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GENERAL MOTORS CORPORATION

GM DEFENSE RESEARCH LABORATORIES

AEROSPACE OPERATIONS DEPARTMENT

EXPERIMENTAL INVESTIGATIONS OF SIMULATED METEOROID DAMAGE TO VARIOUS SPACECRAFT STRUCTURES

PROGRESS REPORT NO. 4

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Scope of Program

The physics of interaction of a meteoroid with a relatively thin metallic shield and the damaging effects of the debris that passes through the shield will be investigated using analytical and experimental techniques. The influence of particle and target density, porosity, and heats of fusion and vaporization will be included in the investigation; and the relative efficiency of various structural concepts compared. The range of impact velocities to be investigated experimentally will be up to 8.0 km/sec. The primary objective of the investigation is the establishment of design criteria and equations to define the penetration mechanics of meteoroids into typical spacecraft structures.

Progress During Reporting Period

A series of calculations employing the computer program describing the response of a circular plate have been performed over the same range of particle sizes and velocities as the "strip approximation." Figures 1 and 2 present a comparison of the results obtained for the 1/8" aluminum particle and the Apollo particle with the strip and plate approximations. In both figures the curves have not been extended below 6 kilometers per second as this is felt to be the lower limit of applicability of these analyses. Also included in Figure 1 are the results of calculations made using the distribution reported in Progress Report No. 3. The distribution has had only a slight effect on the thicknesses predicted, lowering them slightly.

Preliminary studies of the spall phenomenon associated with thin target impact employing the use of a one-dimensional model of the shock wave in the second sheet has given encouraging agreement. The model employs the same S/2 distribution as initially used in the strip approximation. The debris striking the backup is assumed to be uniformly distributed over this area, to be molten and have a thickness such that the striking plate shall have the same mass as the impacting projectile. A one-dimensional elastic-plastic computer program is then employed to calculate the shock strength and profile. Figure 3 shows the results of such a calculation. This predicts a spall fracture for a plate of 9.52 mm thickness and an experiment with a backup of this thickness does evidence spall (D-1338). The spall predicted in this case is a fracture approximately 0.5 mm beneath the rear surface of the backup. This fracture can be observed only by sectioning the backup and etching the surface. This fracture occurs at a pressure of about 13 kilobars. The pressure required to completely detach a portion of the rear surface of the backup would appear to be about 100 kilobars.

Experimental Results

Further experiments to determine the distribution of momentum delivered to the backup structure have been performed using cadmium projectiles and shields at a velocity of 5.6 km/sec. These results are summarized below.

Radius from center of impact cm	Momentum measured Kg meters/sec	Area Meters^2	Momentum / Area Kg/meter sec
0 to 0.953	0.343	2.86×10^{-4}	1200
0.953 to 1.27	0.147	2.21×10^{-4}	665
1.25 to 2.54	0.474	15.0×10^{-4}	316
2.54 to 5.08	0.184	60.8×10^{-4}	30.2
0 to 5.08	1.148*	80.9×10^{-4}	142

*Average of three shots

Figure 4 shows a comparison of the cadmium-cadmium distribution with the previously reported aluminum-aluminum distribution. The distribution of the cadmium-cadmium is less peaked than the aluminum-aluminum distribution. The aluminum debris was in a molten form while the cadmium debris was vaporized and this may account for the flatter cadmium distribution. (It should be noted that the cadmium projectiles have a mass of 0.145 grams while the aluminum projectiles have a mass of 0.047 grams. Thus the measured momentum and momentum densities for the cadmium-cadmium impacts will be greater than the aluminum-aluminum impacts. The portion of the momentum near the center is less for the cadmium.)

A series of experiments were undertaken to determine the effects of using greater than optimum shield thicknesses. The first series was performed using 1100-0 aluminum shields of t_s/d = 1, 2, 3 and 4.

The backup thicknesses were 6.35 mm and then 1.6 mm. The same thickness shield of 7075-T6 aluminum were then impacted with backups of 1.6 mm. These results are shown in Figure 5. The zero shield thickness is the thickness of a backup required to just prevent spall detachment. The total thickness required then drops to the optimum shield thickness and increases from there to a shield that just prevents spall detachment. By connecting these three points (A, B and C) with straight lines a safe total thickness is estimated. Any thickness combination below the line will perforate or spall, any above will be safe.

Proposed Program for Next Reporting Period

During the next reporting period the one-dimensional elastic-plastic calculations will be further investigated to determine their accuracy in predicting spall in thin sheet impacts.

Experiments will be undertaken to examine the effects of projectile porosity, spacing effects and the use of multiple backup sheets.

COMPARISON OF STRIP AND PLATE CALCULATIONS -3.2mm ALUMINUM SPHERE

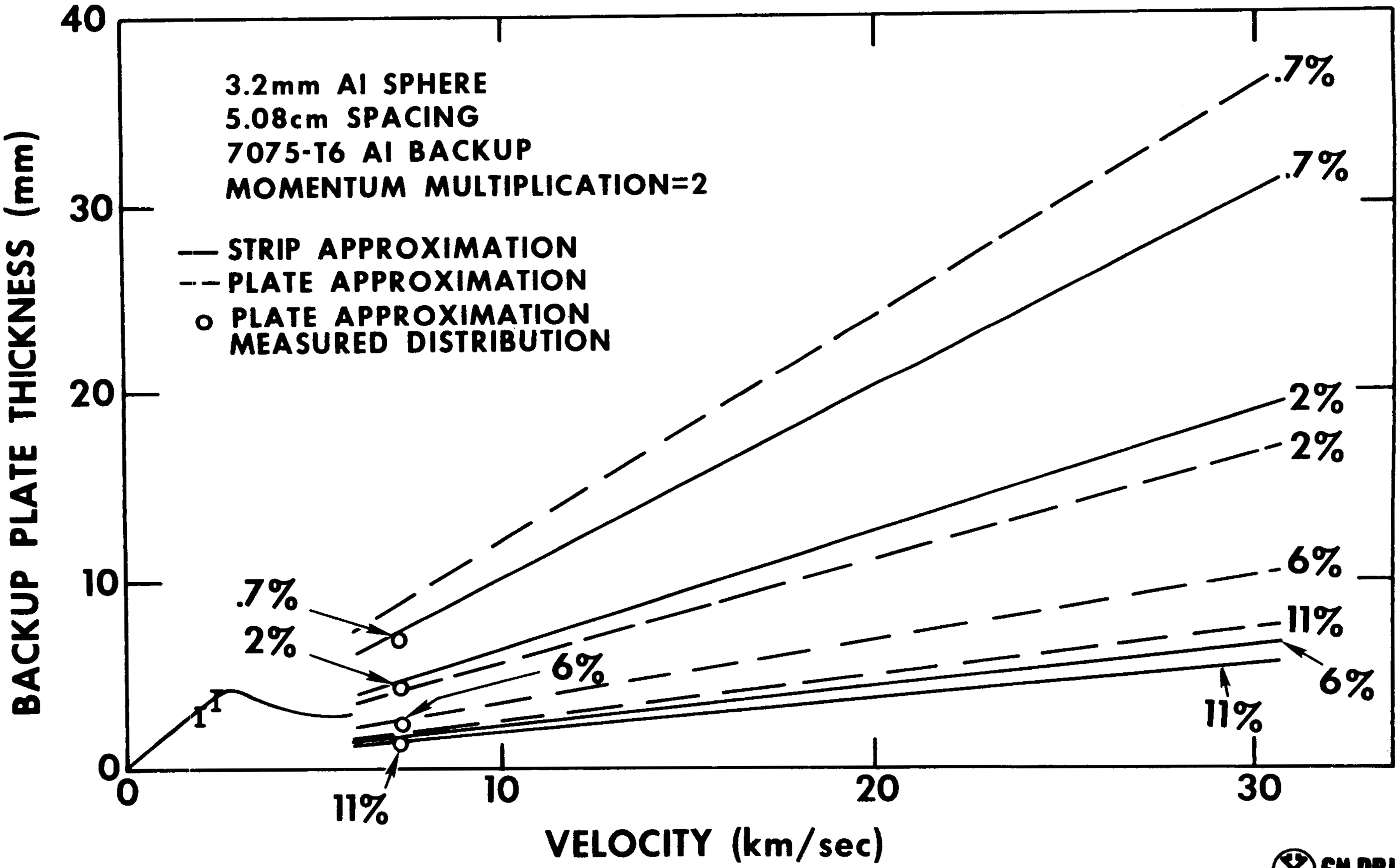


FIGURE 1

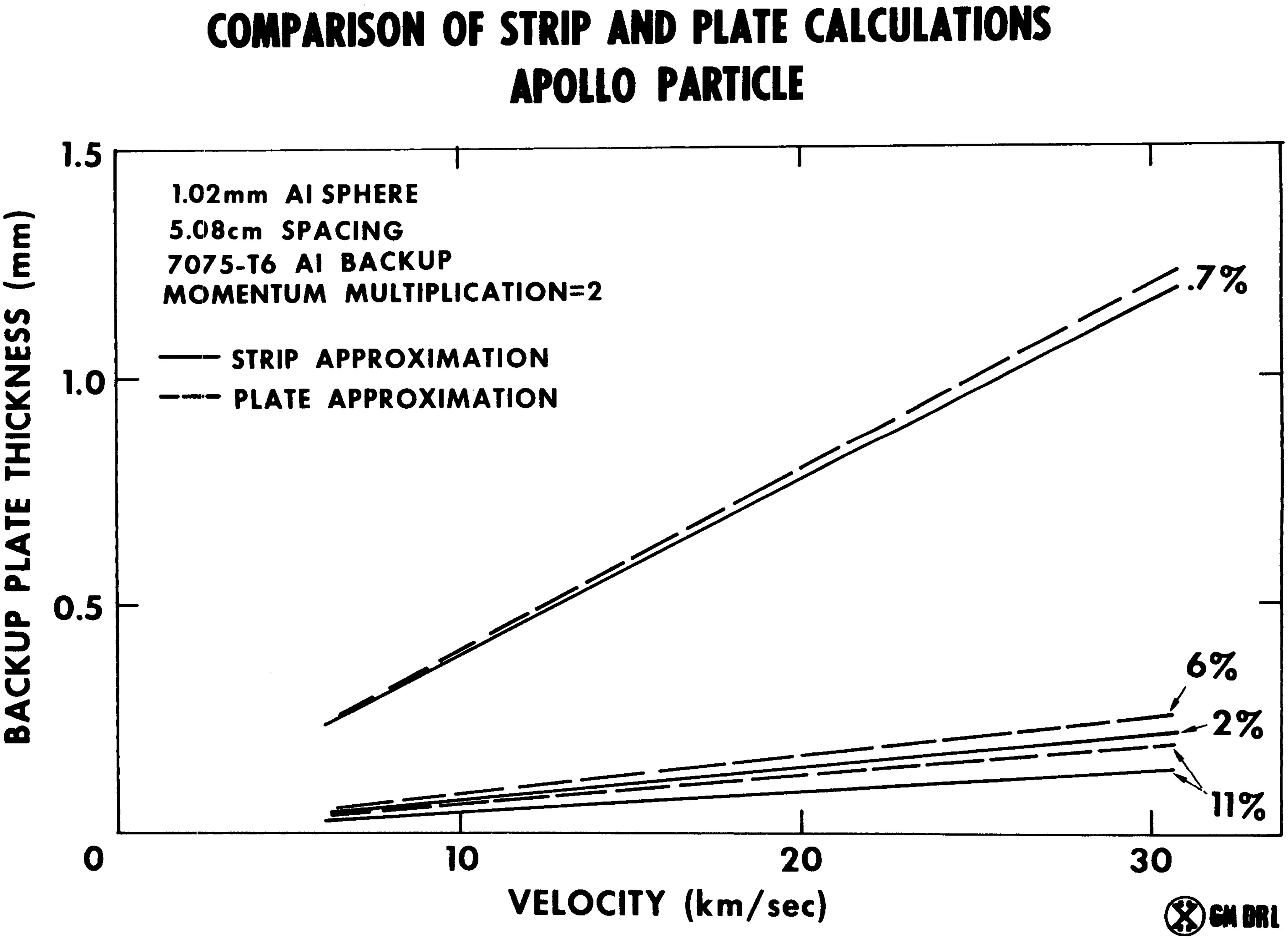
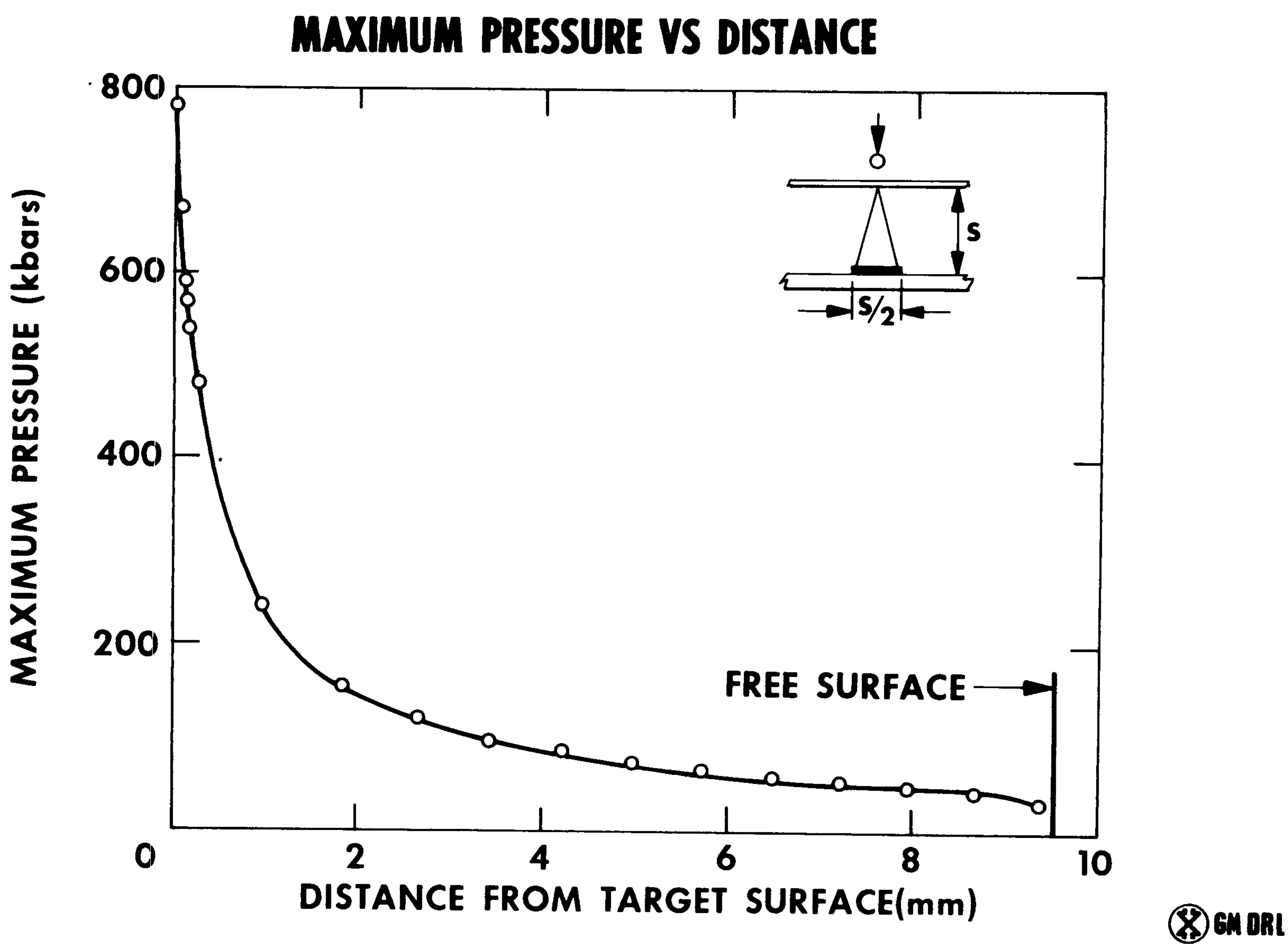

COMPARISON OF STRIP AND PLATE CALCULATIONS
APOLLO PARTICLE
1.02mm Al SPHERE
5.08cm SPACING
7075-T6 Al BACKUP
MOMENTUM MULTIPLICATION=2
STRIP APPROXIMATION
PLATE APPROXIMATION
BACKUP PLATE THICKNESS (mm)
1.5
1.0
0.5
0
10
20
30
VELOCITY (km/sec)
.7%
6%
2%
11%
GM DRL

FIGURE 2



MAXIMUM PRESSURE VS DISTANCE
800
600
400
200
0
2
4
6
8
10
MAXIMUM PRESSURE (kbars)
DISTANCE FROM TARGET SURFACE(mm)
FREE SURFACE
S
S/2
GM DRL

FIGURE 3

MOMENTUM DISTRIBUTION

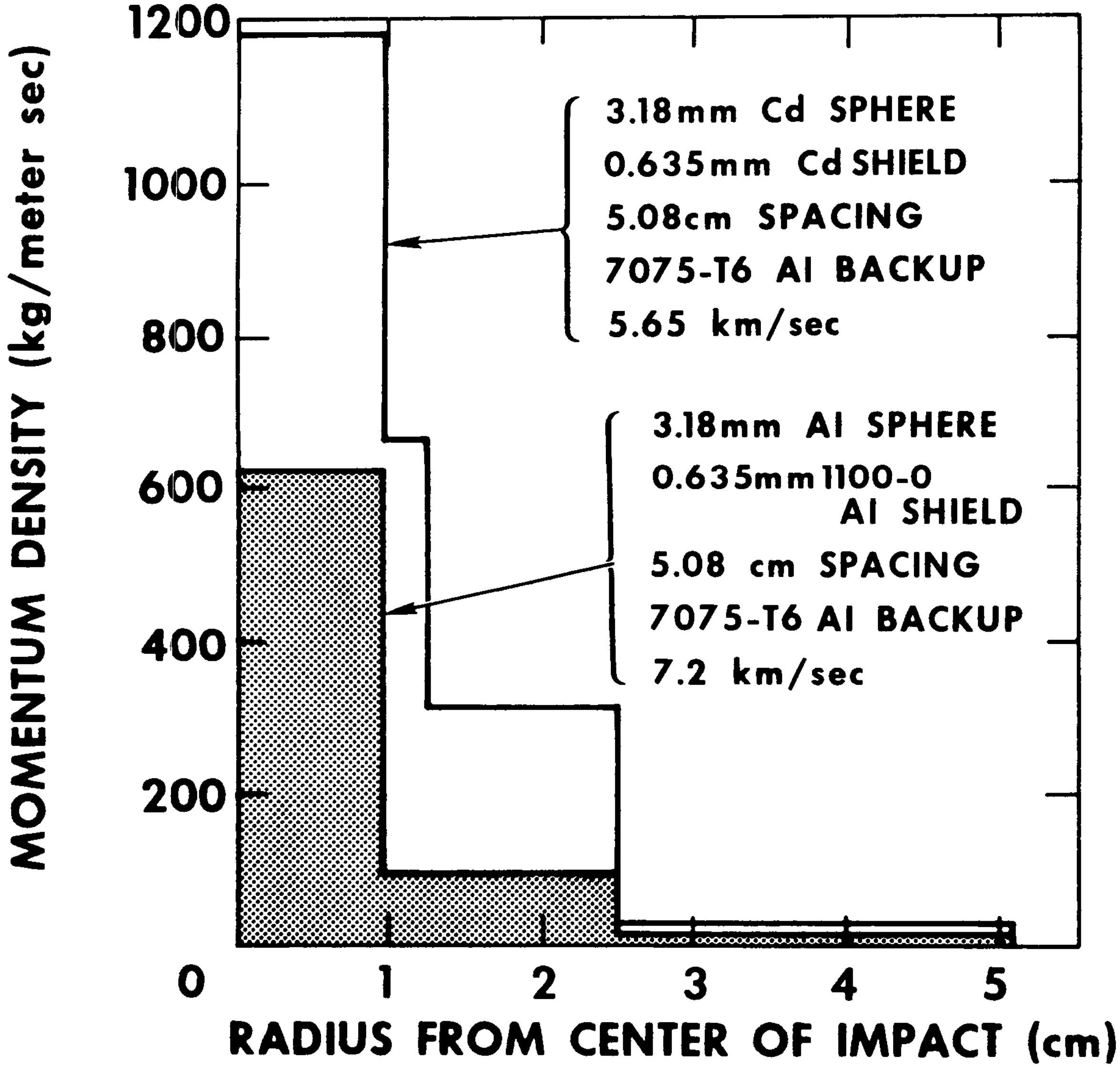


FIGURE 4

GM DRL

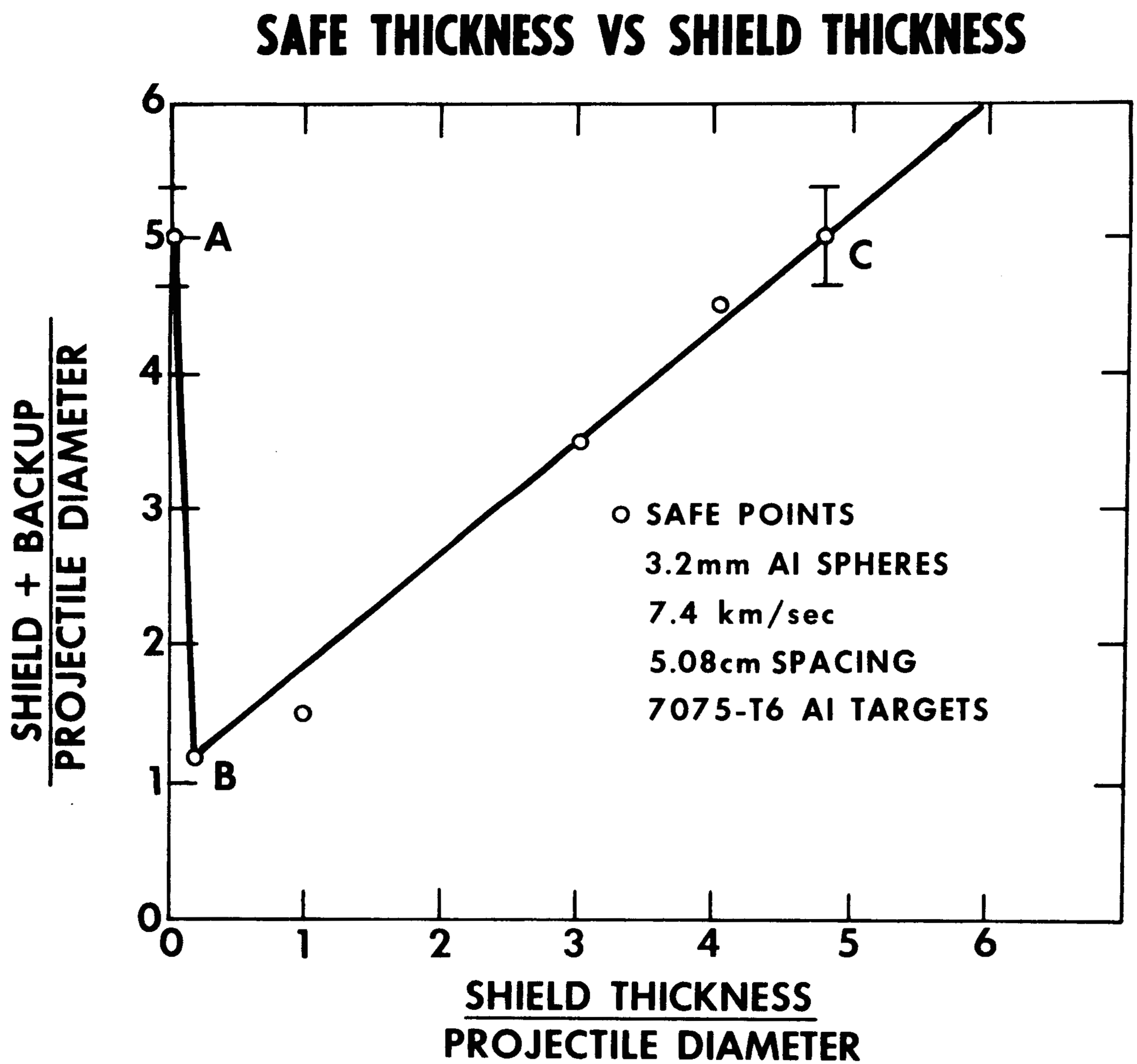

SAFE THICKNESS VS SHIELD THICKNESS
SHIELD + BACKUP / PROJECTILE DIAMETER
SHIELD THICKNESS / PROJECTILE DIAMETER
0
1
2
3
4
5
6
A
B
C
o SAFE POINTS
3.2mm Al SPHERES
7.4 km/sec
5.08cm SPACING
7075-T6 Al TARGETS

FIGURE 5

SHOT NO.	PROJECTILE MATERIAL	DIAMETER (mm)	SHIELD MATERIAL	THICKNESS (mm)	SPACING (cm)	BACKUP MATERIAL	THICKNESS (mm)	VELOCITY (km/sec)	TOTAL PENETRATION (mm)	HOLE SIZE (mm)	SPRAY DIAMETER (mm)	SPRAY ANGLE	MV/mv	REMARKS
D-1307	Al	1.59	1100-0 Al	0.81	5.08	7075-T6 Al	0.40	—	—	—	—	—		NO LAUNCH
1308								—	—	—	—	—		NO LAUNCH
1314		3.18		9.52			6.35	7.59	9.52	14.5	—	—	1.27	
1315				3.18				—	—	—	—	—		NO LAUNCH
1316				12.7				6.88	11.0	16.1	—	—		
1317				3.18				7.47	1.27	14.3	—	—		PISTON HIT
1318	Inlyte	6.35		1.02			12.7	7.26	3.02	11.2	140	108		PISTON HIT
1319	Al	3.18		9.52			1.59	7.38	9.52	14.4	—	—		
1320				3.18				7.41	+	14.5	63	64		PISTON HIT
1321				6.35			6.35	7.50	6.40	15.9	76	74		PISTON HIT
1323							1.59	7.47	+	15.8	76	74		PISTON HIT
1324	Cd		Cd	0.635			12.7	5.38	0.635	7.35	76	74	1.41	
1325								5.70	0.630	7.37	76	74		
1326								5.70	0.762	7.67	76	74		PISTON HIT
1327								5.76	0.630		76	74	1.38	
1328	Al		7076-T6 Al	3.18			1.59	7.50	+	11.7	76	74		PISTON HIT
1329				6.35				7.38	+	10.5	—	—		
1330				12.7				7.44	7.02	11.7	—	—		
1331				9.52				7.50	9.52	7.37	—	—		
1332				12.7				7.47	6.83	11.2	—	—		
1333			1100-0 Al	0.635	1.27		12.7	7.47	2.72	6.78	32	102		
1334					2.54			7.47	1.35		54	90		PISTON HIT
1335								7.32	1.55	6.78	76	74		PISTON HIT
1336					1.27			7.29	2.74	6.76	20	83		
1337	50% FOAM Ni	2.62		1.02	5.08		6.35	3.48	3.18	4.93	63	64		
1338	Al	3.18		0.635			9.52	7.53	1.19	6.48	102	90		
1344	50% FOAM Cu	2.62		1.02			12.7	3.29	0.238	4.59	51	53	1.46	

+ BACKUP BENT

SHOT NO.	PROJECTILE MATERIAL	DIAMETER (mm)	SHIELD MATERIAL	THICKNESS (mm)	SPACING (cm)	BACKUP MATERIAL	THICKNESS (mm)	VELOCITY (km/sec)	TOTAL PENETRATION (mm)	HOLE SIZE (mm)	SPRAY DIAMETER (mm)	SPRAY ANGLE	MV/mv	REMARKS
D-1345	50% FOAM Cu	2.62	1100-0 Al	1.02	5.08	7075-T6 Al	12.7	5.15	2.34	5.82	76	74°	1.26	
1346	50% FOAM Ni							5.03	2.49	5.94	76	74	1.35	
1347								6.70	2.18	—	—	—		PISTON HIT
1348	Cu	2.08						7.10	2.01	6.58	—	—		PISTON HIT