRM Cycle 1 Plume Induced Convection Methodology," REMTECH Report RTN 213-10, Feb. 1991.
- [13] Reardon, J. E., "Criteria for Selection of the ASRM Cycle 1.5 Plume Radiation Design Trajectory," REMTECH Report RTN 213-24, Sep. 30, 1991.
- [14] Reardon, J. E., "Criteria for Selection of the ASRM Cycle 1.5 Plume Convection Design Trajectory," REMTECH Report RTN 213-25, Sep. 30, 1991.
- [15] Bender, R. L. and Brown, J. R., "Evaluation of ET Base Region Zones of Uniform Heating for ASRM Cycle 1.5 Convective Environments," REMTECH Report RTN 213-19, Sep. 23, 1991.
- [16] Palko, Richard L., "Evaluation of the Number of Pressure Ports Required for Prediction of Peak Impact Pressure and Roll Orientation of the SRB During Reentry," REMTECH Report RTN 213-5-01, August 1991.

- [17] Palko, Richard L., "REMTECH Gas Temperature Probe Installation Requirements for ASRB Development Flights," REMTECH Report RTN 213-22, Sep. 17, 1991.