SPACE SHUTTLE

Solid Rocket Motors
Morton Thiokol, Inc

19176
ECS-SS-3059

SRM PROPELLANT, FRICTION/ESD TESTING

12 May 1989

Prepared for:

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SRM PROPELLANT, FRICTION/ESD TESTING

28 April 1989

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ECS-SS-3059

SRM PROPELLANT, FRICTION/ESD TESTING

L. A. Campbell

INTRODUCTION

In years past there was not much concern about electrostatic sensitivity of propellants. At Thiokol, testing was performed on solid propellants with the TCC Electrostatic Discharges (ESD) equipment, with upper limits of 40,000 volts and 8 joules energy. With the acquisition of the Allegany Ballistics Lab (ABL) ESD equipment during a joint venture with Hercules, testing was also done at 5,000 volts at energy levels up to 6.25 joules. During standard hazards testing, most propellants were tested with one or both ESD systems and the sensitivity was usually reported as greater than 8 joules or greater than 6.25 joules, depending on which system was used, since propellants rarely ignited. These energy levels are much higher than would be expected from normal electrostatic voltage build up in propellant handling or casting operations. Generally, however, some level of precaution was taken by grounding or shielding to prevent the possibility of an ignition by ESD.

Following the Pershing II incident in 1985 and the Peacekeeper ignition during core removal on 29 December 1987, it was found that propellant can be much more sensitive to ESD than ever before realized. As a result of the Peacekeeper PK-303 motor near miss incident, a friction machine was designed and fabricated, and used to determine friction hazards during core removal. Friction tests on PK propellant produced no ignitions or indications of positive results, even to pressures on the sample of 13,000 PSI. However, additional testing with an electrical charge being applied across the friction plates resulted in propellant ignitions at low friction pressures and extremely low ESD levels. This condition simulates friction, confinement, pressure and electrostatic voltage build up as a core is removed from a motor. Testing was performed with this equipment on Peacekeeper Propellant (TP-H1207C) to determine the lowest energy levels at which it would ignite. Comparison tests were performed under this study on SRM propellant (TP-H1148), as specified in TEST PLAN, ETP-0359, "SPACE SHUTTLE SRM ELECTROSTATIC SENSITIVITY AND CHARGE GENERATION".

OBJECTIVE

The objective of this test series was to determine the sensitivity of TP-H1148 (SRM) propellant to combined friction pressure and electrostatic stimuli and to compare the sensitivity of the SRM propellant to Peacekeeper propellant (TP-H1207C).

SUMMARY

The low rate, high load friction tester ("V-groove" test), used in the investigation of the Peacekeeper investigation of motors PK-303 and PK-322 incident, was also used in the testing of SRM propellant. While running the friction test, a charged capacitor was discharged across the electrically isolated friction plates. This provided a condition similar to popping a motor core; that is friction, pressure, confinement, and an electrostatic charge. A 550 pF capacitor was charged and connected into the friction plate circuit at about one second intervals for a total of about 15 pulses; 4 pulses before, with the remaining pulses during and after movement of the friction plate. The condition of an electrostatic charge across a very thin film of propellant between two steel friction plates is more severe than is normally seen during normal core popping, and provides a worst case situation.

During the initial phase of the testing, several items were held constant. They were a friction speed of 1/2 inch per second, friction pressure of 1164 psi and the 550 picofarad discharge capacitor. The capacitor charging voltage was changed during testing to provide a variable energy level.

In the initial test series, the test equipment capability was limited to 1000 volts, which, during preliminary testing, was not enough voltage to consistently ignite 0.03-inch thick sheets of first time (once-used) TP-H1148 propellant. However one ignition did occur at 400 volts, with an energy of 44 microjoules, on the once-used propellant.

Some of the propellant was re-used several times so that it was very thin, smashed, broken, and granulated. Under there conditions much less voltage was required for ignition. The lowest voltage that this re-used SRM propellant ignited at was 280 volts, or 22 microjoules. The PK TP-H1207C propellant, tested in a similar manner, ignited at 222 volts or 13.5 microjoules, Table IX. The once-used PK single sheet propellant ignited at 352 volts or 34 microjoules, Table VIII. In general, the SRM TP-H1148 propellant appeared to be less sensitive to the combined friction/ESD stimuli than the PK TP-H1207C propellant.

Later testing, after the modification of the capacitor, "charge", "discharge" switching system and using a higher voltage power supply, was done on single sheets of 0.030-inch thick TP-H1148 propellant, a single sheet covered the entire contacting surfaces of the friction plates. Using the single sheets of 0.030-inch thick propellant resulted in much higher voltages and energy levels required to cause positive results.

Approximately 1200 tests were performed using single sheets of TP-H1148 propellant 0.030-inch thick. These tests were at three friction speeds, four pressures and 20 tests at each of five voltages. The raw data summary sheets are shown in Tables 1 to 6.

In general, most of the ignitions occurred before movement of the friction plates. This would indicate that pressure and not friction is the major cause of the sensitivity of propellants to ESD.

CONCLUSIONS

SRM propellant (TP-H1148) was tested on the combined friction/ESD "V-groove" equipment. The results are summarized in Tables 1 to 6 and igniter probability curves shown in Figures 2 to 12. The minimum ignition levels vs pressure are on Figures 13 to 14.

The data indicate that the TP-H1148 propellant is slightly less sensitive to the combined friction/ESD stimuli than the TP-H1207C propellant. However, the SRM propellant can be ignited with combined friction, pressure and an electrostatic discharge. There was no resolution for three of the probability curves, but the lower ignition levels are shown which is the most important information.

As a comparison, results of previously tested Peacekeeper propellant, (TP-H1207C) are shown in Tables VII and VIII, with the related ignition probability curves shown on Figure 15. The testing that was tabulated in Table 7 and 8 was the only Peacekeeper propellant that was tested using single sheets 0.030 inch thick and provides a better comparison than the other curves which were pieces of "core residue" propellant. The re-used TP-H1148 propellant ignited at the low level of 280 volts, and an energy of 22 microjoules. The once-used sheets of propellant required a higher voltage than the re-used propellant to ignite. The once-used propellant ignited at 400 volts with an energy of 44 microjoules. As a comparison, the Peacekeeper TP-H1207C propellant ignited at 352 volts at 34 microjoules for the once-used propellant (see Table VIII) and 222 volts at 13.5 microjoules for the re-used propellant, (see Table IX).

The once-used 0.030-inch thick single sheet propellant covered the entire "V-groove" friction plate surface and probably held the friction plate surfaces farther apart than when the propellant had been re-used several times.

In comparing TP-H1148 and TP-H1207C propellants, the volumetric resistivity of each propellant should be discussed. The ability of a triboelectrically induced charge to build to a hazardous level in a dynamic propellant-hardware system is a function of the propellant's volumetric resistivity. If the resistance is "low", the generated charge will bleed off as it is generated. According to Dr. Ti Luong in TWR-40029, "ESD data for TP-H1148 and TP-H1207C propellants" the volumetric resistivity for TP-H1148 is 5×10^9 ohm-cm as compared to 2.5×10^{13} ohm-cm for TP-H1207C. The potential for a triboelectric charge build-up in SRM propellant is only 1/5000 of that for TP-H1207C propellant.

Another item that should be considered is the pressure between the SRM core and propellant. Appendix A memo L222-FY89-802, to T. A. Berger, from L. M. Clark; subject: Cont act Pressure Across The Dovetail Region, indicates the SRM propellant contact pressure is 500 psi. According to the tests performed in this study, 1200 in all, using single sheets of 0.030-inch thick of TP-H1148 propellant, a minimum of 2000 volts was required for ignitions to occur at this pressure. Figures 19 and 20 show these data. Because of the lower resistivity of the propellant and with proper tool grounding, SRM operations can be performed safely.

DISCUSSION

Following the Pershing II incident in 1985 and the Peacekeeper ignition during core removal on 29 December 1987, it was found that propellant can be much more sensitive to ESD than ever before realized. As a result of the Peacekeeper PK-303 motor near miss incident, a friction machine was designed and fabricated, and used to determine friction hazards during core removal.

Friction tests on PK propellant produced no ignitions or indications of positive results, even to pressures on the sample of 13,000 PSI. However, additional testing with an electrical charge being applied across the friction pressures and extremely low ESD levels. This condition simulates friction, confinement, pressure and electrostatic voltage build-up as a core is removed from a motor. A sketch of the equipment and the electrical circuit is in Figure 1. Bare steel "V-groove" friction plates, one plate sliding three inches on the other with propellant between, causes the propellant to become very thin. When the dielectric strength of the thin propellant is exceeded by the applied voltage, dielectric breakdown occurs. As this process is repeated several times, with the same propellant being re-used, the propellant becomes smashed, broken, and about the same as being granulated during tool removal operations. Some of the aluminum particles would have the oxide coating rubbed off and could be flattened to the point of acting like a very thin bridge wire. This is probably the most sensitive condition that could occur. This may not be the normal condition but the possibility for a condition like this to exist and cause an ignition in an actual propellant system always exists. This type of testing provides a means of comparing the relative sensitivity of one propellant to another in a combined friction, pressure and ESD environment.

Test data indicates that this friction/ESD test may be more of a confined electrostatic test than a friction test. Previous small scale ESD tests would sometimes show an ignition but very seldom show a sustained flame. During the friction/ESD testing of re-used and smashed propellant under pressure, the sample would often continue to burn after a positive reaction indication. A point of interest is that the positive reactions during this testing were extremely loud. They sounded like high powered rifle shots.

The test series in which single sheets of TP-H1148 propellant were used reacted differently than the early tests where smaller pieces of propellant and re-used propellant were used. The positive reactions were very seldom loud. Usually the sound was only a "click" or a very small "pop". Many times the indication of a positive reaction was only a "smoke" mark on the propellant. Of the 1200 tests performed for this matrix, there was no sustained burning.

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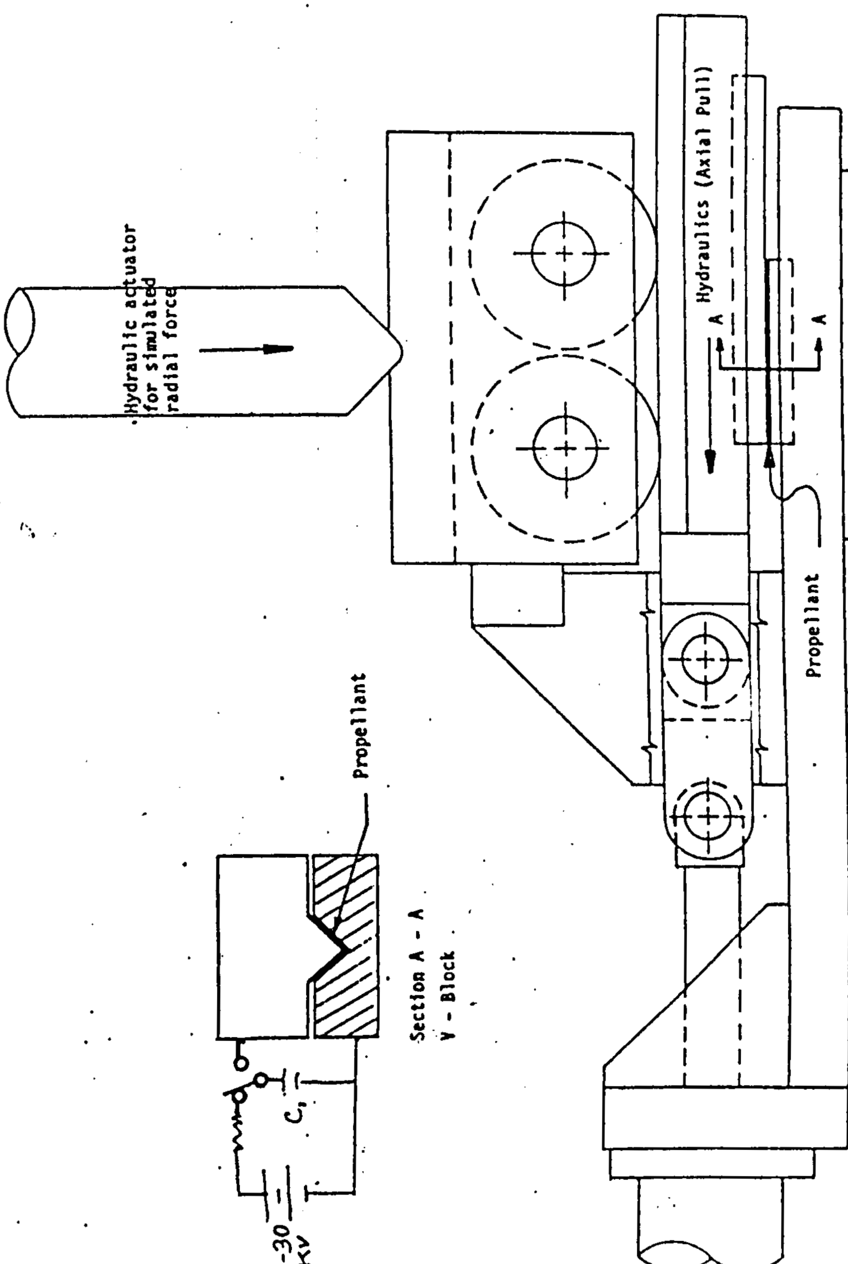

Figure 1.

Equipment Used For Friction/ESD Tests

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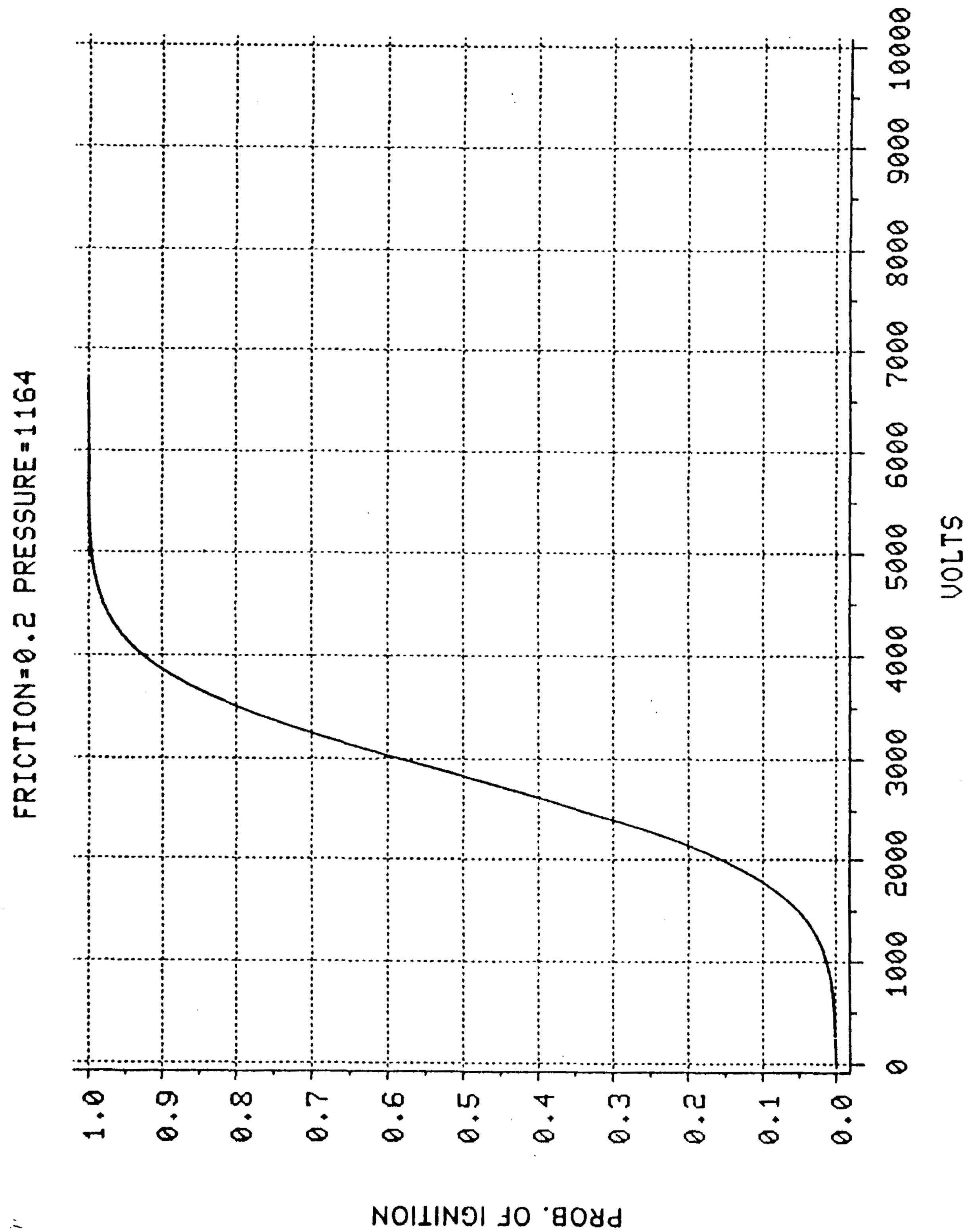

Figure 2.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 0.2 in/sec. Velocity

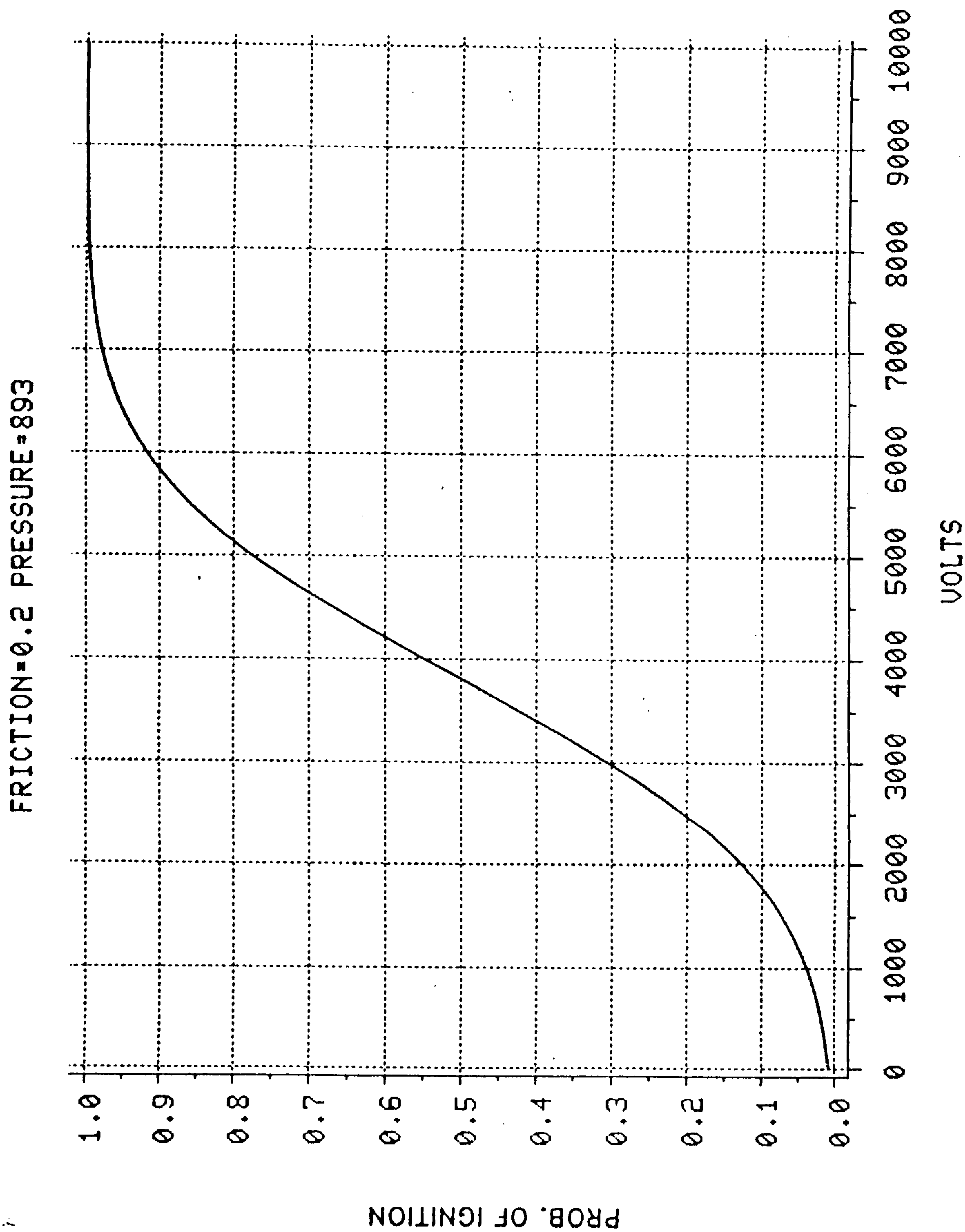

Figure 3.

TP-H1148 Propellant, Probability of Ignition,
Combined Friction-ESD Stimuli, 0.2 in/sec. Velocity

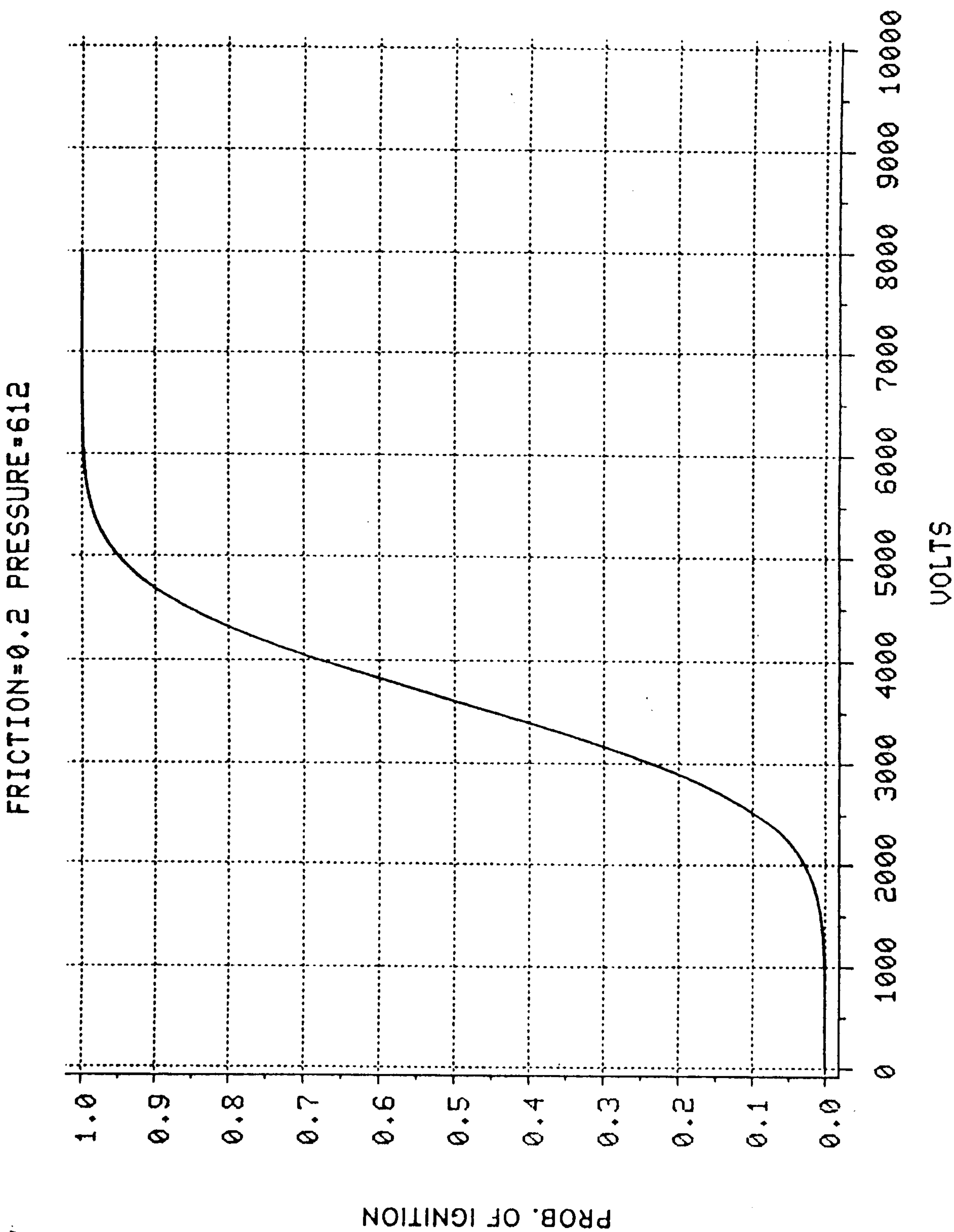

Figure 4.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 0.2 in/sec. Velocity

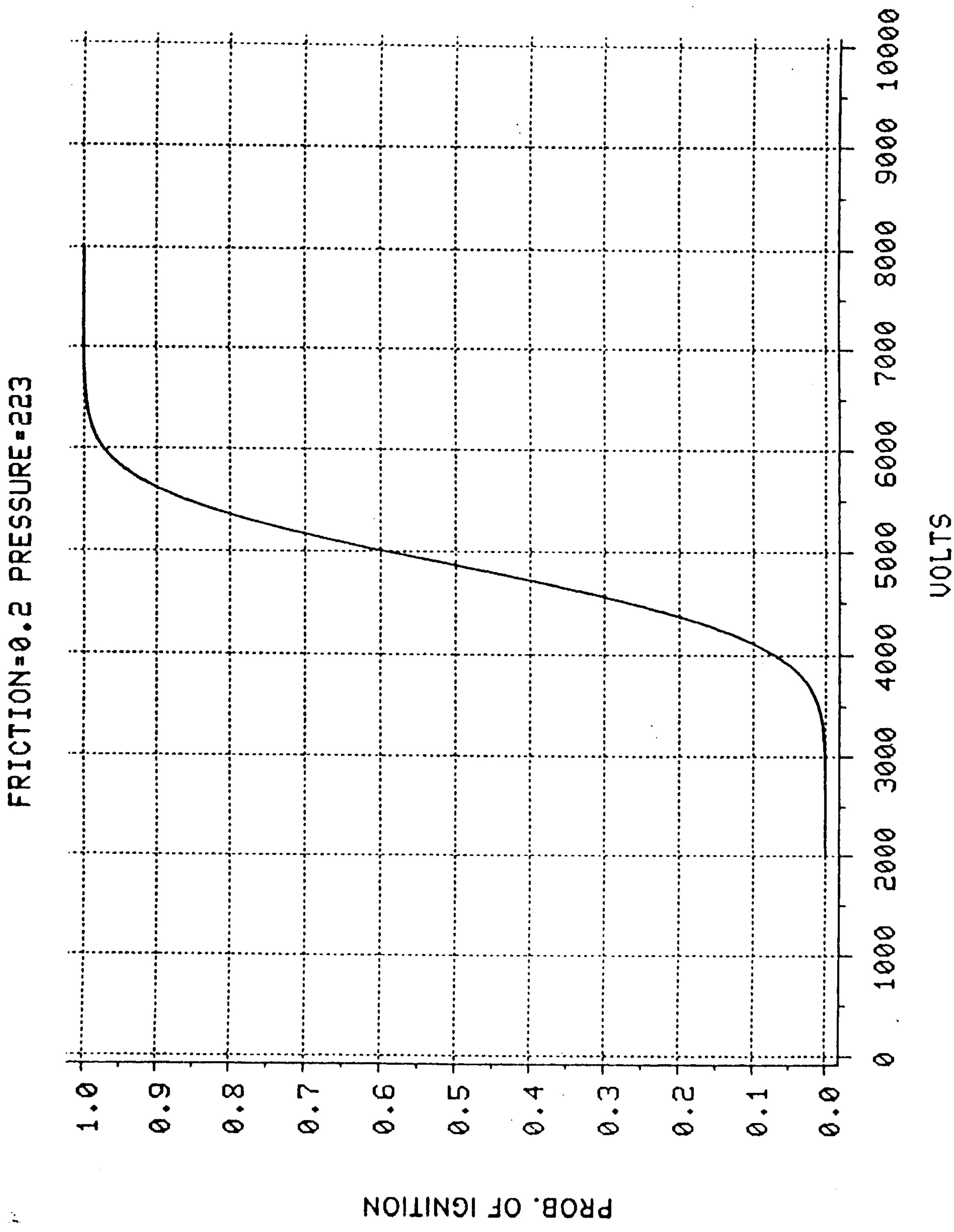

Figure 5.

TP-H1148 Propellant, Probability of Ignition,
Combined Friction-ESD Stimuli, 0.2 in/sec. Velocity

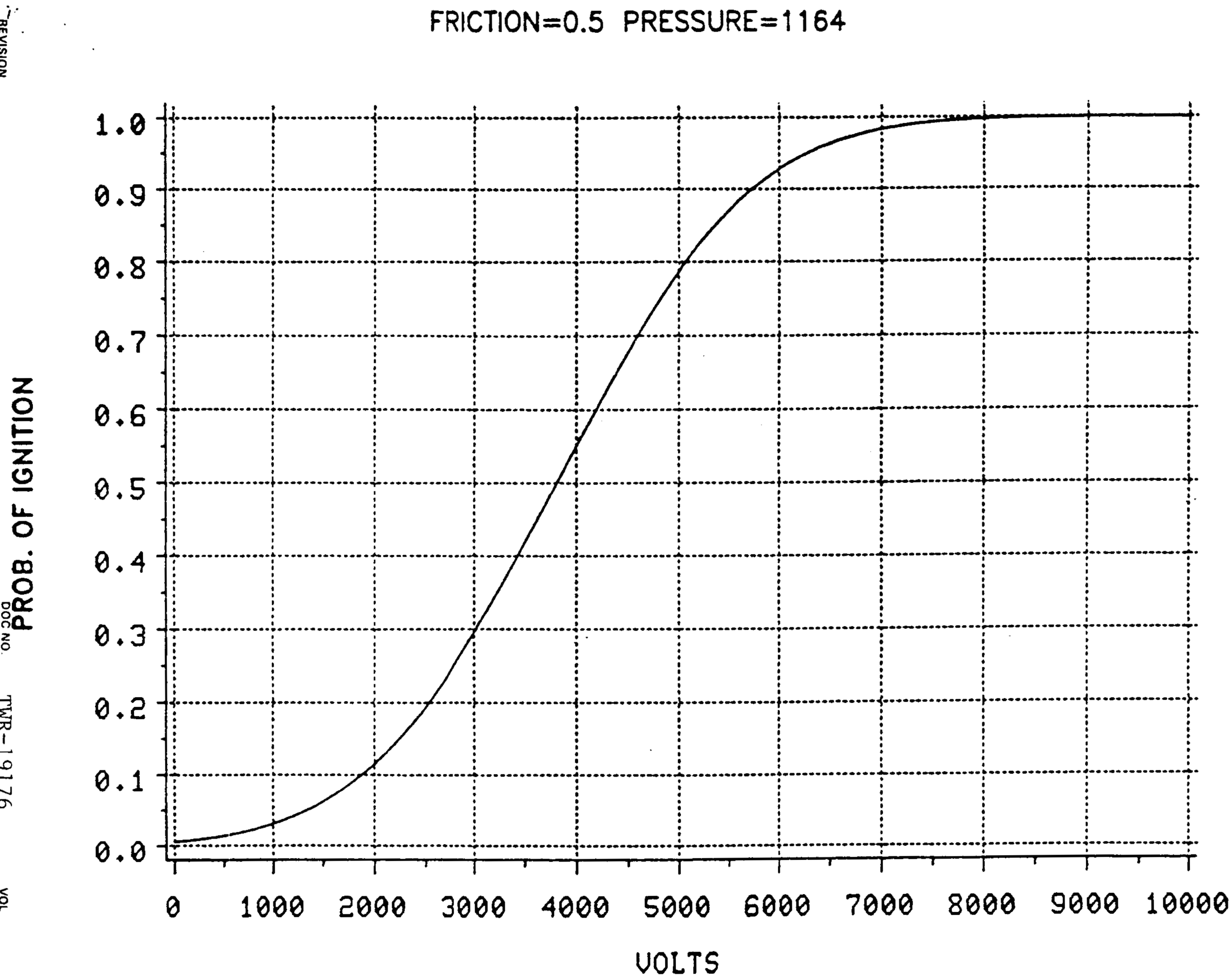

Figure 6.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 0.5 in/sec. Velocity

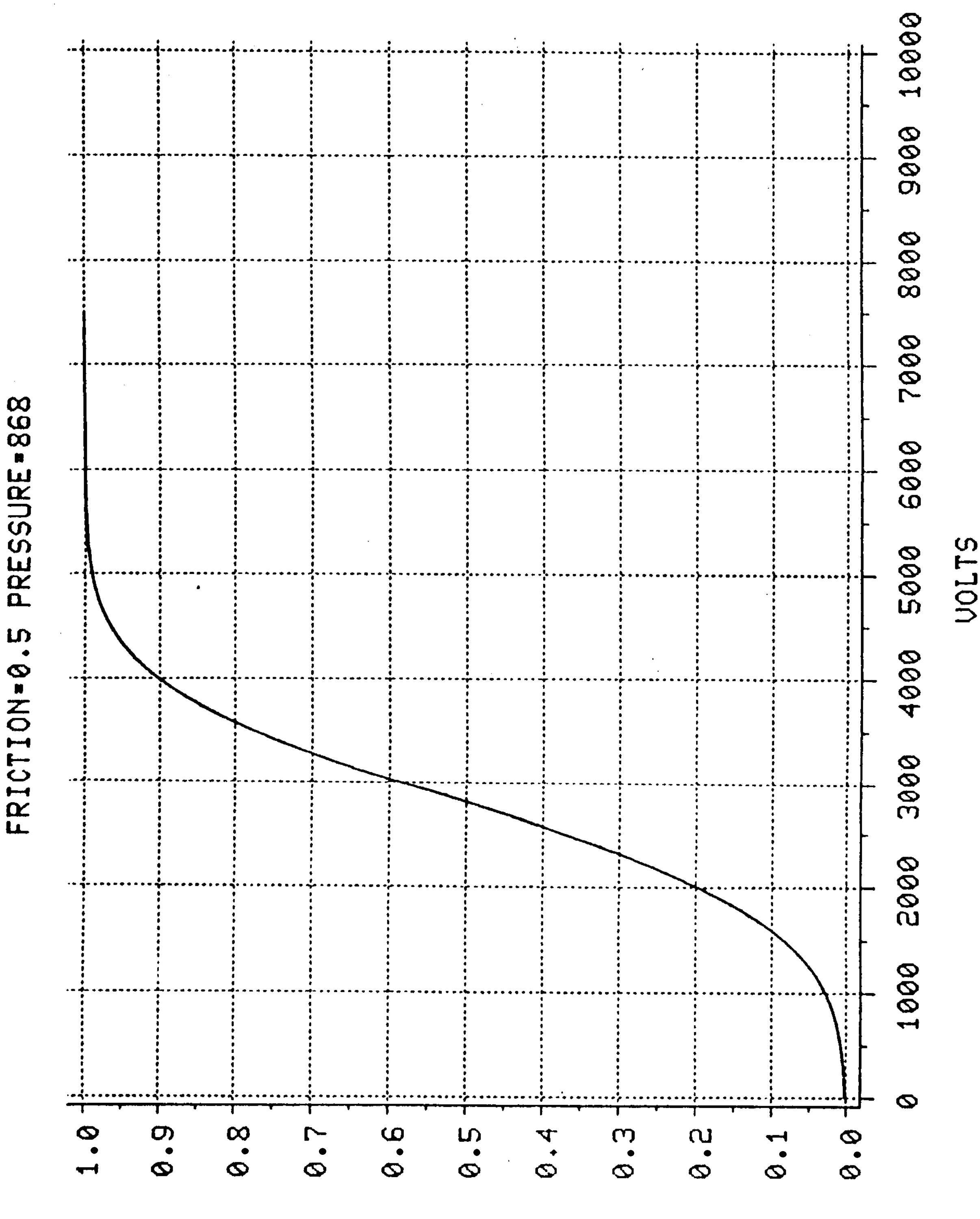

Figure 7.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 0.5 in/sec. Velocity

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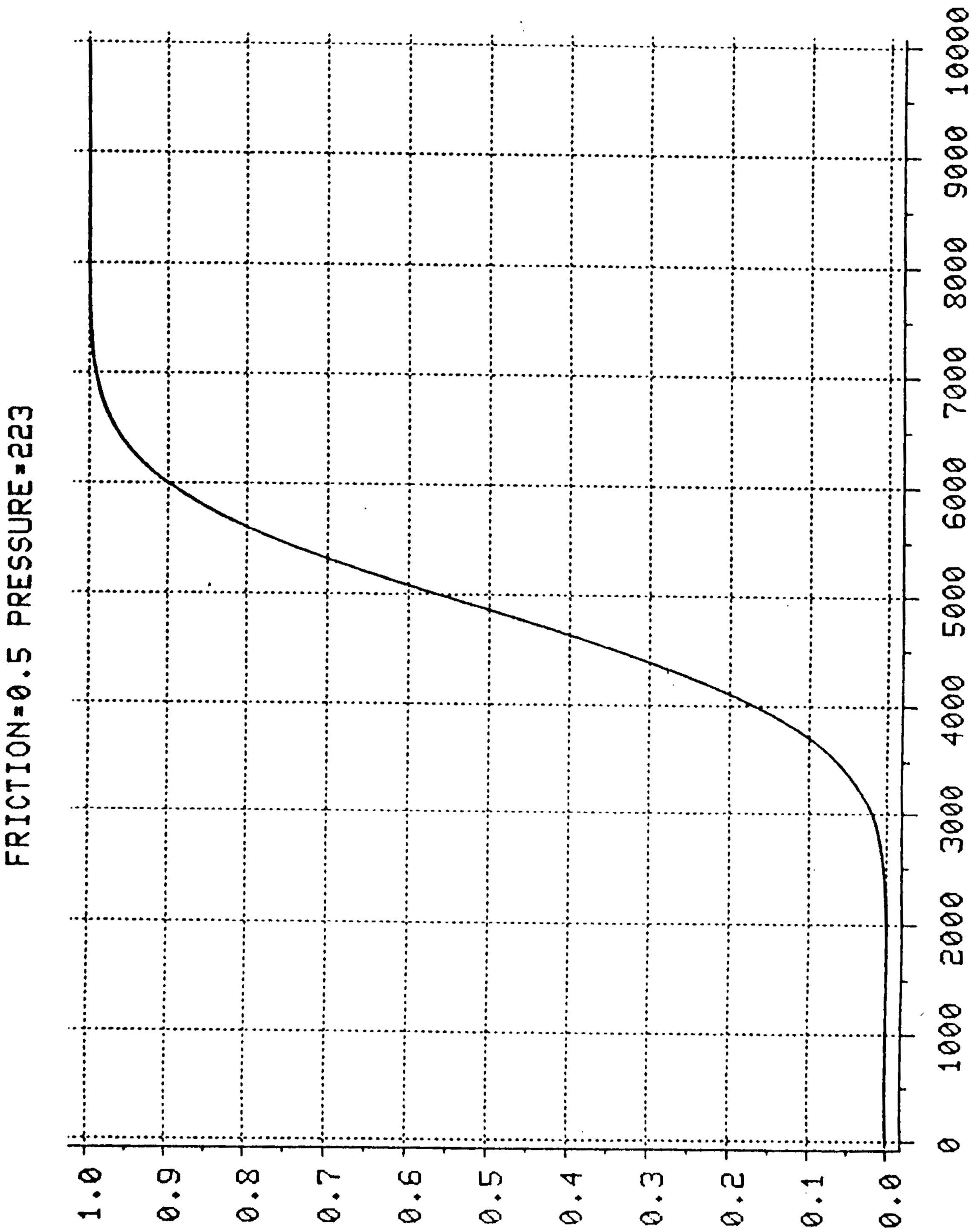

Figure 8.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 0.5 in/sec. Velocity

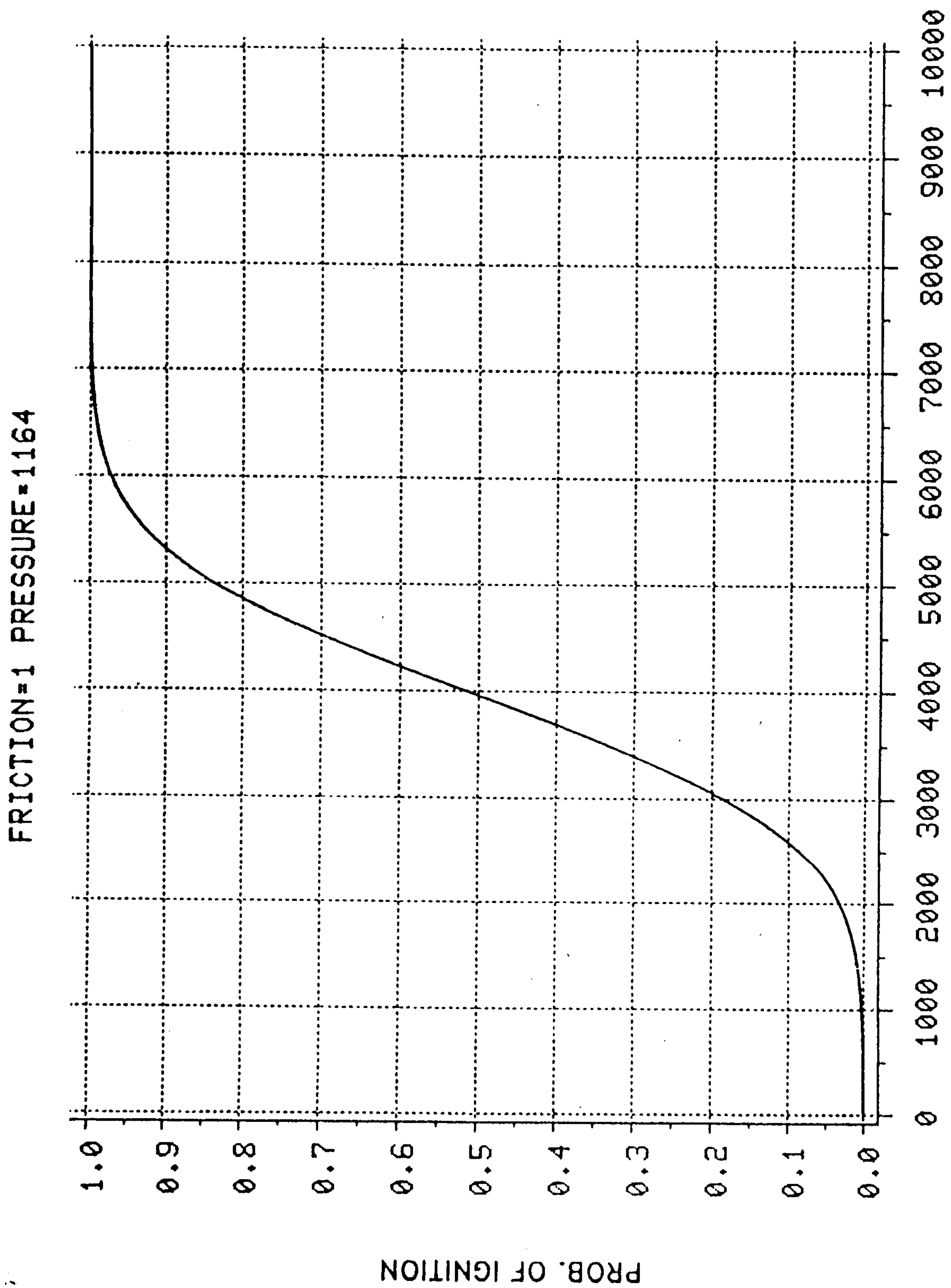

Figure 9.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 1.0 in/sec. Velocity

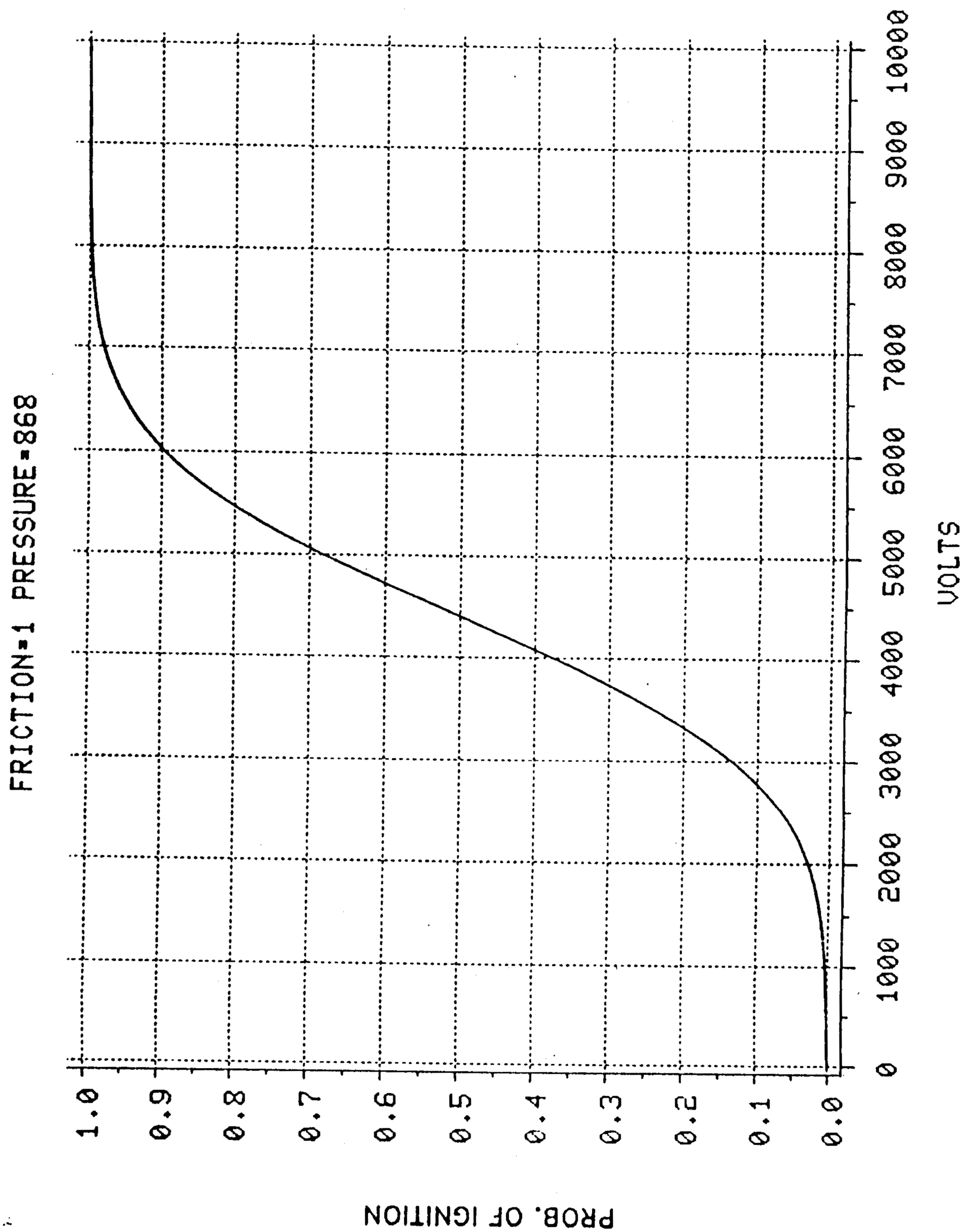

Figure 10.

TP-H1148 Propellant, Probability of Ignition, Combined Friction-ESD Stimuli, 1.0 in/sec. Velocity

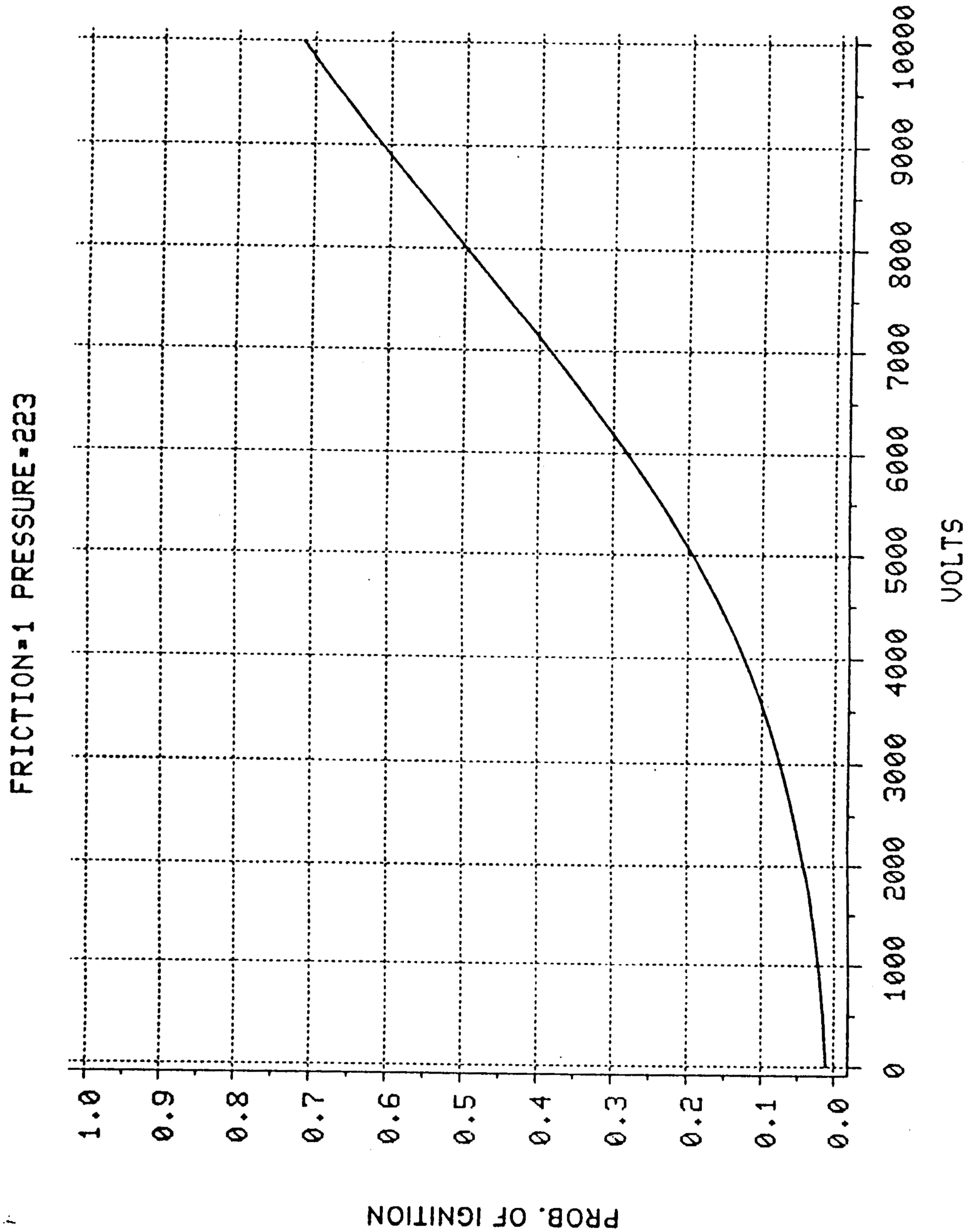

Figure 12.

TP-H1148 Propellant, Probability of Ignition,
Combined Friction-ESD Stimuli, 1.0 in/sec. Velocity,
No Resolution

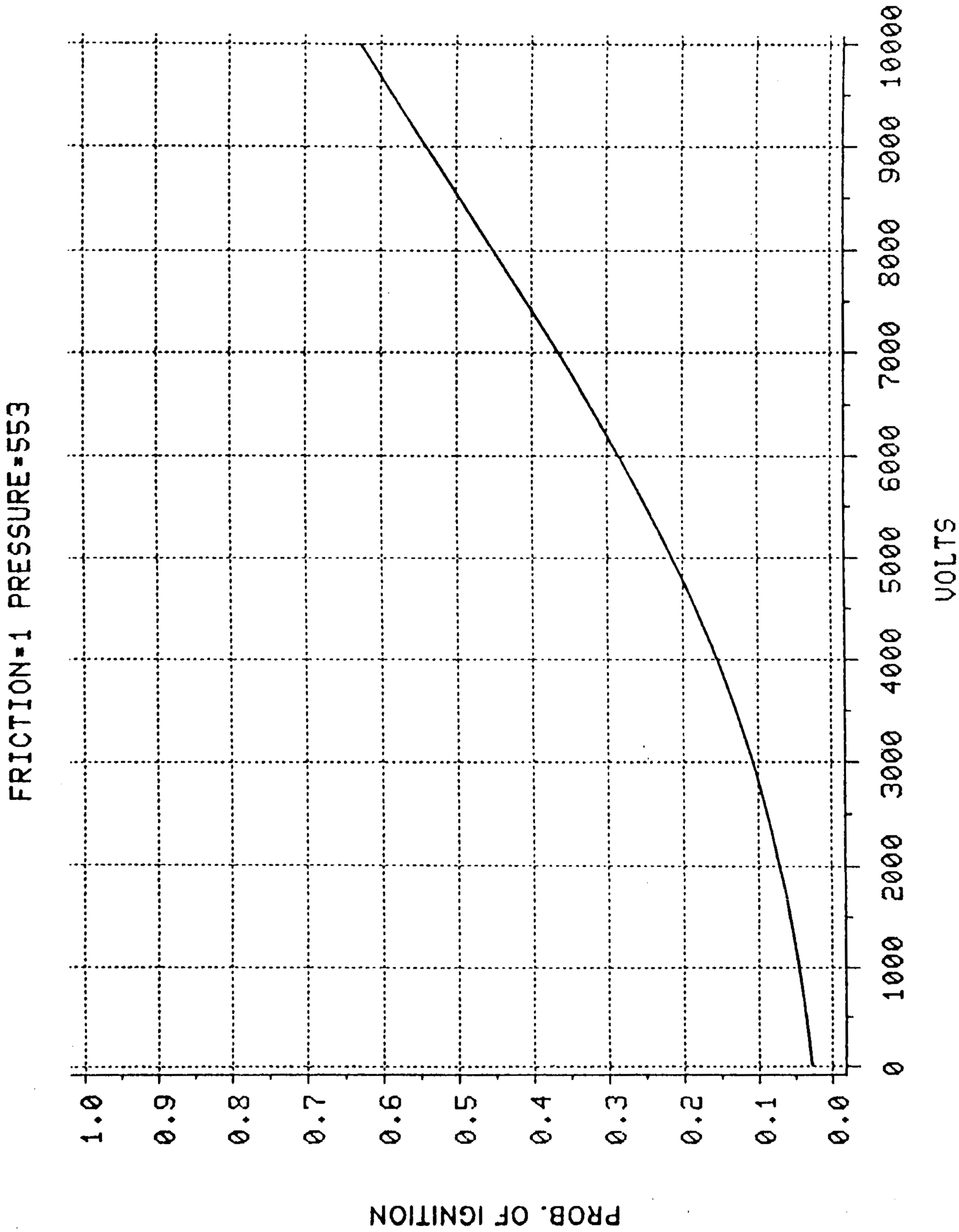

Figure 11.

TP-H1148 Propellant, Probability of Ignition,
Combined Friction-ESD Stimuli, 1.0 in/sec. Velocity,
No Resolution

Figure 13.

Combined Friction-ESD Stimuli Tests

TP-H1148 "V" GROOVE TESTS
Minimum Ignition Voltage vs Pressure
Linear Curve Fit

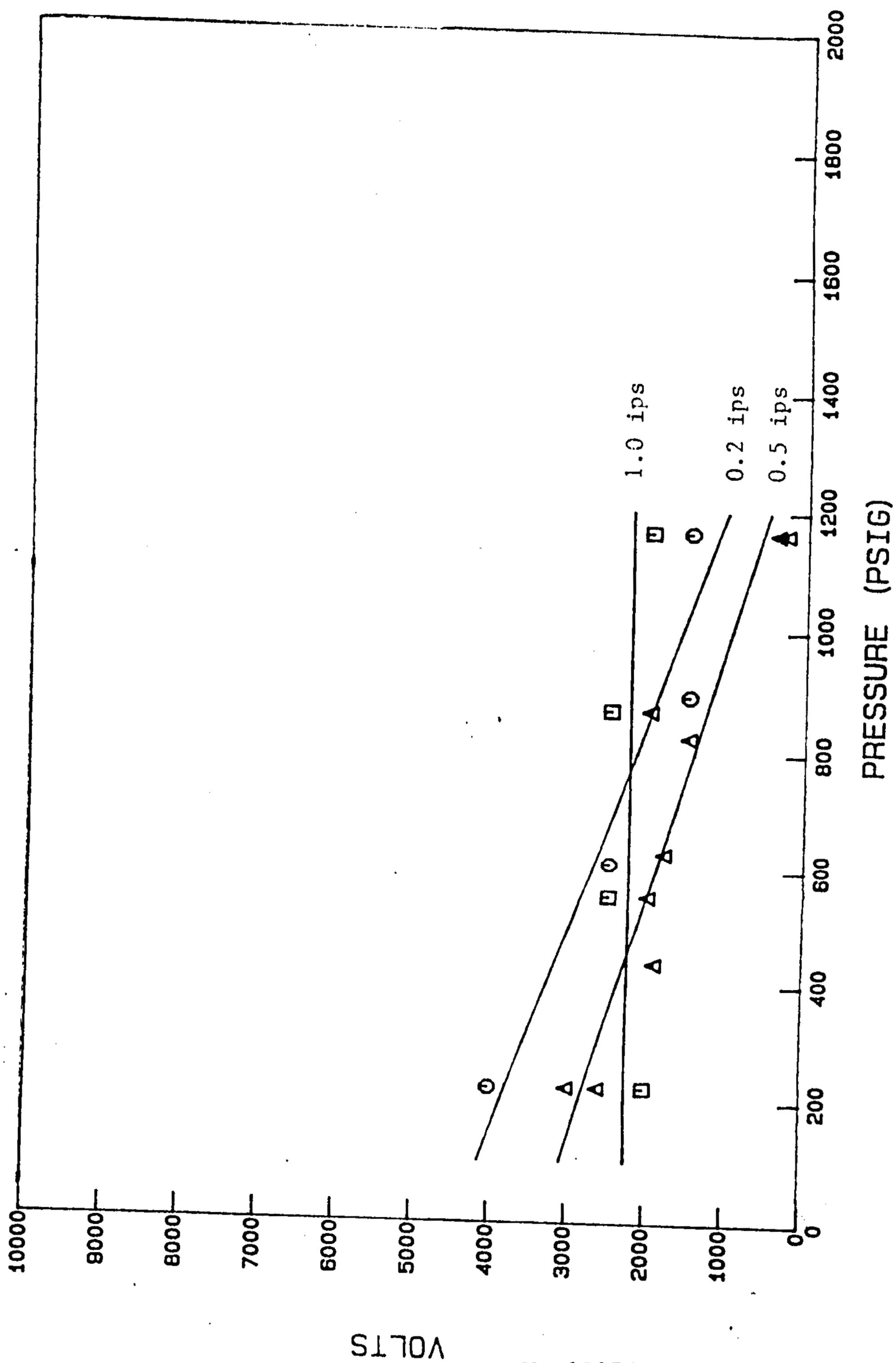

Figure 14.

Combined Friction-ESD Stimuli Tests

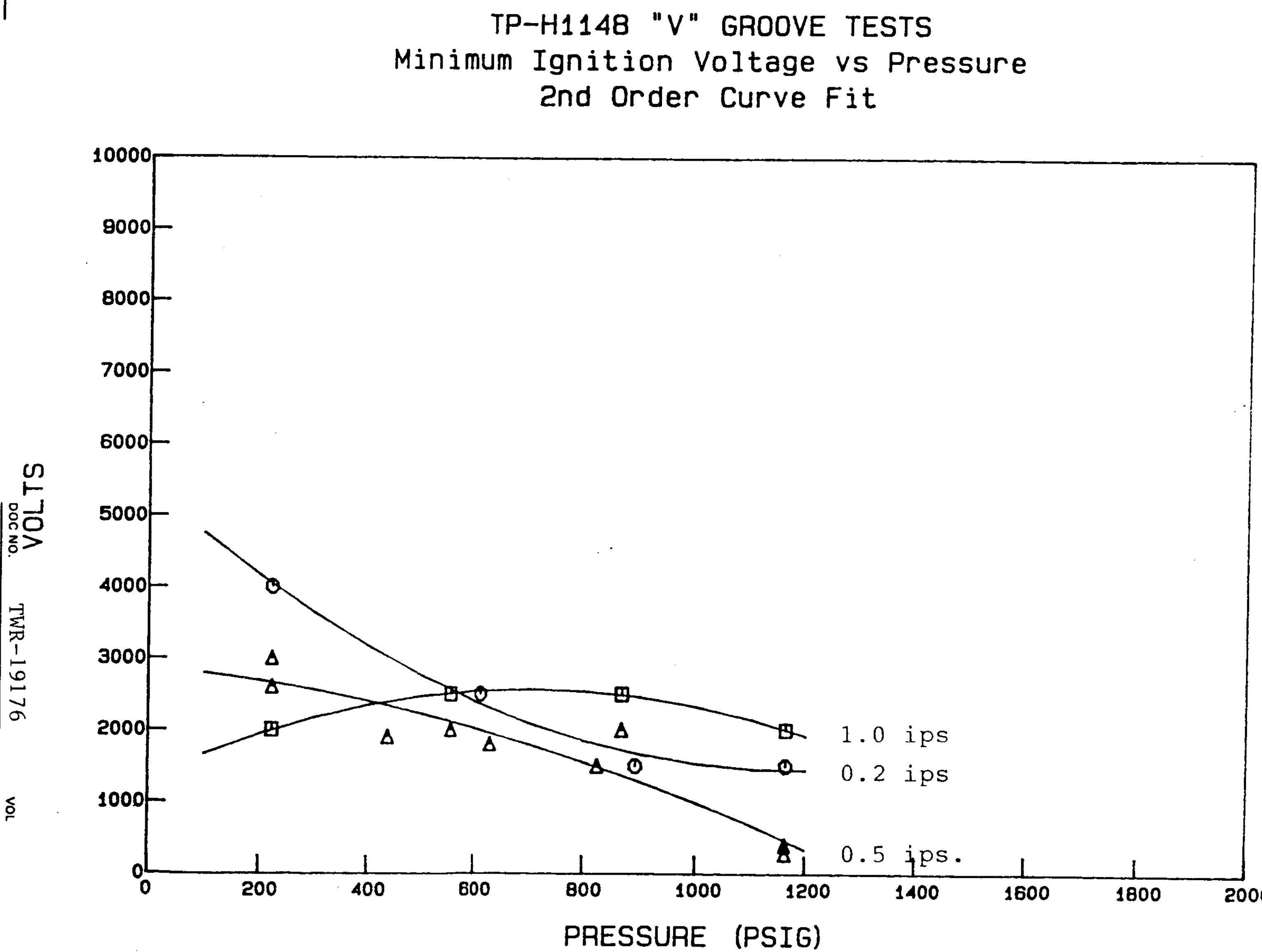

Figure 15.

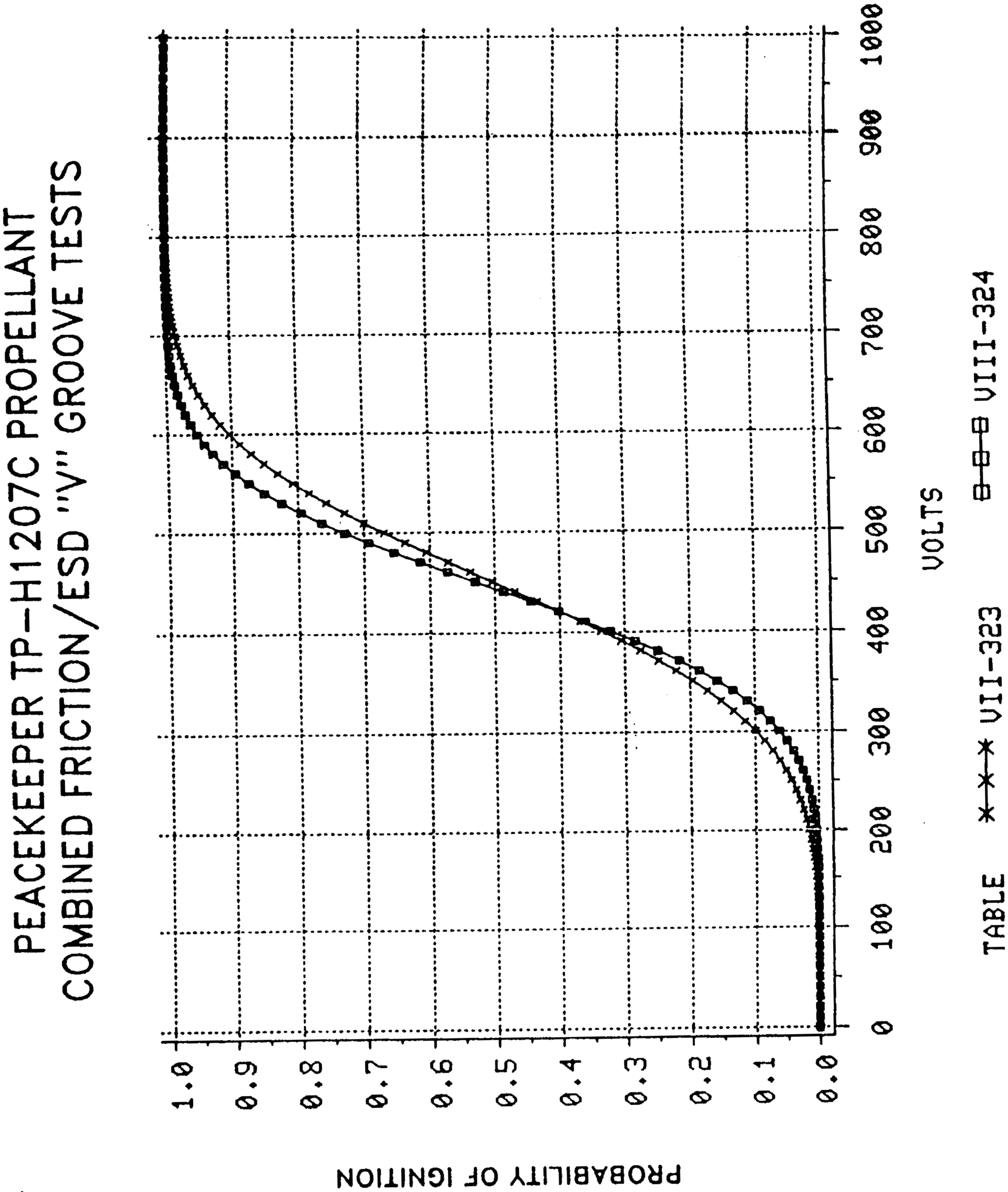
PEACEKEEPER TP–H1207C PROPELLANT
COMBINED FRICTION/ESD "V" GROOVE TESTS
PROBABILITY OF IGNITION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300
400
500
600
700
800
900
1000
VOLTS
TABLE
VII-323
VIII-324

Table I

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TP-H1148 Propellant, Data Tabulation Sheets, Combined Friction-ESD Stimuli, 0.2 in/sec. Velocity

ESD FRICTION TEST
T-16

Propellant Type	TP-H1148	Date	1 / MAR / 89
Hydraulic Pressure	565 psi	Sample Pressure	1164 psi
Friction Speed	0.2 in/sec	Temperature	AMB
V-Groove ✓	Flat Plate ____	Operators	Greg, Doug
Sample Thickness	0.03 inch	Capacitor	550 pf

Voltage	Reaction # of Go	Reaction # of No Go	Comments *
2500	卌	卌 卌 卌	B-||| D-||
2000	|||	卌 卌 卌 ||	B-|||
1500	||	卌 卌 卌 |||	B-||
1000		卌 卌 卌 卌	
3000	卌 卌 |||	卌 ||	B-卌 卌 || D-|

Hydraulic Pressure 100 psi Sample Pressure 223 psi

Voltage	# of Go	# of No Go	Comments
2500		卌 卌 卌 卌	B-
3000		卌 卌 卌 卌	
3500		卌 卌 卌 卌	
4000	||	卌 卌 卌 ||||	B-1 D-1
4500	卌	卌 卌 卌	B-1 D-* A-||||

Hydraulic Pressure ________ Sample Pressure ________

* B = Before Friction Movement
D = During Friction Movement
A = After Friction Movement

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FORM TC 7994-310

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Table II

TP-H1148 Propellant, Data Tabulation Sheets,
Combined Friction-ESD Stimuli, 0.2 in/sec. Velocity

ESD FRICTION TEST
T-16

Propellant Type TP-H1148 — Date 21 / FEB / 89

Hydraulic Pressure 435 PSI — Sample Pressure 893 psi

Friction Speed 0.2 in/sec — Temperature AMB

V-Groove ✓ Flat Plate ____ — Operators Greg Doug

Sample Thickness 0.03 inch — Capacitor 550 pf

Voltage	Reaction: # of Go	Reaction: # of No Go	Comments*	
2500	|||	卌 卌 卌 ||	B - II	D - I
2000	||||	卌 卌 卌 |	B - III	D - I
1500	||	卌 卌 卌 |||	B - I	D - I
1000		卌 卌 卌 卌		
3000	卌	卌 卌 卌	B - IIII	D - I

Hydraulic Pressure 290 PSI — Sample Pressure 612 psi

Voltage	Reaction: # of Go	Reaction: # of No Go	Comments*	
2500	||||	卌 卌 卌 ||	B - III	D - I
2000		卌 卌 卌 卌		
3000	||||	卌 卌 卌 |	B - III	D - I
3500	卌 卌	卌 卌	B - 卌 ||	D - III
4000	卌 卌 |||	卌 |||	B - III	D - II

Hydraulic Pressure ____ Sample Pressure ____

REVISION ____

* B = Before Friction Movement
D = During Friction Movement
A = After Friction Movement

FORM TC 7994-310

DOC NO. TWR-19176 VOL
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Table III

TP-H1148 Propellant , Data Tabulation Sheets,
Combined Friction-ESC Stimuli, 0.5 in/sec. Velocity

ESD FRICTION TEST
T-16

Propellant Type TP-H1148

Date 09 / FEB / 89

Hydraulic Pressure 420 psi

Sample Pressure 868 psi

Friction Speed .5 IN/SEC

Temperature AMB.

V-Groove ✓ Flat Plate ____

Operators Greg , Doug

Sample Thickness 0.03 inch

Capacitor 550 pf

Voltage	Reaction # of Go	Reaction # of No Go	Comments *
2500	卌 卌 ||	卌 |||	B-1 D- 卌 卌 |
2000	卌	卌 卌 卌	B-||| D-||
1500		卌 卌 卌 卌	
3000	卌 卌 ||	卌 |||	B-|| D- 卌 卌
3500	卌 卌 ||	卌 |||	B- 卌 |||| D-|||

Hydraulic Pressure 260 psi

Sample Pressure 553 psi

Voltage	Reaction # of Go	Reaction # of No Go	Comments *
2500	|||	卌 卌 卌 ||	B-1 D-||
2000	||||	卌 卌 卌 |	B-||||
1500		卌 卌 卌 卌	
3000	||	卌 卌 卌 |||	B-||
3500		卌 卌 卌 卌	

Hydraulic Pressure 100 psi

Sample Pressure 223 psi

Voltage	Reaction # of Go	Reaction # of No Go	Comments *
2500		卌 卌 卌 卌	
3000	|	卌 卌 卌 ||||	B D A-1
3500	|	卌 卌 卌 ||||	B D A-1
4000	||	卌 卌 卌 |||	A-4
4500	卌 |||	卌 卌 ||	A- 卌 |||

* B = Before Friction Movement
D = During Friction Movement
A = After Friction Movement

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Table IV

TP-H1148 Propellant, Data Tabulat[illegible] Sheets, Combined Friction-ESD Stimuli, 0.[illegible]ec. Velocity

ESD FRICTION TEST
T-16

Propellant Type TP-H1148 | Date 4 / 7 / 89

Hydraulic Pressure 565 Psi | Sample Pressure 1164 Psi

Friction Speed 0.5 in/sec | Temperature Amb

V-Groove ✓ Flat Plate ____ | Operators Bud & Greg

Sample Thickness 0.030 inch | Capacitor 550 Pf

Voltage	Reaction # of Go	# of No Go	Comments *
2000	III	~~IIII~~ ~~IIII~~ ~~IIII~~ II	B - III
1500	II	~~IIII~~ ~~IIII~~ ~~IIII~~ III	B II
1000		~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~	
2500	III	~~IIII~~ ~~IIII~~ ~~IIII~~ II	B III
3000	~~IIII~~ I	~~IIII~~ ~~IIII~~ IIII	B ~~IIII~~ I

Hydraulic Pressure ________ Sample Pressure ________

Hydraulic Pressure ________ Sample Pressure ________

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FORM TC 7994-310

* B = Before Friction Movement
D = During Friction Movement
A = After Fr[illegible]on Movement

Table V

TP-H1148 Propellant, Data Tabulation Sheets.
Combined Friction-ESD Stimuli, 1.0 in/sec. Velocity

ESD FRICTION TEST
T-16

Propellant Type TP-H1148 Date 9 / mar / 89

Hydraulic Pressure 565 psi Sample Pressure 1164 psi

Friction Speed 1.0 in/sec Temperature AMB.

V-Groove ✓ Flat Plate ____ Operators Greg, Doug

Sample Thickness 0.03 inch Capacitor 550 pf

Voltage	Reaction # of Go	Reaction # of No Go	Comments*
2000	ll	𝍸𝍸𝍸 lll	B-ll
1500		𝍸𝍸𝍸𝍸	
2500	l	𝍸𝍸𝍸 llll	B-l
3000	lll	𝍸𝍸𝍸 ll	B-lll
3500	𝍸 ll	𝍸𝍸 lll	B-𝍸 ll

Hydraulic Pressure ____ Sample Pressure ____

Hydraulic Pressure ____ Sample Pressure ____

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SEC TWR-19176 PAGE

FORM TC 894-110

* B = Before Friction Movement
D = During Friction Movement
A = After Friction Movement

Table VI

TP-H1158 Propellant, DATA Tabulation Sheets,
Combined Friction-ESD, Stimuli, 1.0 in/sec. Velocity

ESD FRICTION TEST
T-16

Propellant Type	TP-1148	Date	6 / MAR / 87
Hydraulic Pressure	100 psi	Sample Pressure	223 psi
Friction Speed	1.0 in/sec	Temperature	AMB
V-Groove	✓ Flat Plate ____	Operators	Greg, Doug
Sample Thickness	0.03 inch	Capacitor	550 pf

Voltage	Reaction: # of Go	Reaction: # of No Go	Comments *
3000	IIII	卌 卌 卌 I	B-II D- - A-I
2500	I	卌 卌 卌 IIII	A-1
2000	I	卌 卌 卌 IIII	B-1
1500		卌 卌 卌 卌	
3500		卌 卌 卌 卌	IIII

Hydraulic Pressure 260 psi Sample Pressure 553 psi

Voltage	# of Go	# of No Go	Comments *
2500	IIII	卌 卌 卌 I	B-IIII
2000		卌 卌 卌 卌	
3000	II	卌 卌 卌 III	B-1 D-1
3500	II	卌 卌 卌 III	B-II
4000	III	卌 卌 卌 II	B-III

Hydraulic Pressure 420 psi Sample Pressure 868 psi

Voltage	# of Go	# of No Go	Comments *
2500	III	卌 卌 卌 II	B-III
2000		卌 卌 卌 卌	
3000	III	卌 卌 卌 II	B-II D-1
3500	卌	卌 卌 卌	B-卌
4000	卌 II	卌 卌 III	B-卌 I

REVISION ____

* B = Before Friction Movement
D = During Friction Movement
A = After Friction Movement

TABLE VII

MORTON THIOKOL "V" GROOVE
COMBINED ESE/FRICTION TESTS
BARE STEEL FRICTION PLATES

Date: 08-17-88
Sample: PK-323 Motor Propellant, Baseline
Capacitor 550 pF
Friction Speed 0.5 in./second
Hydraulic Pressure 100 psi
Sample Pressure 1164 psi

Propellant Sample	Number of Tests	Volts	Microjoules	Results	Comments
0.03-in. Thick	1	512		N	
"	1	512	72	G	After Stroke
"	1	456	57.2	G	Before Movement
"	1	400		N	
Reused Propellant	1	400		N	
"	1	400	44	G	During Stroke
"	2	376		N	
"	1	376	38.9	G	During Stroke
"	7	350		N	
"	1	350	33.7	G	During Stroke
"	1	328	29.6	G	During Stroke
"	2	312		N	
"	1	312	26.8	G	During Stroke
"	10	304		N	
"	1	296		N	

TABLE VIII

MORTON THIOKOL "V" GROOVE
COMBINED ESE/FRICTION TESTS
BARE STEEL FRICTION PLATES

Date: 09-09-88
Sample: PK-324 Motor TP-H1207C Baseline
Carton Mix F380128
Capacitor 550 pF
Friction Speed 0.5 in./second
Hydraulic Pressure 100 psi
Sample Pressure 1164 psi

Propellant Sample	Number of Tests	Volts	Microjoules	Results	Comments
New Propellant	1	480		N	
	1	480	63.4	G	After Movement
	6	352		N	
	1	352	34.1	G	After Movement
	11	304		N	
Reused Propellant	1	408		N	
" "	1	408	45.8	G	
" "	3	352		N	
" "	1	352	34.1	G	Before Stroke
" "	5	304		N	
" "	1	304	25.4	G	During Stroke
" "	16	256		N	
" "	9	272		N	
" "	1	272	20.3	G	During Stroke
" "	12	264		N	

TABLE IX

MORTON THIOKOL "V" GROOVE
COMBINED ESE/FRICTION TESTS
BARE STEEL FRICTION PLATES

Date: 08-18-88 to 08-19-88
Sample: PK Motor 323, TP-H1207C
Core Insert No. 8, Ribbons
Capacitor 550 pF
Friction Speed 0.5 in./second
Hydraulic Pressure 100 psi
Sample Pressure 1164 psi

Propellant Sample	Number of Tests	Volts	Microjoules	Results	Comments
New Propellant, Thin Ribbons	1	352	34.1	G	During Stroke
"	1	304	25.4	G	Before Movement
"	4	256		N	
"	1	272		N	
"	1	272	20.3	G	During Stroke
"	5	264		N	
Reused, Thin Ribbons	6	272		N	
"	1	304	25.4	G	During Stroke
"	1	272		N	
Reused	1	272	20.3	G	Before Movement
"	4	256		N	
"	1	256		N	
"	7	232		N	
"	1	232	14.8	G	During Stroke
"	7	232		N	
"	1	222	13.5	G	After Movement
"	18	200		N	

APPENDIX A

MORTON THIOKOL. INC. L. E. Davis | 240C

Aerospace Group

Space Operations

29 March 1989
L222:FY89:802

TO: T.A. Berger
Manufacturing Engineering

FROM: L.M. Clark
Propellant and Adhesive Structures

SUBJECT: Contact Pressures across the Dovetail Region

INTRODUCTION

This memo provides predictions for contact pressures that occur across the dovetail region of the forward segment tooling. Contact pressures in this region were requested to assist in assessing the ESD hazards associated with the forward segment casting operation.

During the forward segment casting operation, propellant can intrude into the interface between the tip fin and the stub fin. Problems may occur because of the inverse relationship between pressure and the dielectric breakdown voltage of propellant. The dielectric breakdown of propellant has been shown to occur at lower voltages as the pressure on the propellant is increased.

SUMMARY

Structural analysis predicted average contact pressures of approximately 50 psi in the dovetails. Maximum pressures reached local values exceeding 500 psi. These maximum pressures cause concern for two reasons:

- The maximum contact pressures indicate that propellant in the dovetails would have a dangerously low dielectric breakdown voltage.
- The maximum contact pressures are nonconservative because geometric simplifications of the dovetail were required for the analysis.

FINITE ELEMENT ANALYSIS

Modelling. Finite element analysis was performed on a three-dimensional forward segment model using the ABAQUS finite element code. The model consisted of a 16.4° slice of the segment with an unpopped fin former incorporated into the model. (See Figure 1). The dovetail interface region of the fin former was not explicitly modelled, but simplified to assume full radial contact with the core. (See Figure 2). The fin former was assumed to fully adhere to the propellant throughout the core popping operation and was modelled as a uniformly bonded component.

Material Properties. Material properties used in the analysis for grain components are summarized in Tables 1 and 2. These properties have been excerpted from TWR-18011, Rev. A, Supplement B, "RSRM Structural Mechanical Properties Databook, Propellant, Liner, Insulation and Inhibitor".

Loads. Loads on the model included slump loads and thermal cooldown to 90 °F. An equivalent body force was used to assess effects due to the weight of the fin former. The body force used in the analysis assumed a fin former density based on fin volume and the actual weight of the fin former, 2100 lbf.

Boundary Conditions. The model was fixed axially at the aft end of the case. Theta fixes were applied along both symmetry boundaries at the zero degree location and the 16.36 degree location. A radially fixed sliding boundary condition was applied to the stub fin/tip fin interface region.

Results. Analytical results included the contact pressure distributions over the surface of dovetail and reaction forces at the boundary. Radial stresses on the surface range from -470 psi to 525 psi. The radially compressive stress (-470 psi) on the surface is interpreted as the maximum contact pressure across regions A and B of the dovetails. The radially tensile stress (525 psi) must be interpreted as the maximum contact pressure across region C of the dovetails. However, this area of the dovetail is much smaller than the area across which analytical stresses were obtained, and stresses could increase to several times the analytical stress prediction.

VERIFICATION OF THE ANALYSIS

The results of the finite element analysis were validated for order of magnitude accuracy with a simple hand calculation. Once the core is popped, lifting forces to remove it total 89000 lbf. Core weight (39180 lbf) accounts for just part of this lifting force. A conservative assumption is that the remainder of this force is required to overcome friction in the dovetails. Therefore approximately 50000 lbs is needed to overcome friction. The contact force normal to the dovetail is obtained by applying the following relationship:

$$F_f = \mu \times F_n$$

where: F_f = force to overcome friction
μ = 0.09 (coefficient of friction for a Teflon/Teflon interface)
F_n = normal force

The coefficient of friction for the Teflon/Teflon interface is taken from the CRC Handbook of Tables for Applied Engineering Science, Second Edition.

The calculated normal force is 555,555 lbf. When this normal force is distributed over the width of the dovetail and the length of the fin, the resulting average contact pressure is 136 psi. The results of this conservative hand calculation show contact pressures 2.6 times higher than the finite element results, indicating that the finite element predictions are in the appropriate range.

If there are any questions regarding this analysis, I can be reached at extension 6465.

L.M. Clark
L.M. Clark
Propellant and Adhesive Structures

Concurrence:

T.R. Hoffman, Supervisor
Propellant and Adhesive Structures

A.R. Thompson, Acting Manager
Applied Mechanics

cc: G.W. Dixon, R.A. Guthie, J.R. Kapp, D.A. Sebahar, J.H. Stoker, R.B. Thue, R.E. Wynn, L.E. Davis

Table 1. Propellant Material Properties.

TP-H1148 PROPELLANT			
Equivalent Modulus	E	130	psi
Poisson Ratio	ν	0.4999	---
Coefficient of Thermal Expansion	α	6.06x10-5	in/in °F

Table 2. NBR Material Properties

ORTHOTROPIC NBR INSULATION*				
Equivalent Modulus	E1 = 1230	E2 = 460	E3 = 440	psi
Shear Modulus	G12 = 274	G13 = 165	G23 = 155	psi
Poisson Ratio	ν12 = 0.4348 ν21 = 0.1626	ν13 = 0.5552 ν31 = 0.1986	ν23 = 0.8274 ν32 = 0.7914	---
Coefficient of Thermal Expansion	α1 = 1.33	α2 = 8.05	α3 = 21.05	(1.0 x 10-5 in/in °F)

* Material Directions for Orthotropic NBR Insulation
(1) Parallel to Fiber (2) Perpendicular to Fiber (3) Across the Ply

Figure 1. FINITE ELEMENT MODEL USED FOR ANALYSIS OF DOVETAIL CONTACT PRESSURE.

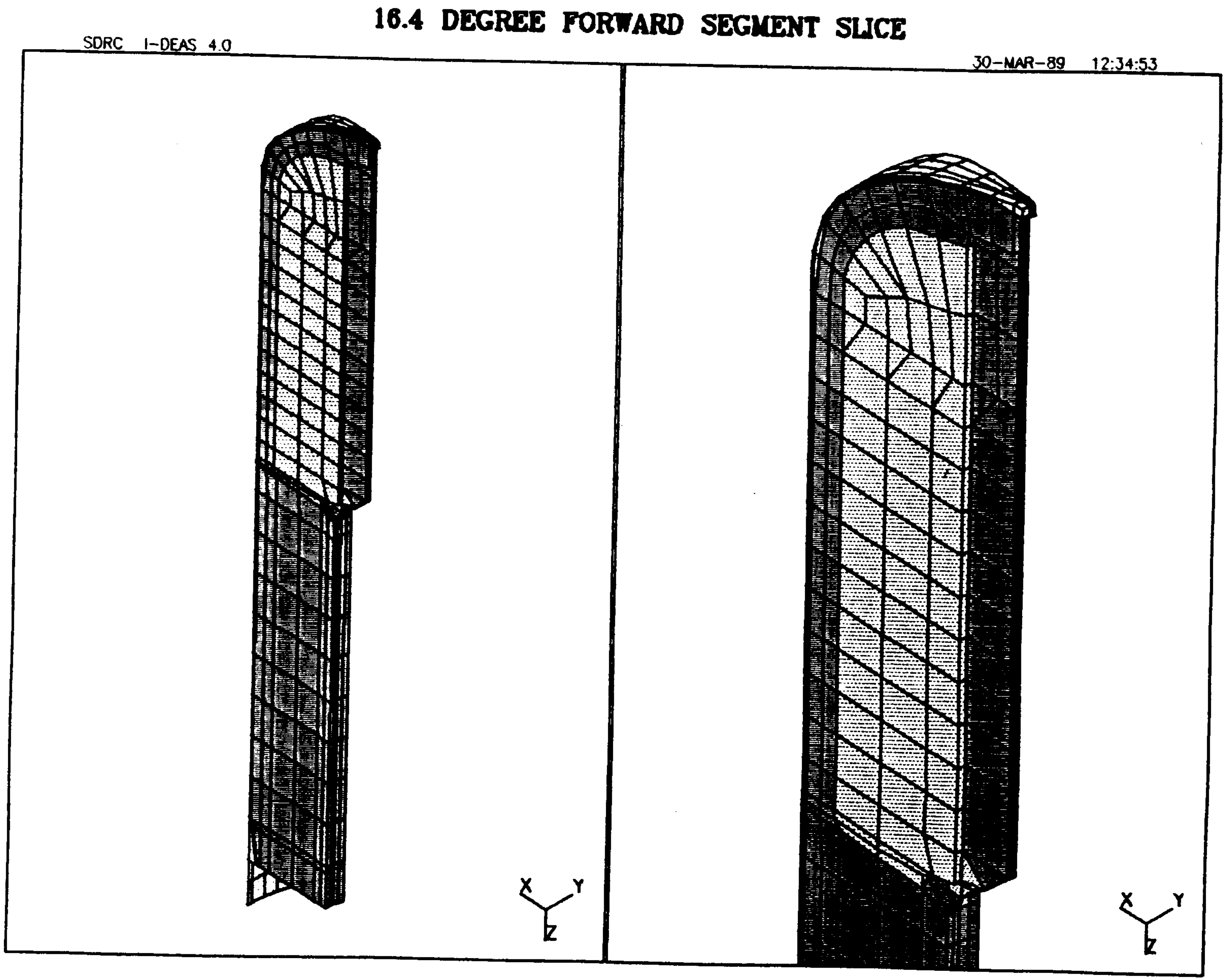

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Figure 2. BOUNDARY CONDITIONS USED FOR ANALYSIS OF DOVETAIL CONTACT PRESSURE.