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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. 1

FOR PERIOD ENDING 30 SEPTEMBER 1964

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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

Earlier studies[1] and subsequent data gathered in the present study have shown that impacts against shielded targets at very high velocities result in very slight penetrations in the second or backup sheet. At these high velocities the debris that passes through the shield will be predominately in the form of vapor; and although this vapor will not penetrate to any significant extent into the backup, it will impose a large load to the backup. The response of the backup structure has been calculated using the general numerical procedure developed by Witmer, et al,[2] for determining the response of structures to blast and impulsive loading.

The backup sheet is represented by a beam or "strip approximation" as shown in Figure 1. The centerline displacement and strain at the center and edge of the loaded portion of the strip were determined for various backup thicknesses, projectile diameters and impact velocities. For these calculations, the momentum felt by the backup was assumed to be equal to twice that of the impacting projectile and to be spread over a diameter equal to one-half the spacing between the shield and the backup. Figures 2 and 3 are typical of the response curves obtained. Figure 2 also includes the centerline displacement obtained experimentally from a Beckman-Whitley framing camera sequence of shot number D-880. The results of calculations are seen to agree quite well with the experimental results.

The backup thickness required versus velocity of the incoming projectile with percent of strain undergone by the backup sheet as a parameter has been calculated and are shown in Figures 4, 5 and 6. The effect of spacing has been considered and is shown in Figure 7.

The experiments that have been conducted to date are summarized on the attached data sheets. These experiments have been of an exploratory nature designed primarily to check the assumptions that have been used in the numerical calculations of the response of the backup sheet. The measurement of the momentum felt by the backup sheet has been measured in many experiments and is expressed as the ratio of that momentum to the momentum of the impacting projectile. Figure 8 shows the results of experiments with aluminum projectiles impacting against aluminum shields. For the thin shields, it can be seen that the momentum multiplication is not too sensitive to velocity above 4.5 kilometers per second. Figure 9 presents this same data as momentum multiplication as a function of shield thickness for two velocities. It is to be noted that the position of the minima has not been shifted to any large extent by the change in velocity. Experiments with 1.60 mm aluminum projectiles fired at 7.8 kilometers per second to duplicate the momentum loading due to a 1.02 mm aluminum projectile impacting at 30.4 kilometers per second have been performed, and the results agree well with the predictions made using the "strip approximation" calculations. Other isolated experiments have indicated that spacing between the shield and backup does not alter the total momentum felt by the backup, that pyrex projectiles do not significantly alter the momentum load, and that a cadmium projectile impacting a cadmium shield producing predominately liquid debris does not significantly alter the momentum multiplication.

Proposed Program for Next Reporting Period

The extension of the previously described numerical procedure to determine the response of a plate to impulsive loading is in progress, and the procedure will be applied to the impact problem when complete. This will provide a more accurate description of the physical situation and check the accuracy of the strip approximation. Investigation of pretensioning of the backup is also being undertaken.

Experiments will be carried out to further determine the momentum multiplication as a function of velocity, shield thickness and material, and projectile properties. Experiments will also be undertaken to investigate the effects of projectile density.

References:

1. C. J. Maiden and A. R. McMillan, "An Investigation of the Protection Afforded a Spacecraft by a Thin Shield," AIAA Preprint No. 64-95 (to be published in the AIAA Journal).

2. E. A. Witmer, H. A. Balmer, J. W. Leech, and T. H. H. Pian, "Large Dynamic Deformations of Beams, Circular Rings, Circular Plates, and Shells," AIAA Preprint No. 2886-63.

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-878	2017 AL	3.18	1100-0 AL	0.534	5.08	7075-T6 AL	3.18	7.68	0.96	6.1	102	90		
879							1.60	7.81	HOLE	—	94	86		PISTON HIT
880							0.813	8.08	HOLE	6.1	89	82.5		
901				0.635			12.7	—	—	—	—	—		NO IMPACT
902								7.46	.69	6.6	94	86		
903								7.29	.92	6.6	97	87.5		
904								7.60	.89	6.6	94	86	1.27	
905				1.02				7.80	1.17	9.2	89	82.5		
909								7.50	1.17	8.6	89	82.5	1.34	
910								2.78	1.11	6.1	51	53.5	1.08	
911								5.43	1.48	7.2	84	79		
912							6.35	4.76	1.76	7.4	79	76	1.31	
913				0.635				4.72	1.96	5.8	81	77	1.25	
914				0.305				4.82	2.49	4.6	86	80.5	1.32	
915				1.60				4.72	1.91	8.6	94	86	1.42	
916				0.305				2.91	3.05	4.1	56	58		
917				1.60				2.85	2.06	6.9	41	44	1.07	
918				0.635				3.78	——	5.8	76	74		SHEAR DISK HIT
919								6.28	1.32	6.1	97	87.5		
920				0.305				6.89	1.58	4.8	102	90		
921				1.60				5.18	1.83	9.2	74	72		
947				0.305				2.91	3.03	4.1	51	53.5		
948								7.56	.69	—	97	87.5		
949				1.60				—	——	—	—	—		NO IMPACT
950				0.635				3.99	3.31	6.1	89	82.5		
951								6.40	1.35	—	97	87.5		PISTON HIT
952				0.305				3.14	——	—	76	74		SHEAR DISK HIT

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-972	2017 AL	1.60	1100-0 AL	0.305	5.08	7075-T6 AL	0.813	7.89	0.33	3.3	99	88.5		
973							0.407	7.78	.79	3.6	97	87.5		BACKUP BENT
974							1.60	7.78	.31	—	102	90		PISTON HIT
975							0.407	7.87	.36	3.6	89	82.5		
976		3.18		0.635			6.35	4.57	2.28	6.4	84	79		
977								6.61	1.12	7.1	102	90	1.29	
978				0.305				7.56	.71	—	97	87.5		PISTON HIT
979				1.60				7.56	2.03	10.9	89	82.5	1.49	
980				0.305				7.65	.84	5.3	97	87.5	1.31	
992								3.00	3.15	4.3	84	79	1.22	
993				0.635				3.87	2.24	5.8	74	72	1.29	
994	PYREX							3.63	1.14	5.8	89	82.5		
995								6.58	1.02	6.4	97	87.5	1.36	
996	2017 AL			1.02	1.27			6.46	2.26	8.4	25	27.5	1.30	
997				0.635	5.08			3.76	1.81	5.6	76	74		
998	Cd		Cd	0.330			12.7	2.94	—	4.6	99	88.5		SHEAR DISK HIT
999								5.34	.56	5.6	99	88.5		
1000								—	—	—	—	—		NO IMPACT
1012	1100-0 AL	4.12x4.14 CYLINDER	1100-0 AL	0.635				4.97	2.85	7.6	109	90.5		
1013								7.22	3.38	8.1	109	90.5	1.51	
1014								5.47	2.09	7.9	109	90.5		
1018	Cd	3.18	Cd	0.330				—	—	—	—	—		NO IMPACT
1019								5.61	.46	5.3	89	82.5	1.34	
1020								—	—	—	—	—		NO IMPACT
1021								—	—	—	—	—		NO IMPACT
1022								—	—	—	—	—		NO IMPACT

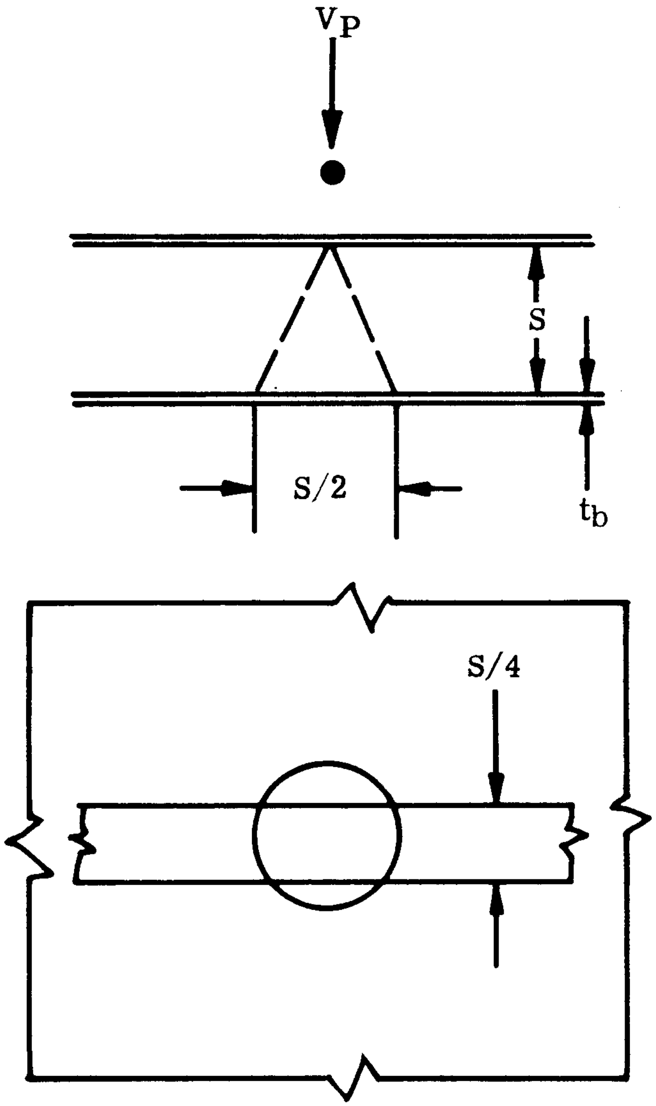

Figure 1 - Strip Approximation

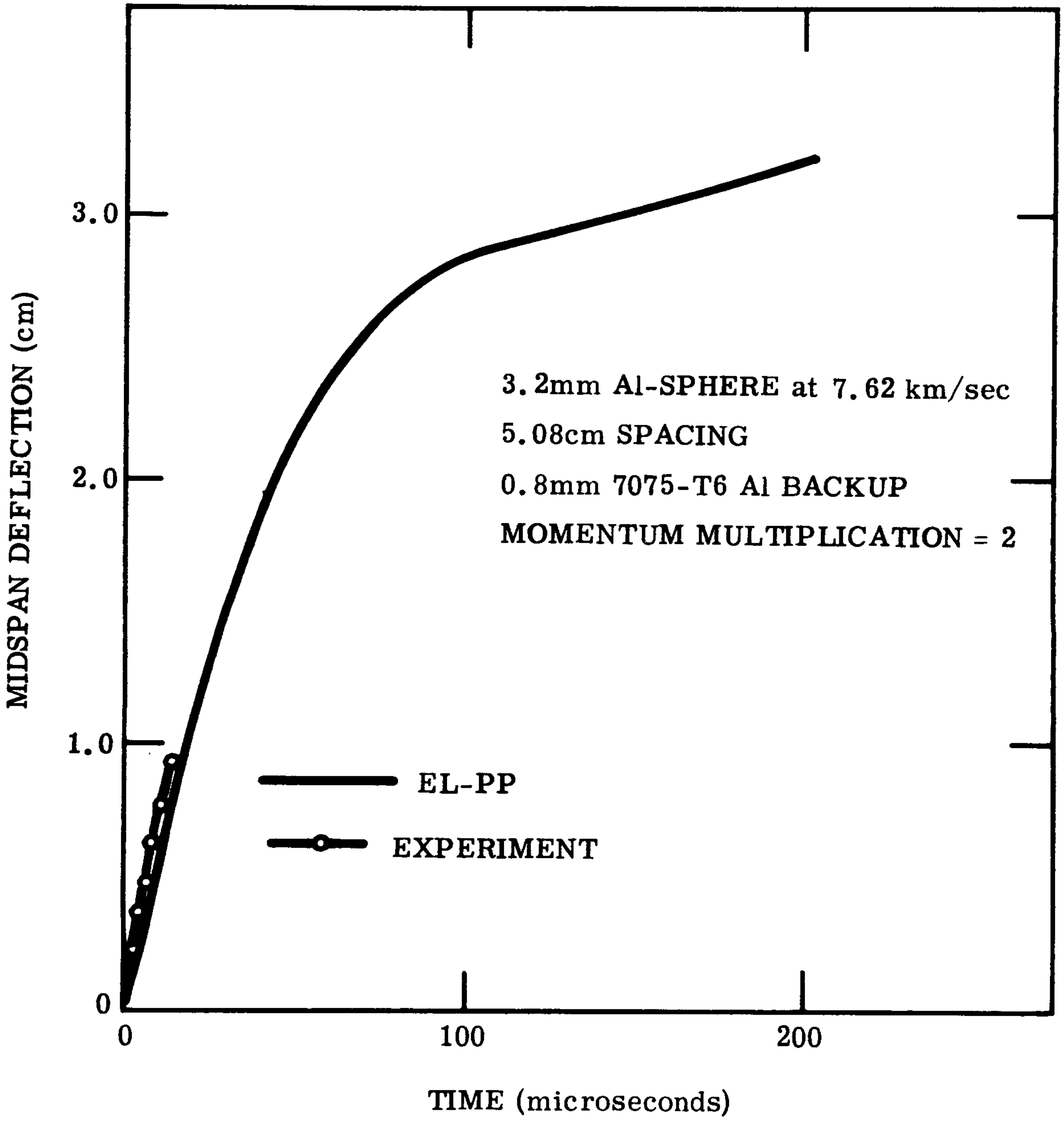

Figure 2 - Centerline Displacement vs Time

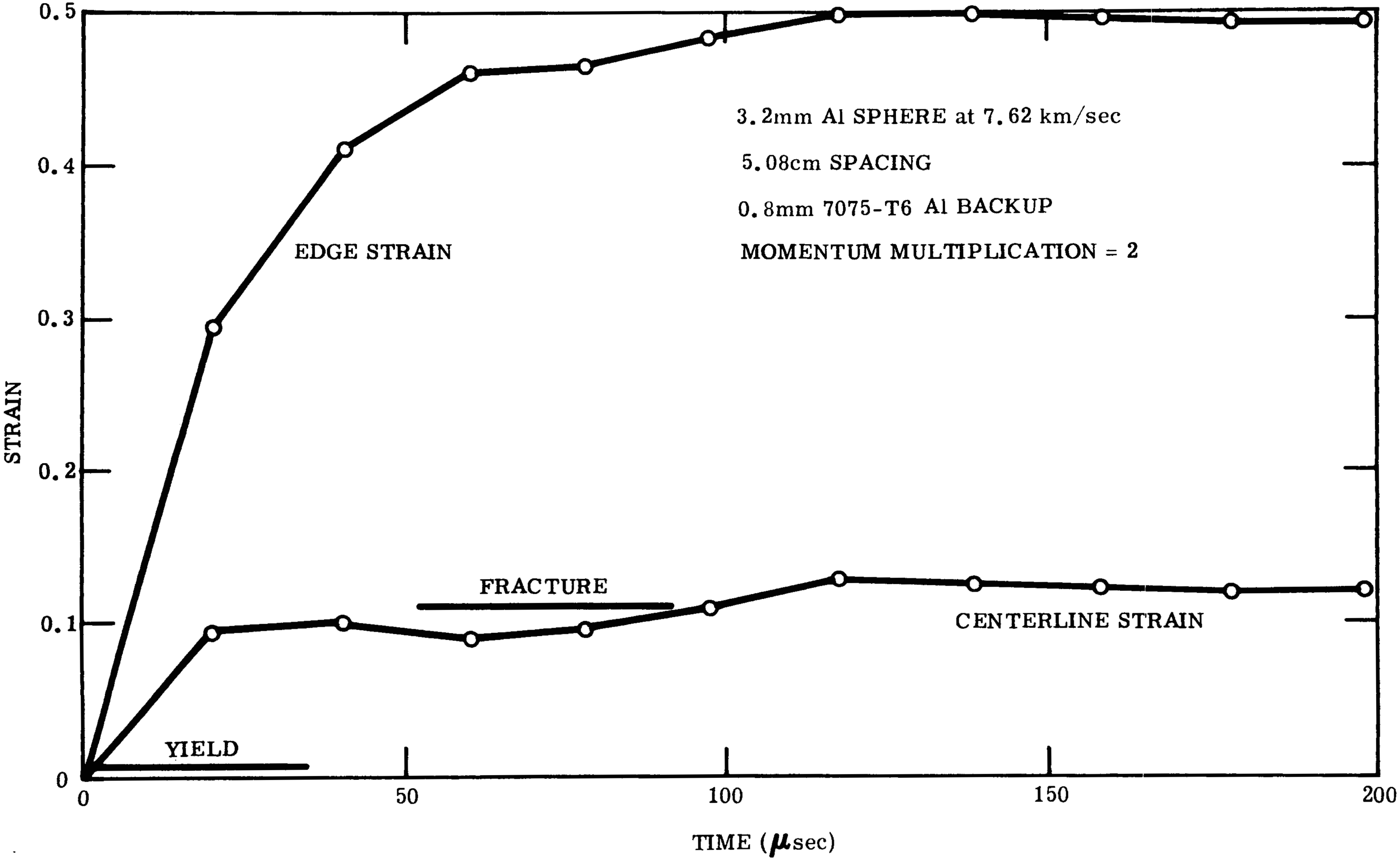

Figure 3 - Strain vs Time

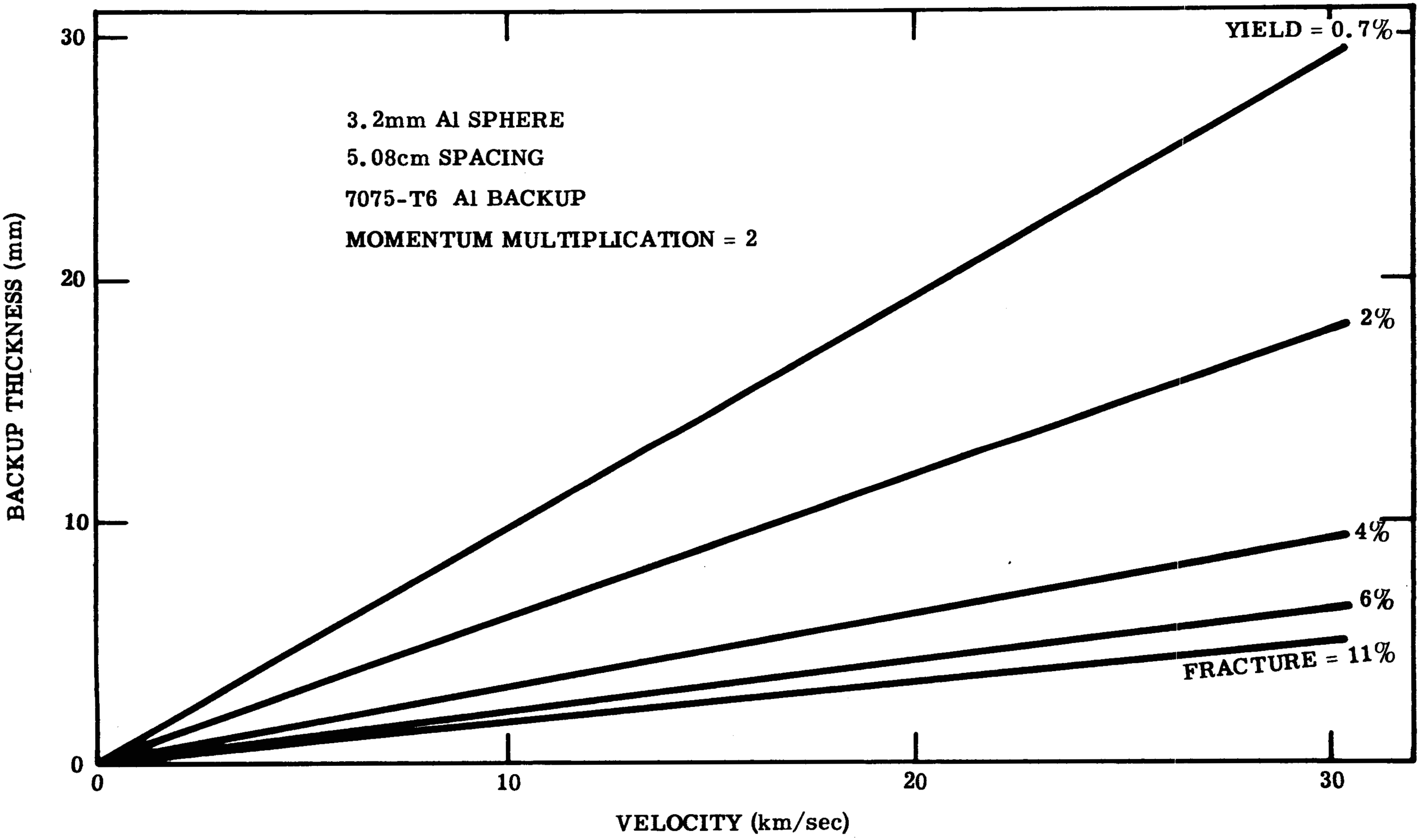

Figure 4 - Backup Thickness Requirements vs Velocity

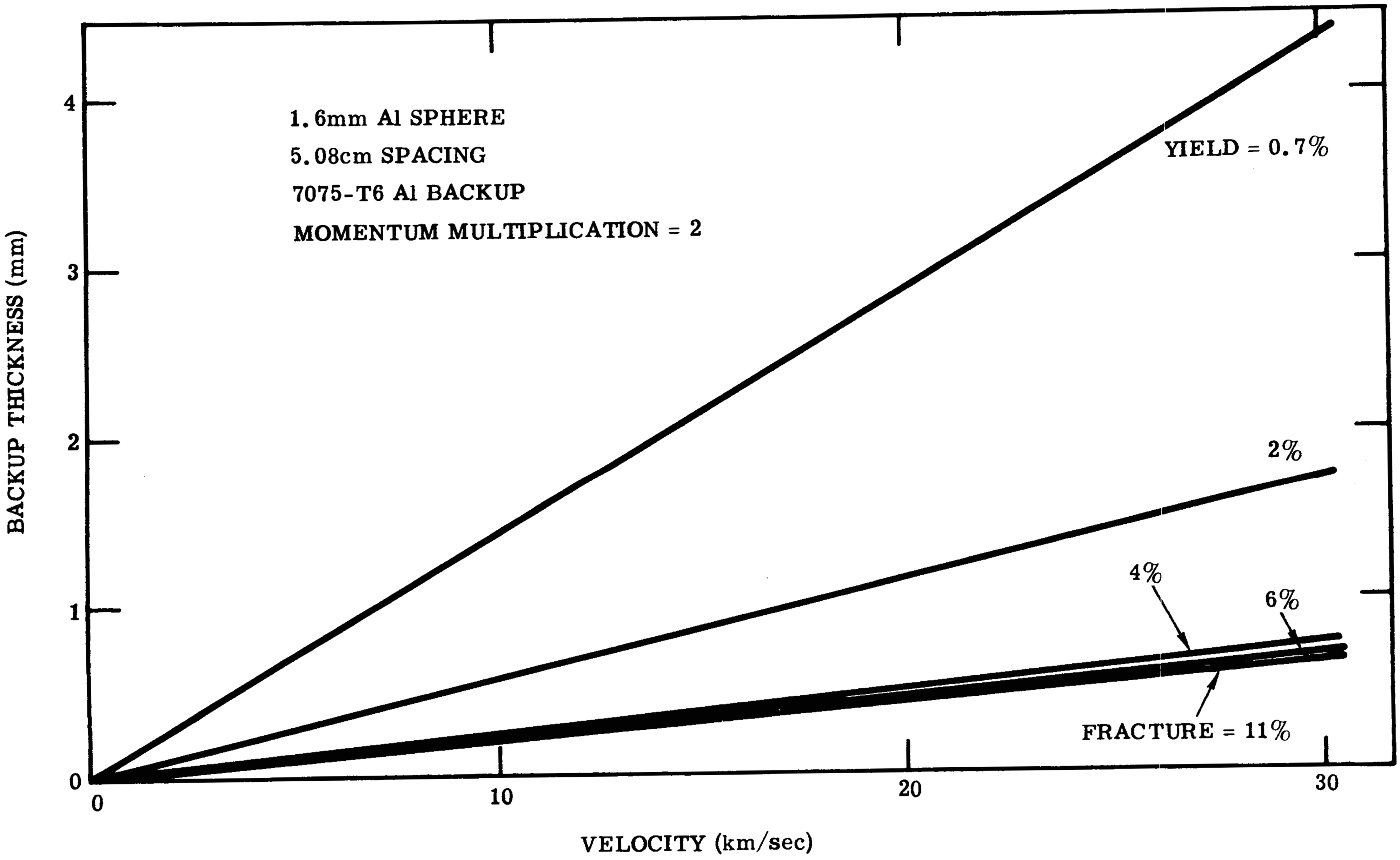

Figure 5 - Backup Thickness Requirements vs Velocity

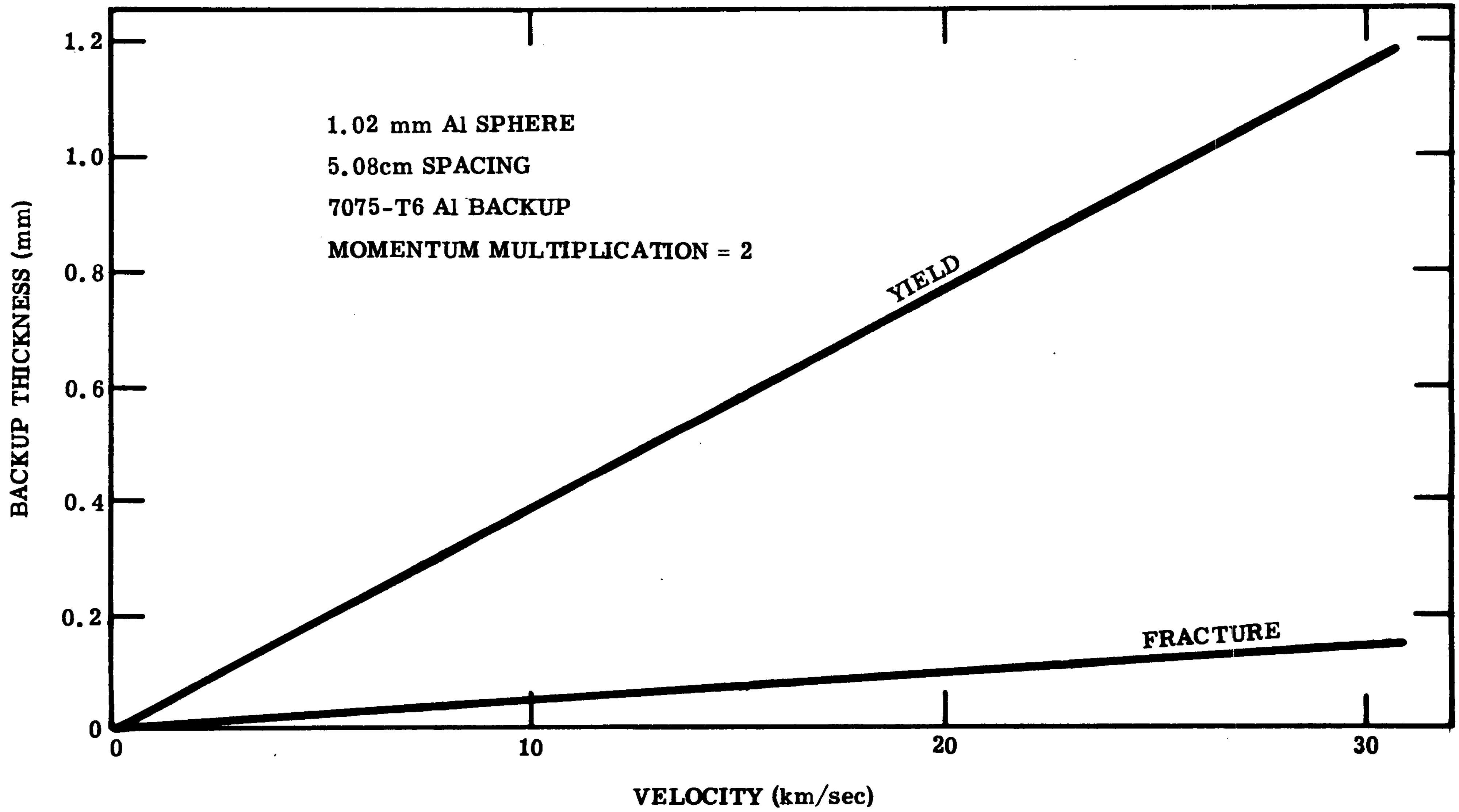

Figure 6 - Backup Thickness Requirements vs Velocity

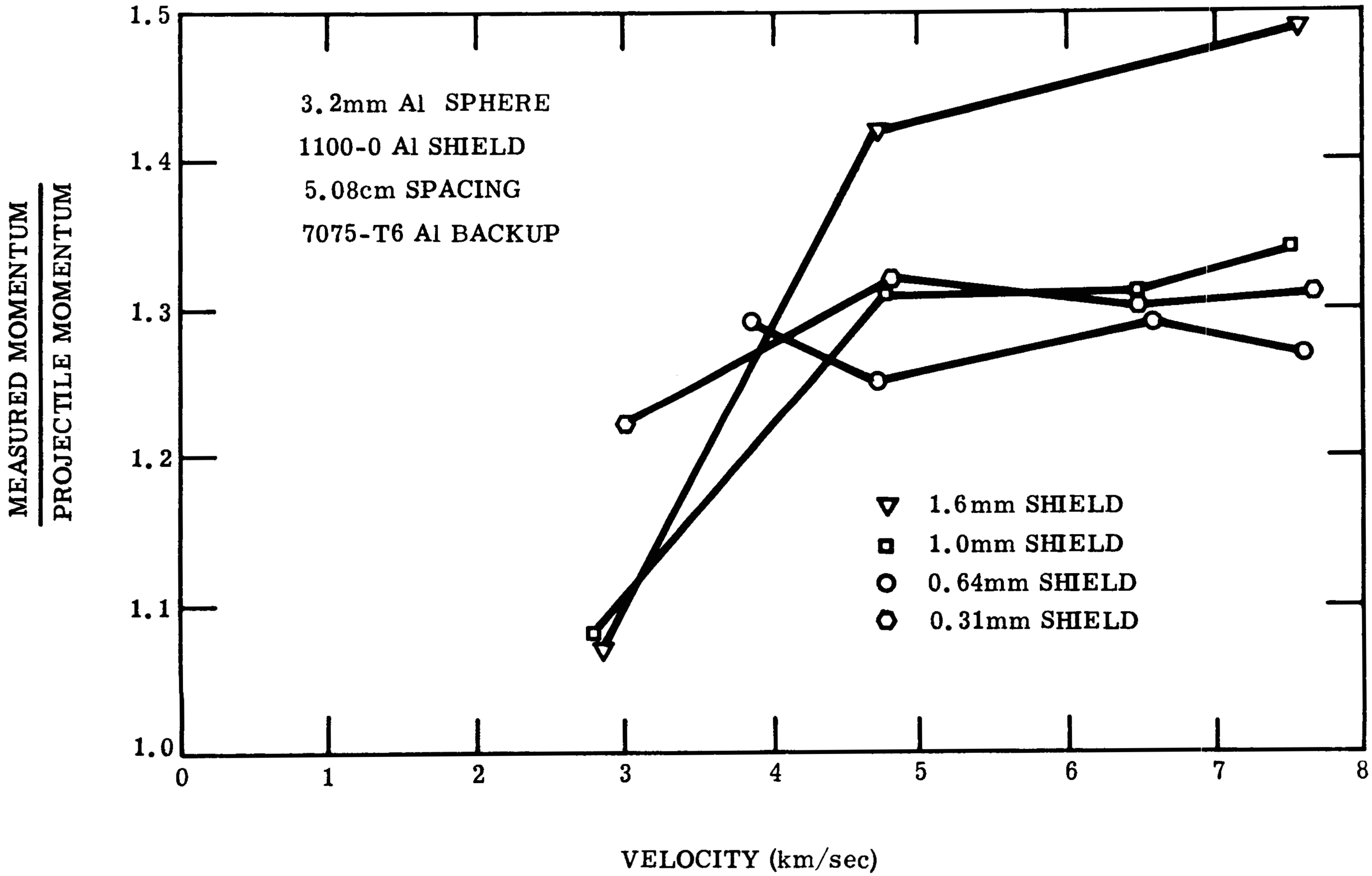

Figure 8 - Momentum Multiplication vs Velocity

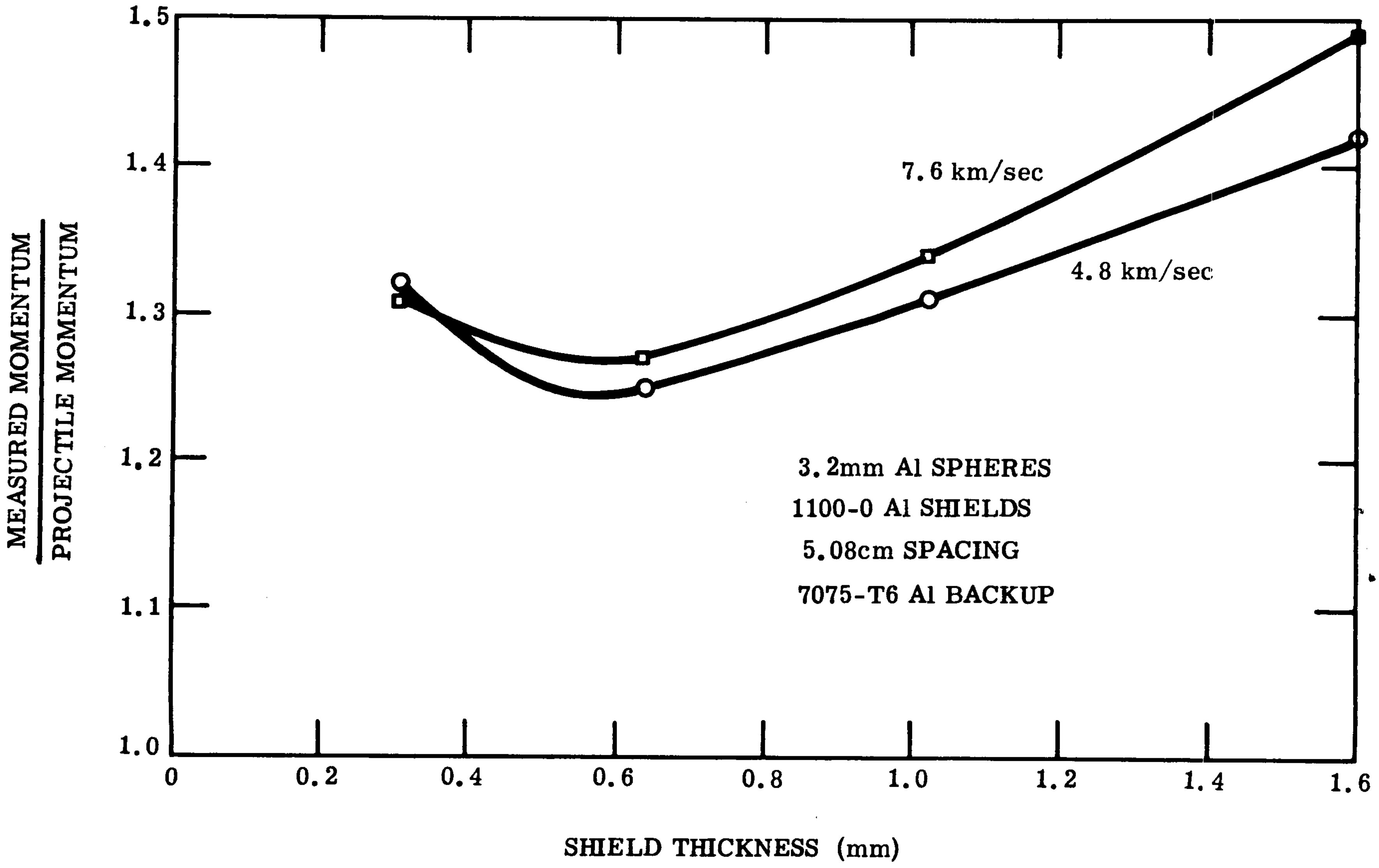

Figure 9 - Momentum Multiplication vs Shield Thickness

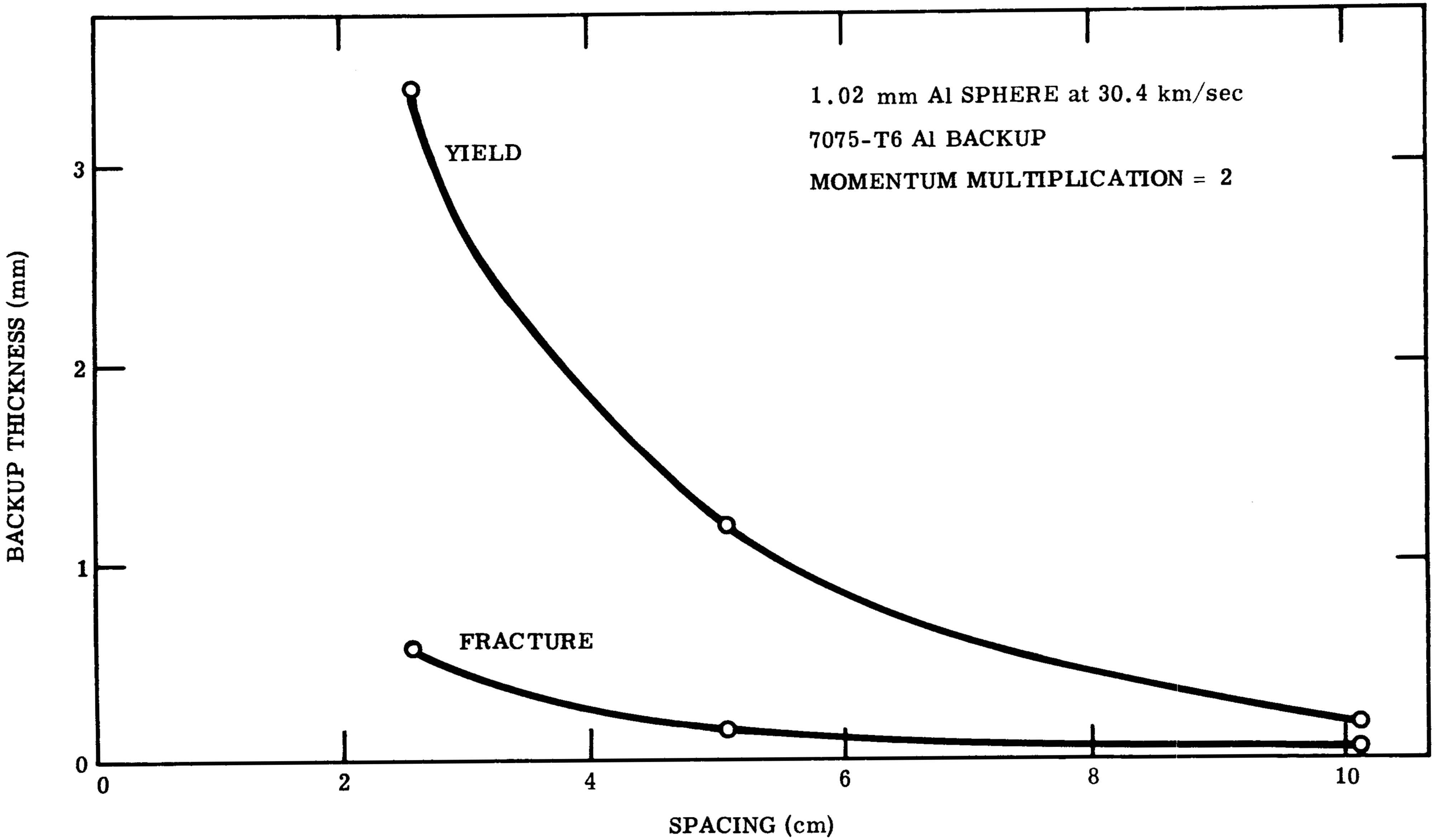

Figure 7 - Backup Thickness vs Spacing