NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
In accordance with Exhibit "D" to Contract AF 04(647)-243, one copy of the subject report is hereby submitted.

Very truly yours,

J. M. Bonner, Superintendent
AF Contract Support

cc: HP/CMO
Attn: Lt. Col. L. C. Wampler, Chief
W. E. Howell (wo/encl)
Mr. J. L. Shrout
HPC STL Representative
Mail Stop 100-B (wo/encl)
Technical Operating Report
B O B Approval No.

FINAL REPORT W2SD-18
STRUCTURAL DEVELOPMENT TEST
CASE M215.02
MTI-478
WEAPON SYSTEM 133A
12 July 1963

Contract Number AF 04(647)-243
Exhibit D, Paragraph IV.A.3

Prepared by
HERCULES POWDER COMPANY
CHEMICAL PROPULSION DIVISION
Bacchus Works
Magna, Utah

Prepared for
HEADQUARTERS
AIR FORCE SYSTEMS COMMAND
United States Air Force
Los Angeles, California
FINAL REPORT W2SD-18
STRUCTURAL DEVELOPMENT TEST
CASE M215.02

Weapon System 133A

Prepared by

T. M. Lester
Development Engineer
Minuteman Design

Reviewed by Reviewed by Approved by

D. W. Austin J. L. Knearem W. L. Gunther
Supervisor, Design Superintendent Wing I - V Minute Wing I - V Project Manager
FOREWORD

This report outlines work accomplished by the Case Design Group, Chemical Propulsion Division at the Bacchus Works of Hercules Powder Company for the continued development of Rocket Motor M-57, Minuteman Stage III.

Authority for preparation of this report is specified in Contract AF 04(647)-243, Exhibit D, Paragraph IV.A.3.

Published by
The Publications Group
Graphic Services Department
HERCULES POWDER COMPANY
Bacchus Works
Magna, Utah
ABSTRACT

Structural development test W2SD-18, Case M215.02, was conducted at the Bacchus Works, Hercules Powder Company on 10 March 1962 to determine the structural integrity of the Wing II, M-57E1 rocket motor case when subjected to flight load conditions of axial load, shear load, and bending moment conducted at room temperature environment.

Case M215.02 failed under the combined effects of an axial load of 65.5 kips, a shear load of 6.5 kips, and a bending moment of 1194.3 in.-kips.

From the test results, an average Poisson's ratio of 0.1936 and a compressive modulus of elasticity of $4.88 \times 10^6$ psi were calculated for the cylindrical section of the case.

It was concluded that the Wing II case represented in this test is capable of withstanding the structural requirements imposed on the aft tangent line during the maximum $q_\alpha$ (See Boeing document D2-3877-4) condition experienced during first stage action time.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>iii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vi</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vi</td>
</tr>
</tbody>
</table>

## I INTRODUCTION

A. Purpose ...................................................... 1  
B. Test Objectives ................................. 1  

## II TECHNICAL DISCUSSION

A. Test Specimen Description ................. 2  
B. Test Procedure .............................. 3  
C. Test Results ............................. 3  

## III CONCLUSIONS ................................. 6
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specimen Reinforcement Diagram</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Instrumentation Location</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Test Setup</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Case in Test Fixture (Representation)</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Programmed Load (Y - T Plot)</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>$P_1$ Compressive Load vs Time Trace</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>$P_2$ Compressive Load vs Time Trace</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>$P_3$ Shear Load vs Time Trace</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>Hoop Strain vs Time</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>Longitudinal Strain vs Time</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>Deflection vs Time</td>
<td>17</td>
</tr>
<tr>
<td>12</td>
<td>Failure Area Schematic</td>
<td>18</td>
</tr>
<tr>
<td>13</td>
<td>Failure Area</td>
<td>19</td>
</tr>
</tbody>
</table>

LIST OF TABLES

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>W2SD-18 Test Data vs Time and Load</td>
<td>20</td>
</tr>
</tbody>
</table>
A. PURPOSE

Structural development test W2SD-18 was conducted as a part of a Wing II Continued Development Program in the development of a lighter weight case for the third stage Minuteman. This test, a duplicate of test W2SD-17, was carried out to determine whether the light weight case design would meet the required flight load conditions as specified in Boeing Document D2-3877-4.

The purpose of this test was to gain information in determining the structural integrity of the new Wing II M-57E1 rocket motor case under simulated flight requirements of combined axial load, shear load, and bending moment at room temperature.

The test was conducted 10 March 1962 by Hercules Powder Company at facilities located at Bacchus, Utah.

B. TEST OBJECTIVES

Test objectives were:

(1) To determine the physical capabilities of the aft tangent line area of the Wing II M-57E1 rocket motor case under combined external loading of axial load, shear load, and bending moment at room temperature.

(2) To determine modulus of elasticity and Poisson's ratio values for the critical areas of the case at room temperature.
SECTION II
TECHNICAL DISCUSSION

A. TEST SPECIMEN DESCRIPTION

The test specimen was a standard Wing II rocket motor case (Ref: HPC drawing 01A00221) number M215.02 which was constructed of Spiralloy. The nominal outside diameter was 37.5 in. The distance between tangent lines was 43.0 in. The case configuration is described in the following paragraphs.

1. Cylindrical Section

The cylindrical section of the case consisted of seven layers of 90° windings and six layers of 14.5° helical windings; the thrust termination (TT) port areas were each additionally reinforced with six glass wafers and six TT ply mats. The theoretical thickness was 0.16 in. except in the TT port reinforced area. (The case was pressurized to 50 psig to simulate structural support received from propellant.)

2. Domes

The forward and aft domes were each wound with four layers of 14.5° windings; the nozzle port areas on the aft dome were additionally reinforced with four glass wafers which were 16 in., 17 in., 18 in., and 19 in. in diameter, respectively. The minimum theoretical thickness at the tangent line was 0.06 in.

3. Forward Skirt

The forward skirt build-up consisted of two layers of 14.5° windings, nine layers of reverse 143 weave glass cloth, one layer of 90° windings, and three layers of 90° nylon roving. The nominal wall thickness was 0.17 in. and the length was 12.575 in. measured from the forward tangent line. For additional reinforcement of the forward skirt for this test, ten layers of 181 weave glass cloth were also applied to the external surface of the forward skirt. A 0.250 in. thick aluminum ring sleeve was internally bonded to the inner surface of the skirt, and the forward Y-joints were filled with Armstrong C-7 epoxy. (See Figure 1.)

4. Aft Skirt

The aft skirt build-up consisted of two layers of 14.5° windings, twenty-two layers of reverse 143 weave glass cloth, one layer of 90° winding, and three layers of 90° nylon roving. The nominal wall thickness was 0.313 in. and the length was 6.2 in. measured from the aft tangent line.
A two-cycle cure of the resin was used in the manufacture of this case. The lamination materials used were Union Carbide's ERLA 2256 resin and HTS 144 ends/in. glass roving.

In preparation for the test, a metal-reinforced R & D section was attached to the forward skirt and a reinforced second-to-third stage inter-stage section was fastened to the aft skirt.

B. TEST PROCEDURE

After installation of the instrumentation (Figure 2), the assembly was mounted in an upright position in the compression load testing device as shown in Figure 3. This device consisted of three hydraulic rams designated P₁, P₂, and P₃. Ram P₁ was positioned on the base at point 0° and ram P₂ at 180°. P₃ was mounted on the crosshead 70 in. forward from the center of the TT port area at 180°. The force from P₃ was normal to the longitudinal centerline of the case. A representation of the case installed in the test fixture is shown in Figure 4.

The instrumentation was attached to the recorders and checked out for accuracy (polarity, calibration). After this was completed, the simulated flight loads were applied as programmed on the Y-T plot. (See Figure 5.) The actual traces are shown in Figures 6 through 8.

C. TEST RESULTS

Test objectives were met as indicated by the test results outlined below. Test data are shown graphically in Figures 9 through 11 and are listed in Table I.

The case failed when the plane of weakness between the body and skirt juncture sheared, causing all the structural load to be carried by the skirt windings. (See Figures 12 and 13.) Because of this phenomenon, the skirt windings folded over themselves at the aft tangent line. The above mentioned plane of weakness is caused when the case is cured in two stages; once, after body wind, and again after the skirts have been wound to the unit.

The case was subjected to the following loads when failure occurred:

Axial Compressive Load = 65.5 kips at room temp
Bending Moment = 1194.3 in.-kips at room temp
Shear Load = 6.5 kips at room temp

The above loads were calculated using Figures 6 through 8 for the aft tangent line where failure occurred.
From the equation

\[ P_{eq} = P + 2 \frac{M}{R} \]

where: \( P_{eq} \) = equivalent axial compressive load
\( P \) = applied axial compressive load
\( M \) = applied bending moment
\( R \) = distance in in. from the case longitudinal centerline to the point of calculation (\( R = 18.75 \))

The above equivalent axial compressive load is 192.9 kips.

The loads that the case was required to withstand as dictated by STL at the time the test was conducted, were:
- Axial compressive load = 56 kips at 1500°F
- Bending moment = 1200 in.-kips at 1500°F
- Shear load = 6.5 kips at 1050°F

The above load condition gives an equivalent axial compressive load of 184 kips.

The final design requirements for the aft tangent line per Boeing document Number D2-3877-4 (max q condition) are:
- Axial compressive load = 47.4 kips at 1500°F
- Bending moment = 727.9 in.-kips at 1500°F
- Shear load = 4.24 kips at 1500°F

The above load combination corresponds to an equivalent axial compressive load of 125.1 kips.

The above required load of 125.1 kips simulates the load experienced by the third stage case aft tangent line during first stage operating condition (max q condition). The theoretical surface temperature of the case during this period of flight is 1500°F. At the above temperature the critical buckling stress of the case degrades 7 percent. The ratio of 125.1 kips over 0.93 gives a value of 134.5 kips. This value is the room temperature requirement corresponding to the value required at 1500°F.

The ratio of 192.9 kips to 134.5 kips gives a margin of safety of 1.43. This is in excess of design requirements which include a 1.25 safety factor.
During the instrumentation checkout pre-test load cycle, the case was accidentally subjected to a bending moment of 1,200 in.-kips at the aft tangent line. The affect of this bending moment on the ultimate capability of the case is unknown.

The average Poisson's ratio for the cylindrical section between the TT ports is 0.1936. This value was obtained from gages J, K, P, and N and agrees favorably with past data.

Using strain gage N, the compressive modulus of elasticity (E), is $4.88 \times 10^5$ psi; this value is high but not impractical. Electronic deflection indicators (EDI) 3 and 6 show an average E of $6.45 \times 10^6$ psi for the cylindrical section forward of the TT ports. The value for this area, from past tests on cases of this design, is $3.5 \times 10^6$ psi; the reason for the high modulus (E) on this test case is unknown.

Structural test WZSD-17 was identical to this test on a case of the same design. Refer to Hercules Powder Company document Number MTI-477 for a comparative report.
SECTION III

CONCLUSIONS

From the test results it can definitely be concluded that the Wing II rocket motor case is capable of meeting and exceeding the present structural requirements of the aft tangent line during the first stage operation condition (max $q\alpha$) as defined in Boeing document D2-3877-4.
Figure 2. Instrumentation Location
Figure 3. Test Setup
Figure 4. Case in Test Fixture (Representation)
Figure 5. Programmed Load (Y - T Plot)
Figure 10. Longitudinal Strain vs Time
WINDINGS PUSHED FORWARD & OVER ONE ANOTHER

SKIRT BUILDUP SHEARED FROM BODY WINDINGS

AFTER FAILURE

SKIRT WINDINGS

BODY WINDINGS

INSULATOR

BEFORE FAILURE

Figure 12. Failure Area Schematic
Figure 13. Failure Area
TABLE I
W2SD-18 TEST DATA VS TIME AND LOAD

<table>
<thead>
<tr>
<th>TEST TIME IN SECONDS</th>
<th>0.00</th>
<th>2.60</th>
<th>8.00</th>
<th>13.40</th>
<th>18.00</th>
<th>24.00</th>
<th>29.50</th>
<th>34.90</th>
<th>41.60</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>APPLIED LOADS IN KIPS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>3.500</td>
<td>5.000</td>
<td>10.000</td>
<td>15.000</td>
<td>20.000</td>
<td>25.000</td>
<td>30.000</td>
<td>35.000</td>
<td>40.000</td>
</tr>
<tr>
<td>P2</td>
<td>3.500</td>
<td>5.000</td>
<td>6.000</td>
<td>6.000</td>
<td>12.000</td>
<td>14.000</td>
<td>17.000</td>
<td>20.000</td>
<td>25.000</td>
</tr>
<tr>
<td>P3</td>
<td>1.000</td>
<td>5.000</td>
<td>1.500</td>
<td>2.500</td>
<td>3.000</td>
<td>4.000</td>
<td>5.000</td>
<td>6.200</td>
<td>6.500</td>
</tr>
</tbody>
</table>

| **STRAIN IN MICRO INCHES PER INCH** |      |      |      |       |       |       |       |       |       |
| SGA                   | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| SGB1                  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| SGC                   | 40.090 | 66.136 | 194.805 | 360.918 | 485.100 | 649.472 | 501.818 | 1082.272 | 1140.736 |
| SGD1                  | 32.911 | 63.952 | 159.647 | 335.239 | 459.995 | 618.632 | 758.323 | 917.975 | 704.726 |
| SGE                   | 18.900 | 23.625 | 47.250 | 94.500 | 146.475 | 231.525 | 278.773 | 334.750 | 354.375 |
| SHG                   | 4.009 | 12.027 | 44.100 | 80.181 | 116.263 | 124.281 | 160.303 | 166.409 | 260.484 |
| SGGJ                  | 59.909 | 119.981 | 179.727 | 239.636 | 499.545 | 359.454 | 599.090 | 658.999 | 716.969 |
| SGK                   | 26.045 | 28.063 | 40.090 | 64.145 | 80.181 | 96.218 | 120.272 | 128.296 | 140.336 |
| SGM                   | 40.090 | 56.114 | 90.181 | 136.302 | 160.303 | 200.454 | 236.536 | 240.563 | 261.436 |
| SGPF                 | 20.405 | 40.090 | 60.181 | 160.303 | 200.454 | 240.545 | 320.727 | 366.818 | 440.934 |

| **DEFLECTION IN INCHES** |      |      |      |       |       |       |       |       |       |
| ED11                  | 0.001 | 0.001 | 0.002 | 0.002 | 0.004 | 0.007 | 0.010 | 0.015 | 0.017 |
| ED12                  | 0.000 | 0.001 | 0.002 | 0.005 | 0.006 | 0.012 | 0.018 | 0.025 | 0.032 |
| ED13                  | -0.001 | -0.002 | -0.007 | -0.012 | -0.016 | -0.020 | -0.025 | -0.032 |       |
| ED14                  | -0.000 | -0.000 | -0.001 | -0.003 | -0.004 | -0.005 | -0.007 | -0.010 |       |
| ED15                  | -0.001 | -0.000 | -0.002 | -0.002 | -0.004 | -0.005 | -0.007 | -0.010 |       |
| ED16                  | -0.000 | -0.002 | -0.007 | -0.012 | -0.017 | -0.020 | -0.025 | -0.032 |       |
| END                   |      |      |      |       |       |       |       |       |       |
## DISTRIBUTION LIST

**FINAL REPORT W2SD-18 STRUCTURAL DEVELOPMENT TEST (U)**

MTI-478

<table>
<thead>
<tr>
<th>Copy No.</th>
<th>Recipient</th>
<th>Mail Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hq. BSD (AFSC), Norton AFB; Attn: BSRPQ-1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Hq. BSD (AFSC), Norton AFB; Attn: BSRPQ-2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>STL, Norton AFB; Attn: Mr. R. L. Greengard</td>
<td></td>
</tr>
<tr>
<td>4 thru 8</td>
<td>STL, Redondo Beach; Attn: Mr. R. J. Brown</td>
<td></td>
</tr>
<tr>
<td>9 thru 18</td>
<td>Armed Services Technical Information Agency, Arlington 12, Virginia</td>
<td></td>
</tr>
<tr>
<td>19 thru 22</td>
<td>Central Intelligence Agency, Washington 25, D. C.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>HQ OOAAS (OOYI), Hill AFB, Utah</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>ABL; Attn: Mr. J. C. Foster</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>HPC, Rocky Hill; Attn: Mr. L. B. Johnston</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>D. W. Austin</td>
<td>100-K-2-8</td>
</tr>
<tr>
<td>27</td>
<td>T. W. Barnes</td>
<td>100-K-2-6</td>
</tr>
<tr>
<td>28</td>
<td>G. M. Crook</td>
<td>11-K-2-8</td>
</tr>
<tr>
<td>29</td>
<td>R. E. Folsom</td>
<td>111</td>
</tr>
<tr>
<td>30</td>
<td>R. G. Foust</td>
<td>100-K-1-6</td>
</tr>
<tr>
<td>31</td>
<td>W. L. Gunter</td>
<td>100-K2-0</td>
</tr>
<tr>
<td>32</td>
<td>M. F. Jensen</td>
<td>11-K-2-8</td>
</tr>
<tr>
<td>33</td>
<td>J. L. Knearem</td>
<td>100-K-2-0</td>
</tr>
<tr>
<td>34</td>
<td>T. I. Lester</td>
<td>11-K-2-8</td>
</tr>
<tr>
<td>35</td>
<td>J. H. Main</td>
<td>505</td>
</tr>
<tr>
<td>36</td>
<td>R. R. Russell</td>
<td>100-K2-6</td>
</tr>
<tr>
<td>37</td>
<td>J. N. Sherman/R. L. Schaefer/J. N. Bohn</td>
<td>100-K-1-0</td>
</tr>
<tr>
<td>38</td>
<td>E. F. Shultz</td>
<td>100-K-2-0</td>
</tr>
<tr>
<td>39</td>
<td>D. E. Wachs</td>
<td>703</td>
</tr>
<tr>
<td>40</td>
<td>E. P. Whaley</td>
<td>100-B</td>
</tr>
<tr>
<td>41, 42</td>
<td>Publications Library</td>
<td>702</td>
</tr>
<tr>
<td>43, 44</td>
<td>Library/Central File</td>
<td>509-C</td>
</tr>
</tbody>
</table>

| --       | J. L. Morse (letter only)                                               | 502       |
| --       | A. H. Nielson (letter only)                                             | 81-16-1   |
| --       | S. E. Patti (letter only)                                               | --        |