SID 67-251

EXPERIMENTAL HYPERVELOCITY IMPACT RESEARCH

NAS8-21007

Final Technical Report

Prepared by

C. N. Scully

Approved by

C. J. Morin
Director, Space Sciences

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

SID 67-251

EXPERIMENTAL HYPERVELOCITY IMPACT RESEARCH

NAS8-21007

Final Technical Report

Prepared by

C. N. Scully

Approved by

E. J. Morin
Director, Space Sciences

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

TECHNICAL REPORT INDEX/ABSTRACT

ACCESSION NUMBER							DOCUMENT SECURITY CLASSIFICATION	
							Unclassified	

TITLE OF DOCUMENT

EXPERIMENTAL HYPERVELOCITY IMPACT RESEARCH

LIBRARY USE ONLY

AUTHOR(S)

C. N. Scully

CODE	ORIGINATING AGENCY AND OTHER SOURCES	DOCUMENT NUMBER
	Department 097-200, Space Sciences, S&ID/Dny.	SID 67-251

PUBLICATION DATE	CONTRACT NUMBER
	NAS8-21007

DESCRIPTIVE TERMS

HYPERVELOCITY IMPACT

BALLISTIC LIMITS

METEOROID PERFORATION SENSORS

ABSTRACT

THE EXPERIMENTAL RESULTS OF A SERIES OF HYPERVELOCITY IMPACT FIRINGS WITH BOROSILICATE GLASS PROJECTILES, IN SEVERAL SIZE RANGES FROM 20 TO 50 MICRONS IN DIAMETER, ON BOTH SEMI-INFINITE AND THIN SHEET TARGETS ARE REPORTED. THE DATA ALLOWS THE DETERMINATION OF THE THRESHOLD VELOCITY FOR PERFORATION FOR THE THIN SHEET TARGETS AS WELL AS THE VARIATION OF DEPTH OF PENETRATION WITH VELOCITIES IN THE SEMI-INFINITE TARGETS. AMONG THE THIN SHEETS IMPACTED WAS THE 0.0015" THICK CAPACITOR SENSOR PANEL OF THE PEGASUS SATELLITE MICROMETEOROID DETECTION SYSTEM. THE EXPERIMENTS COVER THE RANGE OF 18,900 FEET PER SECOND TO 65,000 FEET PER SECOND.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
TARGET MATERIALS	1
EXPERIMENTAL TECHNIQUES	1
PERFORATION THRESHOLDS	2
SEMI-INFINITE TARGET IMPACTS	3
MISCELLANEOUS FIRINGS	3
SUMMARY	3

TABLES

Table No.	Title	Page
1	Impact Velocities Leading to Perforation of 0.0015" Pegasus Detector Panels by 0.0013" Diameter Borosilicate Glass Spheres	5
2	Impact Velocities Leading to Perforation of 0.001" Half-Hard 302 CRES by 0.0009" Diameter Borosilicate Glass Spheres	6
3	Impact Velocities Leading to Perforation of 0.002" Half-Hard 302 CRES by 0.0013" Diameter Borosilicate Glass Spheres	7
4	Penetration Depth to Projectile Diameter Ratio for 0.0011" Borosilicate Spheres Impacting 1100 Aluminum	8
5	Penetration Depth to Projectile Diameter Ratio for 0.0009" Borosilicate Spheres Impacting 302 CRES	9
6	Penetration Depth to Projectile Diameter Ratio for 0.0013" Borosilicate Spheres Impacting 302 CRES	10
7	Impact Velocities Leading to Perforation of 0.0015" Pegasus Detector Panels by 0.0009" Diameter Borosilicate Glass Spheres	11
8	Impact Velocities Leading to Perforation of 0.001" Half-Hard 302 CRES by 0.0013" Diameter Borosilicate Glass Spheres	11
9	Impact Velocities Leading to Perforation of 0.0002" Half-Hard 302 CRES by 0.00202" Diameter Borosilicate Glass Spheres	11

INTRODUCTION

The experimental program described in this report had two objectives. The first was, by a series of hypervelocity impacts, the determination of the threshold velocity for perforation of specific materials impacted by artificial micrometeoroids. The threshold velocity for perforation is customarily referred to as the ballistic limit or the minimum velocity at which a specific projectile is capable of producing a perforation in a particular thin target. The materials of interest in this program were those employed in previous micrometeoroid measurement satellite experiments. The second objective was the determination of the projectile diameter to impact crater depth ratio for craters produced in semi-infinite targets of the same material composition and physical properties as the thin sheet targets studied in the first objective over a range of velocities encompassing the threshold perforation velocity for the thin sheet experiments.

TARGET MATERIALS

The target materials were supplied by the George C. Marshall Space Flight Center and consist of Type 302 corrosion resistant steel in the half-hard condition in thickness of 0.001" and 0.002" and a nominal 0.0015" capacitor from the perforation sensor layer of a Pegasus micrometeoroid perforation detection satellite panel. In addition 2" x 3" x 0.375" of Type 302 CRES, reportedly in the same heat treat condition as the thin sheet material and 1.5" x 1.5" x 0.105" Type 1100-0 aluminum.

EXPERIMENTAL TECHNIQUES

The firing experiments were conducted in North American Aviation's Mark IV Electrothermal Gun System in its Space Sciences Department, Space and Information Systems Division, Downey, California. The gun system which accelerates spherical silicate projectiles with a diameter range of 20 to 90 microns by aerodynamic drag forces produced by a dense flowing plasma, has been described in a series of previous reports. The most complete description appears in the Proceedings of the Seventh Hypervelocity Impact Symposium.

The method for determining the threshold perforation velocity was to provide a series of impacts over a wide range of velocities in sufficient number as to clearly define the minimum velocity projectile capable of producing a perforation. In order to determine the threshold velocity, the targets were mounted within the hypervelocity range target chamber with two viewing photomultiplier tubes. The field of view of the first photomultiplier tube was restricted to the front surface of the target material and detected the luminous impact flash. The impact flash signal was recorded on one channel of a two-beam oscilloscope,

Tektronix Type 551 with Type K pre-amplifier. The field of view of the second photomultiplier was restricted to the rear surface of the target and, in event that a perforation took place, a luminous flash from the rear surface was detected and recorded on the second channel of the two-beam oscilloscope. Coincidences of impact flash and rear surface flash was evidence that the incident projectile has produced a perforation. All other range instrumentation techniques have been described in the referenced source.

It was a restriction in the statement of work that the projectile diameters be such that the threshold perforation velocity was in excess of 10 Km/sec (32,800 feet per second). For this reason each of the thin sheet target materials were subjected to impacts by borosilicate glass spherical projectiles (density 2.23) over a range of velocities in order to determine which projectile diameters would be used for the acquisition of impact data for perforation experiments. The projectile diameters chosen for principle experiments were 22.9 microns (0.0009"), 33.0 microns (0.0013") and 51.4 microns (0.00202"). Standard deviation from the mean diameter was 2.5%.

The thin sheet Type 302 CRES was used in the "as received" condition. Precision measurements of received material indicated an actual thickness of 0.0018" for the nominal 0.002" CRES and 0.0009" for the nominal 0.001". The Pegasus sensor material was received in the form of a flight type 20" x 40" double surface panel. The full-scale panel was cut into two-inch squares and the plastic foam backing removed from the capacitor. The adhesive bonding material used to join the capacitor to the plastic foam panel remained on the capacitor surface. The target sheet therefore consisted of a multi-layered structure of 0.0015" aluminum, a bonded Mylar layer, a vapor deposited copper layer, and a layer of adhesive. The overall average thickness was 0.0019". This fact is significant in the interpretation of the perforation threshold data.

PERFORATION THRESHOLDS

Based upon the determination of the projectile diameters whose impacts lead to perforations at velocities above 32,800 feet per second, a series of firings were conducted for each of three specific thin sheet targets.

The results of the perforation experiments for 0.0013" diameter spheres on 0.0015" Pegasus detector panels is summarized in Table 1. A total of 30 perforations were obtained over a range of velocities from 57,300 feet per second down to 39,400 feet per second. No perforations were obtained at any velocities below 39,400 feet per second, and this value may be considered as the threshold velocity for perforations for this specific combination of projectile and target materials. The summary of perforation experiments for 0.0009" diameter projectiles on 0.001" 302 CRES is summarized in Table 2. A total of 35 perforations were obtained over the velocity range from 65,000 feet per second down to 38,800 feet per second. No perforations were obtained with any impacts below the lower limit. Table 3 summarizes the perforation

experiments with 0.0013" diameter projectiles on 0.002" 302 CRES where a total of 30 perforations were obtained over the velocity range from 60,200 feet per second down to 40,100 feet per second.

SEMI-INFINITE TARGET IMPACTS

It is the objective of this particular task to determine the ratio of crater depth to projectile diameter for each of the target materials and for each of the combinations of projectile diameters and target materials at the penetration threshold velocity for the thin sheet targets. To accomplish this end, a series of firings were conducted with appropriately sized projectiles on each of the target materials and the crater depth to projectile diameter ratio determined for each impact for which there was range indication that the impact was produced by an intact projectile. Table 4 summarizes the values of p/d for each of 31 craters obtained over an impact velocity range of 49,800 feet per second down to 15,400 feet per second for 0.0013" diameter projectiles on 1100 aluminum. Table 5 summarizes similar measurements for the 32 impact craters produced by 0.0009" diameter projectiles on 302 CRES over the velocity range from 54,300 feet per second to 24,900 feet per second. Similarily, Table 6 gives equivalent data for the 31 craters produced by 0.0013" diameter spheres on 302 CRES of 56,800 feet per second down to 24,900 feet per second.

MISCELLANEOUS FIRINGS

During the first portion of the effort, which consisted of a series of impact experiments on thin sheet targets for the purpose of determining the appropriate diameter of projectiles to be employed for the main body of firings, certain data points were obtained using different combinations of projectile diameters and targets than those employed in the main program. While the results of these firings indicated that the projectile diameter was such that the penetration threshold was below the desired value of 32,800 feet per second, the data is considered to have some value for the interpretation of both the laboratory experiments and the behavior of certain materials under space meteoroid impact. The results of these firings are summarized in Tables 7, 8 and 9.

SUMMARY

The p/d values for those impacts obtained at the penetration threshold velocity for each combination of projectile and target materials may be determined by drawing a smooth curve through the individual p/d values over the full velocity ranges indicated in Tables 4, 5 and 6. An anomalous result is noticed in the case of the 0.0015" Pegasus capacitor target. At the threshold perforation velocity of 39,400 feet per second, the corresponding p/d in the semi-infinite material is 2.04. If one assumes that the target material

is basically 0.0015" aluminum, this would lead to a ratio of the thickness of the thin target material to the depth of penetration in the semi-infinite material of 0.56. This result cannot be accepted as having any significance. It should be remembered that the capacitor target was a composite target of four different materials, three of which have appreciable thickness. The influence of the adhesive bonding material used to provide adherance of the capacitor structure to the one-inch thick plastic foam is not negligible and appears to significantly increase the resistance to perforation by projectiles of the diameter used in the experiments.

Table 1. Impact Velocities Leading to Perforation of 0.0015" Pegasus Detector Panels by 0.0013" diameter Borosilicate Glass Spheres

Velocity, Feet per Second	Firing Reference No.
57,300	8194
56,100	7953
56,100	8207
54,700	7944
54,700	7953
54,700	7957
52,300	7976
52,200	7944
50,100	7948
50,100	7952
49,100	7948
49,100	7952
49,100	8217
49,100	8225
48,100	7952
48,100	7953
48,100	8324
48,100	8325
47,200	7949
47,200	7969
46,300	7947
46,300	8324
45,400	7972
45,400	8221
45,400	8224
45,400	8324
44,600	7943
43,000	8217
40,100	8320
39,400	8224

Table 2. Impact Velocities Leading to Perforation of 0.001" Half-hard 302 CRES by 0.0009" Diameter Borosilicate Glass Spheres

Velocity, Feet Per Second	Firing Reference No.
65,000	8012
63,300	8017
63,300	8035
60,200	8007
57,300	8033
56,100	8018
56,100	8020
56,100	8041
54,700	7983
54,700	8001
54,700	8009
54,700	8013
52,700	8023
52,300	8003
52,300	8013
52,300	8029
52,300	8043
51,200	8003
51,200	8035
49,100	8014
48,100	8010
48,100	8031
46,300	8013
45,400	8037
43,000	7978
42,200	8024
41,500	8013
41,500	7983
40,800	7978
54,700	8315
46,300	8314
44,600	8313
43,700	8313
43,700	8314
38,800	8317

Table 3. Impact Velocities Leading to Perforation of 0.002" Half-hard 302 CRES by 0.0013" Diameter Borosilicate Glass Spheres

Velocity, Feet Per Second	Firing Reference No.
60,200	8069
60,200	8070
60,200	8074
58,700	8077
57,300	8081
56,100	8055
54,700	8120
54,700	8120
53,500	8071
53,500	8083
53,500	8120
52,300	8062
52,300	8063
52,300	8096
52,300	8121
52,300	8121
50,100	8060
50,100	8096
49,100	8066
49,100	8085
48,100	8124
47,200	8097
46,300	8108
45,400	8121
43,700	8101
43,000	8061
42,200	8097
41,500	8060
40,100	8112

Table 4. Penetration Depth to Projectile Diameter Ratio for 0.0013" Borosilicate Spheres Impacting 1100 Aluminum

Crater Depth to Projectile Diameter Ratio	Impact Velocity Feet per Second	Firing Reference No.
2.23	49,800	8338
1.92	37,000	8343
1.69	30,900	8343
1.39	22,800	8344
1.69	32,100	8348
1.69	31,700	8348
1.85	34,900	8348
1.66	30,100	8348
2.08	38,800	8348
1.77	33,400	8348
1.62	29,800	8348
1.15	15,400	8348
1.31	20,700	8348
1.62	28,100	8348
1.92	36,400	8348
2.08	39,400	8348
1.92	37,000	8348
1.58	27,700	8348
1.62	27,700	8350
2.23	45,200	8350
1.81	33,900	8350
2.00	39,400	8350
2.08	42,200	8354
1.85	35,400	8354
1.31	22,200	8354
1.46	24,900	8358
1.38	24,700	8358
1.54	27,800	8363
1.00	15,900	8352
1.15	20,000	8351
1.15	18,900	8351

Table 5. Penetration Depth to Projectile Diameter Ratio for 0.0009" Borosilicate Spheres Impacting 302 CRES

Crater Depth to Projectile Diameter Ratio	Impact Velocity Feet Per Second	Firing Reference No.
1.33	54,300	8421
1.28	47,000	8422
1.28	50,800	8426
1.22	48,700	8426
.555	28,100	8426
.555	26,800	8426
.50	26,500	8426
.555	28,100	8427
1.00	40,000	8428
.445	24,900	8430
.78	33,000	8430
.61	29,800	8430
.61	26,200	8430
1.11	43,700	8430
.555	25,400	8430
.61	26,000	8430
1.00	39,400	8430
1.33	52,000	8431
1.33	49,700	8436
.89	35,900	8437
1.22	44,400	8442
1.39	52,100	8445
1.00	41,500	8445
.945	38,200	8446
.89	37,600	8446
1.00	39,400	8446
1.22	45,300	8446
1.06	43,700	8446
1.11	45,300	8450
1.11	43,700	8451
1.34	48,700	8451
1.22	46,000	8458

Table 6. Penetration Depth to Projectile Diameter Ratio for 0.0013" Borosilicate Spheres Impacting 302 CRES

Crater Depth to Projectile Diameter Ratio	Impact Velocity Feet per Second	Firing Reference No.
1.38	56,800	8379
1.31	49,700	8383
1.23	45,300	8383
1.16	45,300	8389
1.11	43,500	8389
1.16	44,400	8389
1.00	41,500	8389
1.23	47,000	8389
1.16	46,000	8389
1.23	46,000	8389
1.00	40,700	8391
.85	33,400	8391
.695	31,000	8391
.85	32,600	8391
.73	31,300	8391
.54	24,400	8391
.615	26,600	8391
.575	25,200	8391
.615	26,600	8394
.54	24,900	8394
1.23	47,000	8394
.54	24,700	8394
.85	31,700	8396
1.08	42,700	8396
1.23	48,700	8396
1.00	38,200	8396
1.23	46,000	8396
1.31	54,300	8398
1.54	55,500	8407
1.39	54,300	8407
1.46	55,500	8413

Table 7. Impact Velocities Leading to Perforation of 0.0015" Pegasus Detector Panels by 0.0009" diameter Borosilicate Glass Spheres

No perforations were obtained with any impacts between 14,000 and 60,000 feet per second.

Table 8. Impact Velocities Leading to Perforation of 0.001" Half-hard 302 CRES by 0.0013" Diameter Borosilicate Glass Spheres

Velocity, Feet Per Second	Firing Reference No.
49,100	7996
46,200	7996
28,300	7997
14,200	7997

Table 9. Impact Velocities Leading to Perforation of 0.002" Half-hard 302 CRES by 0.00202" Diameter Borosilicate Glass Spheres

Velocity, Feet Per Second	Firing Reference No.
45,400	8049
41,500	8049
40,100	8048
40,100	8051
39,400	8053
37,600	8045
36,500	8053
36,000	8051
35,400	8047
34,900	8047
30,900	8052