N91-10879

Conjugate (Solid/Fluid) Computational Fluid Dynamics Analysis of the Space Shuttle Solid Rocket Motor Nozzle/Case and Case Field Joints

D. Doran, NASA/MSFC, L. W. Keeton, P. J. Dionne, and A. K. Singhal, CFD Research Corporation

This work describes three-dimensional, conjugate (solid/fluid) heat transfer analyses of new designs of the Solid Rocket Motor (SRM) nozzle/case and case field joints.

The main focus of the study has been to predict the consequences of multiple "rips" (or debonds) in the ambient cure adhesive packed between the nozzle/case joint surfaces and the bond line between the mating field joint surfaces. The models calculate the transient temperature responses of the various materials neighboring postulated flow/leakpaths into, past and out from the nozzle/case primary O-ring cavity and case field capture O-ring cavity. These results were used to assess if the design was failsafe (i.e. no potential O-ring erosion) and reusable (i.e. no excessive steel temperatures).

The models are adaptions and extensions of the general purpose PHOENICS fluid dynamics code.

A non-orthogonal coordinate system was employed and 11,592 control cells for the nozzle/case and 20,088 for the case field joints are used with non-uniform distribution. Physical properties of both fluid and solids are temperature dependent.

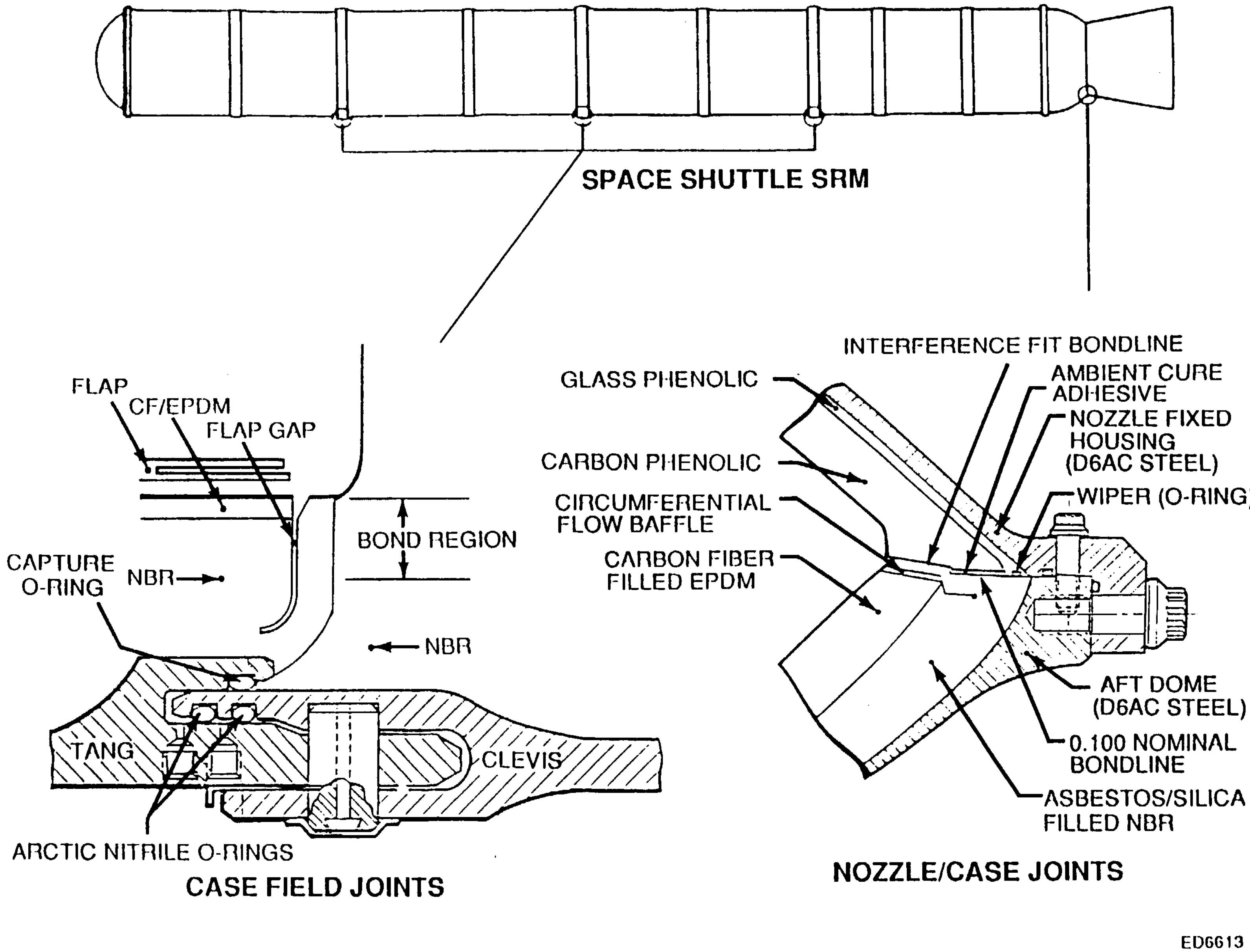
A number of parametric studies were run for both joints with results showing temperature limits for reuse for the steel case on the nozzle joint being exceeded while the steel case temperatures for the field joint were not. O-ring temperatures for the nozzle joint predicted erosion while for the field joint they did not.

SRB NOZZLE/CASE AND CASE FIELD JOINT FLOW AND THERMAL ANALYSIS

OVERVIEW

- PROBLEM DEFINITION
- OBJECTIVES
- TECHNICAL APPROACH
- RESULTS
- PROGRAM IMPACT AND CONCLUSIONS

5-1571-9-102


SPACE SHUTTLE SRM
FLAP
CF/EPDM
FLAP GAP
BOND REGION
CAPTURE O-RING
NBR
NBR
TANG
CLEVIS
ARCTIC NITRILE O-RINGS
CASE FIELD JOINTS
INTERFERENCE FIT BONDLINE
GLASS PHENOLIC
AMBIENT CURE ADHESIVE
NOZZLE FIXED HOUSING (D6AC STEEL)
CARBON PHENOLIC
CIRCUMFERENTIAL FLOW BAFFLE
WIPER (O-RING)
CARBON FIBER FILLED EPDM
AFT DOME (D6AC STEEL)
0.100 NOMINAL BONDLINE
ASBESTOS/SILICA FILLED NBR
NOZZLE/CASE JOINTS
ED6613

SRB NOZZLE/CASE AND CASE FIELD JOINT FLOW AND THERMAL ANALYSIS

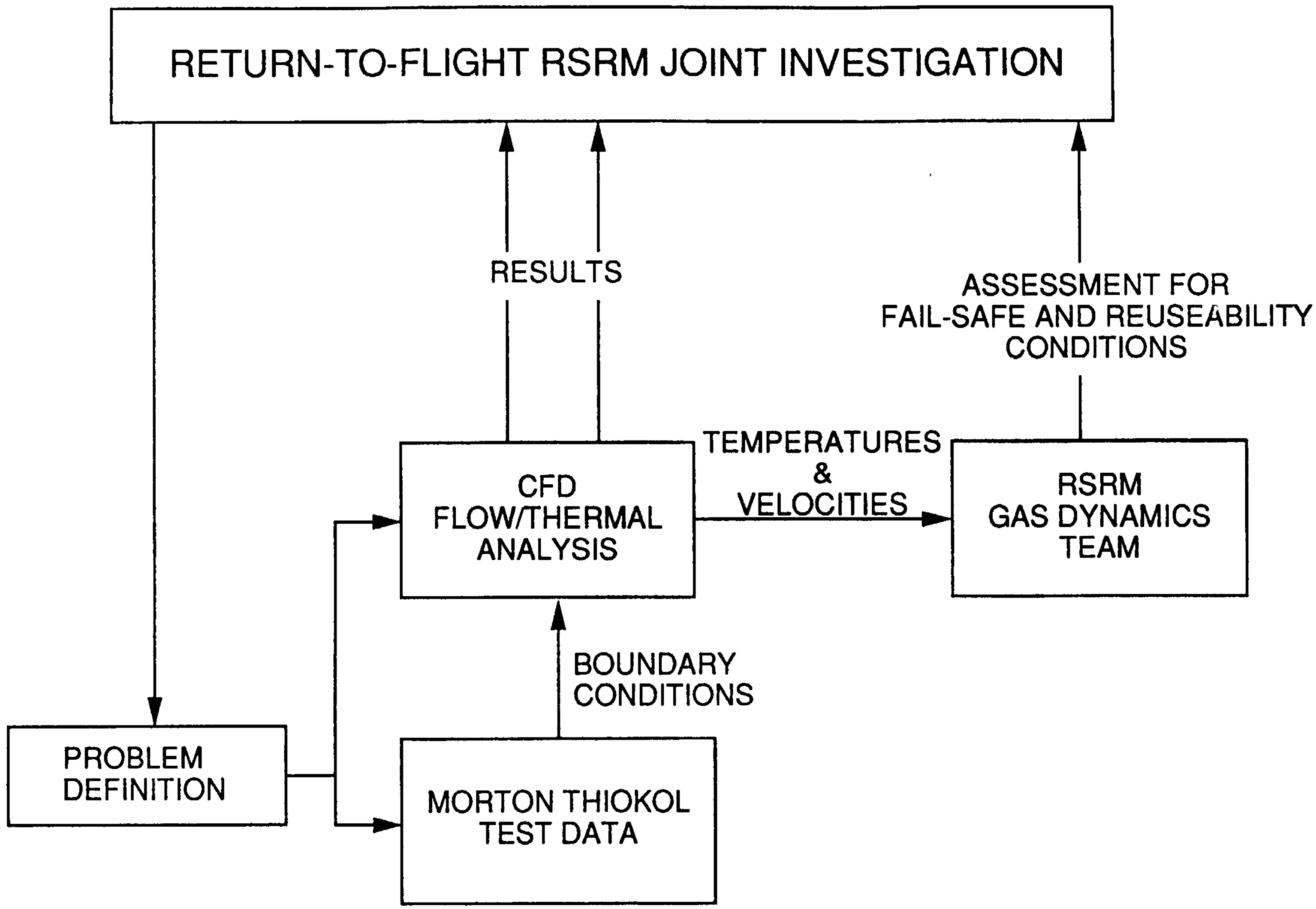
OBJECTIVE: DEFINITION OF THE FLOW AND THERMAL ENVIRONMENTS IN THE SRB NOZZLE/CASE AND CASE FIELD JOINTS ASSUMING SEVERAL POSTULATED DOUBLE LEAKPATHS THROUGH THE NOZZLE/CASE AMBIENT CURE ADHESIVE AND THE CASE FIELD BOND LINE BETWEEN THE MATING FIELD JOINT SURFACES

JUSTIFICATION: TO DEFINE CONSERVATIVE, BUT CREDIBLE DESIGN AND FAIL-SAFE CONDITIONS AND CRITERIA FOR NOZZLE/CASE AND CASE FIELD JOINT THERMAL ANALYSIS

DESIGN - TEMPERATURES WHICH GUARANTEE REUSABILITY OF METAL PARTS AND NO EROSION OF O-RING SEALS

FAIL-SAFE - TEMPERATURES WHICH GUARANTEE A STRUCTURAL SAFETY FACTOR OF 1.0 ON METAL PARTS AND NO EROSION OF ONE SEAL

5-1572-9-102


RETURN-TO-FLIGHT RSRM JOINT INVESTIGATION
RESULTS
ASSESSMENT FOR FAIL-SAFE AND REUSEABILITY CONDITIONS
CFD FLOW/THERMAL ANALYSIS
TEMPERATURES & VELOCITIES
RSRM GAS DYNAMICS TEAM
BOUNDARY CONDITIONS
PROBLEM DEFINITION
MORTON THIOKOL TEST DATA

5-1624-9-103

SRB NOZZLE/CASE AND CASE FIELD JOINT FLOW AND THERMAL ANALYSIS

APPROACH: APPLICATION OF 3-D NAVIER-STOKES CODE (PHOENICS) TO FLOW IN THE DEBOND GAP AND O-RING REGIONS COUPLED WITH HEAT CONDUCTION OF THE FLUID AND NEIGHBORING "SOLIDS" (NOZZLE/CASE 11592 CELLS; CASE FIELD 20088 CELLS)

PHOENICS

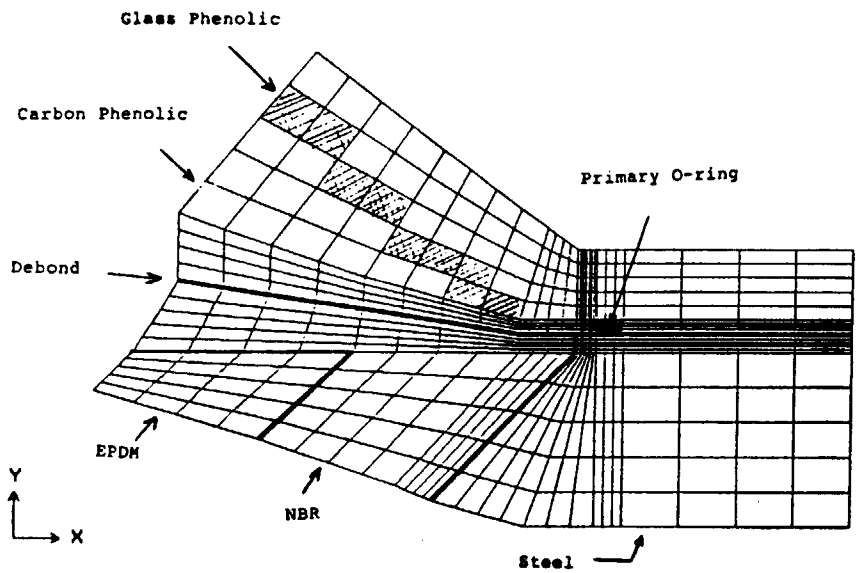
- (PARABOLIC, HYPERBOLIC, OR ELLIPTIC NUMERICAL INTEGRATION CODE SERIES)

MODEL USES:

- BODY-FITTED COORDINATES
- FINITE-VOLUME FORMULATION
- 3-D TRANSIENT
- K-EPSILON TURBULENCE MODEL
- TEMPERATURE DEPENDENT SOLID AND FLUID PROPERTIES
- WALL FUNCTIONS (LOG LAW OF THE WALL)
- CHILTON-COLBURN FORM OF REYNOLDS ANALOGY FOR HEAT TRANSFER AT WALL

5-1573-9-102

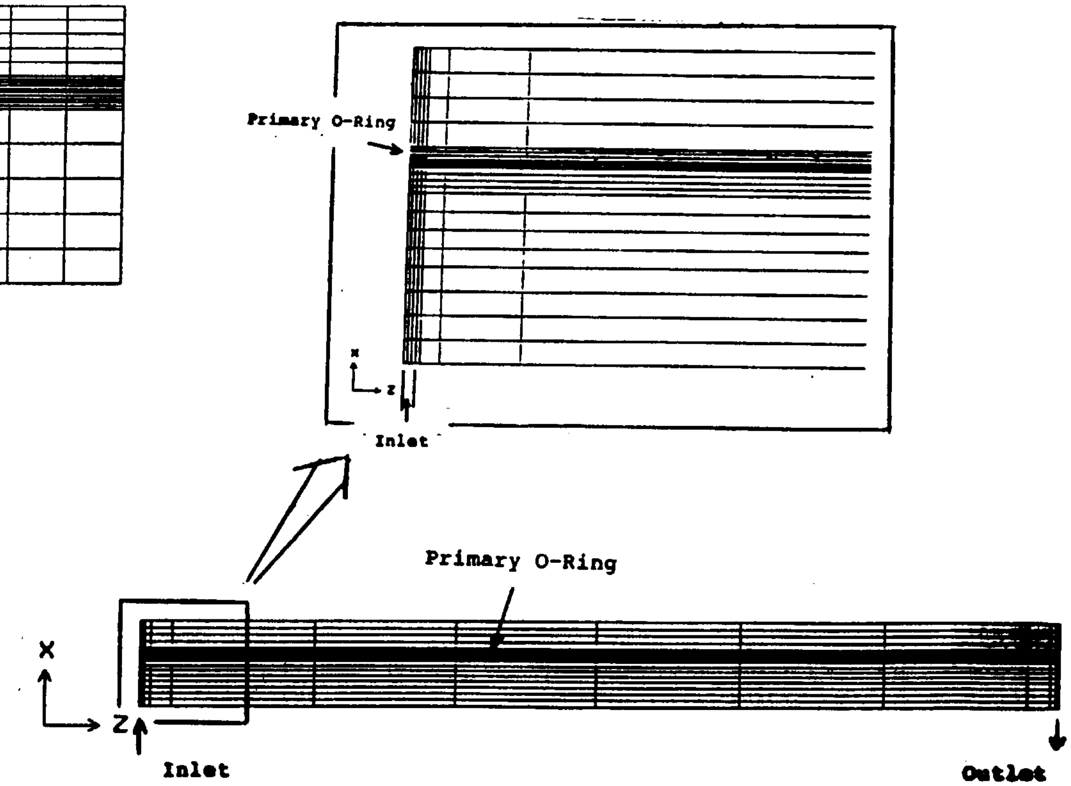
GRID



NX = 23

NY = 28

NZ = 18



SUMMARY OF MAXIMUM TEMPERATURES FOR NOZZLE/CASE JOINT MODEL

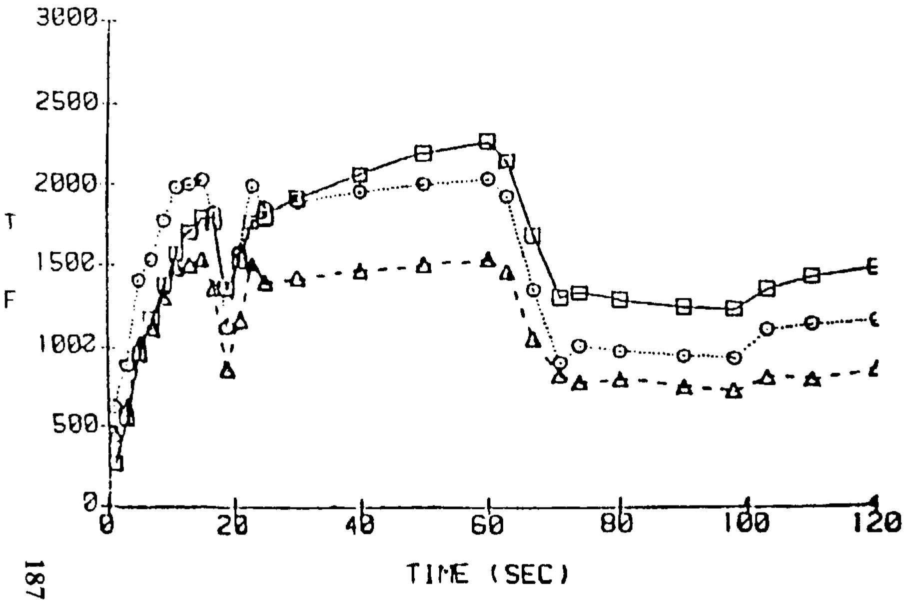
Run No.	Insul. Gap (in.)	Steel Gap (in.)	Debond Width (5) (in.)	Diff. P (psi)	Diff. P Angle (deg)	T max Gas (deg F)	T max Steel (deg F)	T max O-ring (deg F)	Notes
1	.024	.004	F.O.	1.08	0 – 180	142	180	105	
2	.024	.010	F.O.	1.08	0 – 180	295	230	170	
3	.024	.004	3.5	1.08	0 – 180	1120	1092	769	
4	.024	.010	3.5	1.08	0 – 180	2071	1432	1423	
5	.024	.015	F.O.	envelope	0 – 180	258	132	129	
6	.100	.050	F.O.	envelope	0 – 180	1125	659	607	
7	.024	.008	3.5	envelope	0 – 180	1628	1117	885	
8	.024	.008	3.5	QM–4	0 – 180	1103	742	582	
9	.024	.008	3.5	QM–4	0 – 180	1153	769	601	1
10	.024	.008	3.5	QM–4	0 – 120	1256	852	667	1
11	.024	.008	3.5	QM–4	0 – 120	1643	1380	909	1,2
12	.050	.010	0.4	QM–4	0 – 120	2898	2320	1510	1,2
13	.050	.010	0.4	QM–4	0 – 120				1,2,3
14	.024	.008	3.5	QM–4	0 – 120	1502	1304		1,2,3
15	.046	.008	0.75	QM–4	0 – 120	2276	2352	1856	1,2,3
16	.090	.008	0.75	QM–4	0 – 120	2834	2846	2341	1,2,3
17	.046	.008	0.75	QM–4	0 – 120	2278	2359	1859	1,2,3,4
18	.046	.008	0.75	QM–4	0 – 120	2278	2351	1858	1,2,3,6
19	.046	.008	0.75	QM–4	0 – 120	2211	2252	1847	1,2,3,7
20	.046	.008	0.75	QM–4	0 – 120	2083	2353	1691	1,2,3,8
21	.046/.020	.008	0.75	QM–4	0 – 120	2089	2178	1588	1,2,3,9
22	.046/.020	.008	0.75	QM–4	0 – 120	2059	2187	1568	1,2,3,9,10
23	.046/.020	.008	0.75	QM–4	0 – 120	2053	2272	1543	1,2,3,9, 11
24	.046/.020	.008	0.75	QM–4	0 – 120	1866	2255	1509	1,2,3,9,11,12,13
25	.046/.020	.008	0.75	DM–8	0 – 120	1610	1818	1274	2, 3, 9, 11

Notes:

1. Improved modeling of QM–4 duty cycle
2. Model revised to open NBR/glass phenolic area 360 deg. and improve average material properties
3. Material properties computed as function of temperature
4. Same as Run 15 but with number of time steps doubled
5. One-half of values listed input to model due to symmetry
6. 2 X nominal number of grid nodes in Z direction
7. Increased number of grid nodes in X direction (<2 X nominal)
8. 2 X nominal number of grid nodes in X direction
9. Model regrided to provide two insulation gap width capability
10. Y grid sensitivity. Number of insulation cells increased
11. K-Epsilon turbulence model
12. Y grid sensitivity. Number of fluid cells increased by factor of 2
13. Calculation of O-ring wall temperature corrected

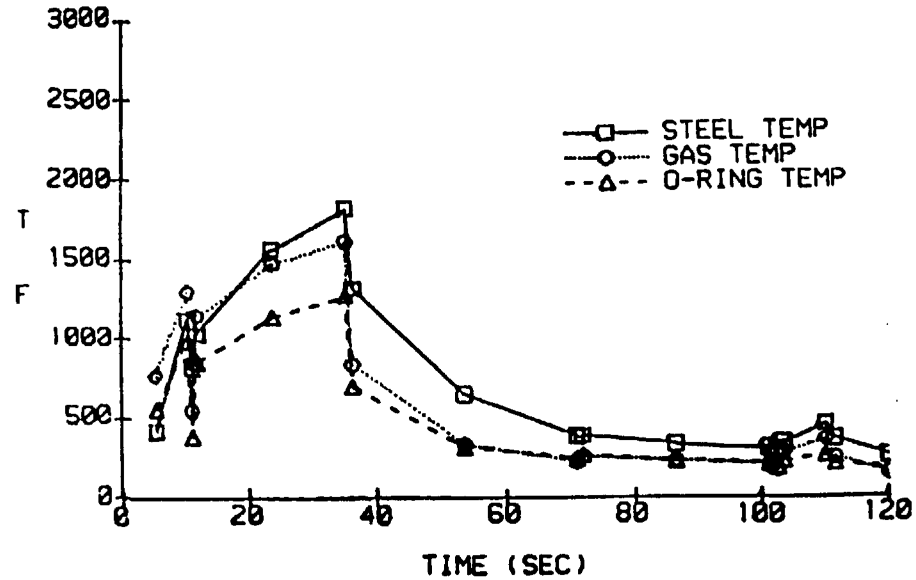
5-1576-9-102

NOZZLE/CASE JOINT PHOENICS RUN

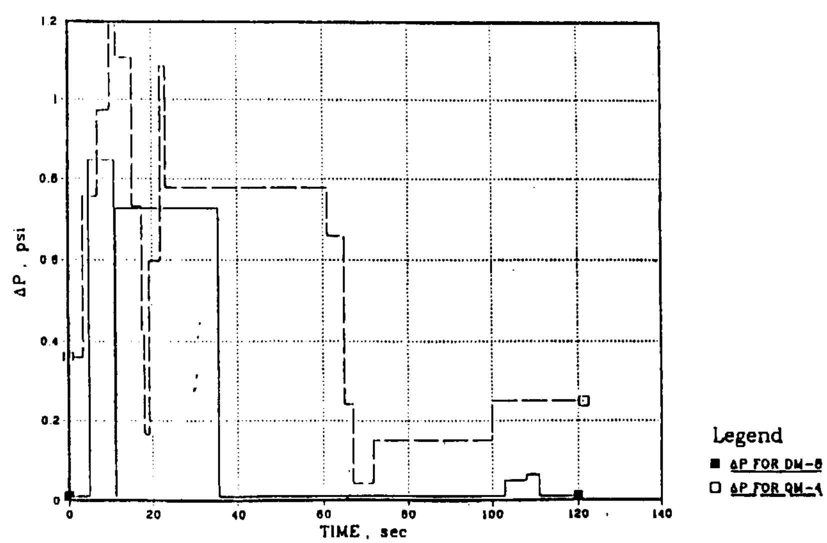


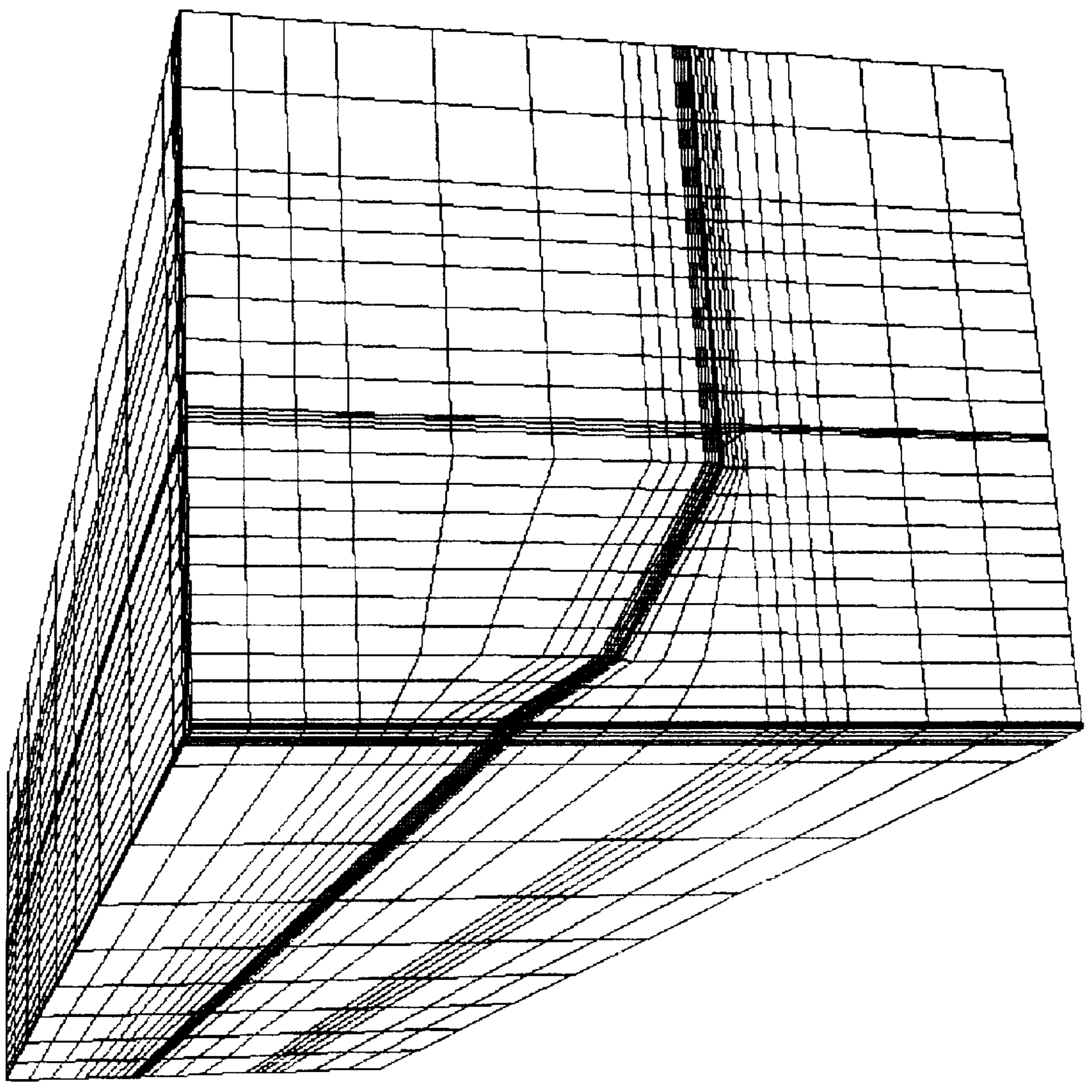
QM-4

NOZZLE/CASE JOINT PHOENICS RUN



DM-8



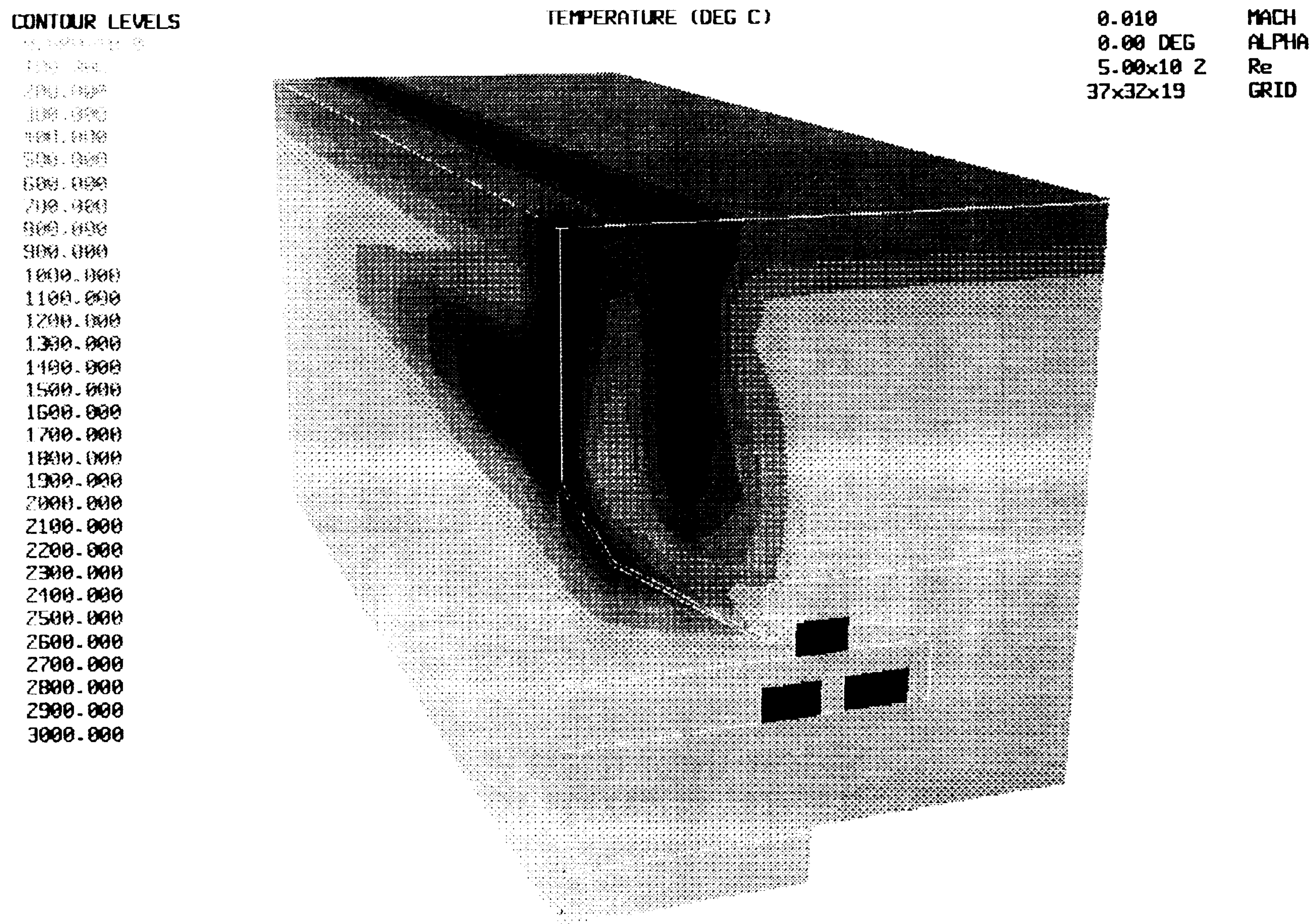

GRID
37x32x19
GRID

SUMMARY OF MAXIMUM TEMPERATURES FOR FIELD JOINT MODEL

RUN	SPECIFICATION				CALCULATED RESULTS		
NO.	G1 (IN)	CIRCUM. DEBOND WIDTH (IN)	CIRCUM. DEBOND ANGLE (DEG)	Δp PSI	TMAX STEEL (DEG C)	TMAX GAS (DEG C)	TMAX O-RING (DEG C)
1	0.002	2.8	120	0.5	16.1	13.9	13.6
2	0.002	2.8	15	0.5	16.2	14.1	13.7
3	0.016	0.25	120	0.5	16.5	23.3	14.2
4	0.016	0.25	15	0.5	161.7	746.6	607.4
5	0.016	0.25	15	0.1	21.0	65.4	42.3

NOTE: FOR ALL CASES G2 = 0.0264", AND G3 = 0.0241"

5-1569-9-105


CONTOUR LEVELS
200.000
300.000
400.000
500.000
600.000
700.000
800.000
900.000
1000.000
1100.000
1200.000
1300.000
1400.000
1500.000
1600.000
1700.000
1800.000
1900.000
2000.000
2100.000
2200.000
2300.000
2400.000
2500.000
2600.000
2700.000
2800.000
2900.000
3000.000
TEMPERATURE (DEG C)
0.010 MACH
0.00 DEG ALPHA
5.00x10 2 Re
37x32x19 GRID

SRB NOZZLE/CASE AND CASE FIELD JOINT FLOW AND THERMAL ANALYSIS

PROGRAM IMPACT:

- STEEL CASE TEMPERATURE LIMIT FOR REUSE (1000°F)
  - EXCEEDED FOR NOZZLE/CASE JOINT (IF 2 LEAKPATHS OCCUR WHICH IS VERY UNLIKELY)
  - WITHIN LIMIT FOR CASE FIELD JOINT
- ABLATION TEMPERATURE LIMIT FOR O-RINGS (700°F)
  - EXCEEDED FOR NOZZLE/CASE JOINT (IF 2 LEAKPATHS OCCUR WHICH IS AGAIN UNLIKELY)
  - WITHIN LIMIT FOR CASE FIELD JOINT (EXCEPT ONE CASE WHERE FLOW PATH IS ONLY OVER 15°)

CONCLUSIONS:

- ANALYSIS CONSIDERED CONSERVATIVE, DUE TO WORST CASE SCENARIOS BEING ANALYZED
- ANALYSIS PERFORMED TO VERIFY OTHER ANALYSIS BEING DONE IN PARALLEL, AT MORTON THIOKOL TO SUPPORT RETURN-TO-FLIGHT STATUS
- PROBABILITY OF TWO LEAKPATHS OCCURING IS ONE IN ONE-THOUSAND SO DESIGN MEETS FAIL-SAFE AND REUSEABILITY CONDITIONS.

5-1623-9-103