Project 627-33
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PROGRESS REPORT NO. 3

# AFT-END CLOSURE STUDY
# FOR POLARIS A-3 ROCKET MOTOR CASE

By

H. W. Stevenson
R. A. Harrington

Contract NOw-61-0499-C (FBM)

The B. F. Goodrich Company

Akron, Ohio

Navy Bureau of Weapons

## 1. SCOPE

This is the third in a series of six monthly progress reports to summarize the results of the work performed on Navy Bureau of Weapons Contract NOw-61-0499-C (FBM). This report covers the work performed during the period from July 26, 1961, through August 26, 1961.

## 2. PURPOSE OF STUDY

This contract provides for the study of the aft dome section of the Polaris A-3 Rocket Motor Case and has the following objectives:

a. Reduce bending stress under internal pressurization between metal fitting and fiberglass chamber.

b. Analyze stress pattern around port openings and design optimum port reinforcement for this stress pattern.

c. Design optimum rubber bond between metal cluster fitting and fiberglass chamber.

d. Increase reliability and stress level of fiberglass chamber.

## 3. AREA OF STUDY FOR PERIOD

Work for this period has been concentrated in the following areas:

a. Testing of shear test specimens for determining the optimum adhesive bond between aluminum cluster fitting and fiberglass chamber.

b. Continuing hydrostatic testing of the fabricated sub-scale chambers.

c. Studying the factors and theory involved in the bond stress.

## 4. TESTING SHEAR TEST SPECIMENS

a. The scope of work for developing an optimum bond between the aluminum cluster fitting and the fiberglass was limited to a study with three rubber compounds because adhesive studies are being conducted under another Navy contract. The objective of this study was to determine the effects of bond line thickness, tensile strength and modulus of the rubber compound upon the bond strength.

b. Specimens for adhesion tests were fabricated with 0.010 inch, 0.030 inch and 0.100 inch rubber sheet stock. The sheet stock was calendered to the proper gauge with the 0.030 inch and 0.100 inch having multiple calender plies. The rubber compounds selected for this adhesion study are listed below. Stress strain curves for these compounds are shown in Figure 1.

39322 - B. F. Goodrich - A silica filled nitrile rubber

139WH45 - B. F. Goodrich - A high modulus nitrile rubber compound

V-52 - General Tire & Rubber - An asbestos filled nitrile rubber

c. The single-lap shear specimens were constructed as shown in Figure 4 of Progress Report No. 1. The aluminum sheet was 0.040 gauge 7075-T6. The metal was prepared for bonding by the following procedure.

(1) Degrease in trichloroethylene

(2) Grit blast with 200 mesh grit

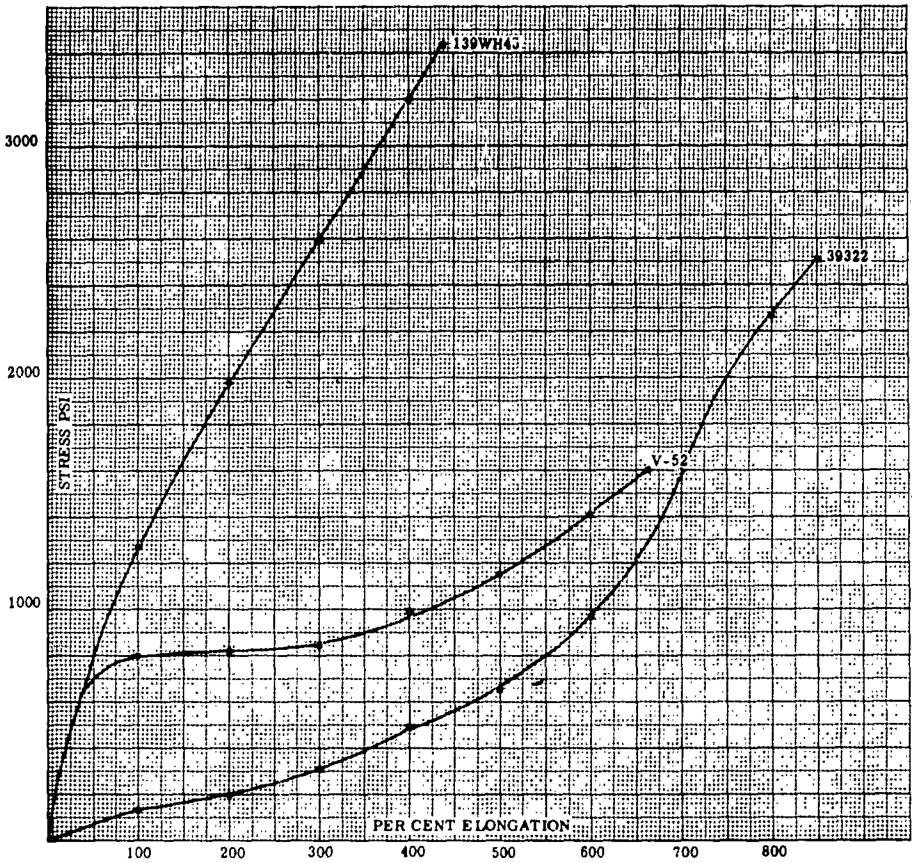



Figure 1. Stress curves for selected test compounds.

(3) Apply one coat of Ty-Ply BN rubber adhesive primer

(4) Apply one coat of 0139WH23 cement

(This cement was used for 39322 and 139WH45 samples. The cement used for the V-52 samples was 0139WH50.)

d. Ty-Ply BN is a product of Marbon Chemical Company used for adhesion of rubber to metal. Cements 039WH23 and 0139WH50 are nitrile rubber cements used with the 39322 and V-52 insulator compounds. The rubber sheet stock was cleaned with methyl-ethyl ketone and air dried to remove solvent before applying to the primed metal. One complete set of specimens was made by curing the rubber to the metal before bonding to the fiberglass. The second set of specimens was made with uncured rubber; the rubber and fiberglass were cured in one operation. The uncured rubber sheet was prepared for bonding to the fiberglass by first cleaning with methyl-ethyl ketone and then applying a flexible epoxy adhesive. The epoxy adhesive was allowed to "B" stage until it reached a tacky state; then the fiberglass laminate was placed in position with the specimen cured. The cured rubber sheet was cleaned with trichloroethylene, followed by buffing with 80 grit emery. The flexible epoxy adhesive was then applied and allowed to "B" stage until tacky. The fiberglass laminate was applied and the specimen cured. All specimens were cured in a press with electrically heated platens with 25 psi pressure.

The flexible epoxy primer was compounded using Epon 828 from Shell Chemical Company, and LP-3 from Thiokol Chemical Company. The adhesive was cured with Curing Agent D from Shell Chemical Company. The recipe is listed below:

| Material | Parts per hundred |
|---|---|
| Epon 828 | 65.0 |
| LP-3 | 35.0 |
| Curing Agent D | 8.4 |

f. Test results on the adhesion samples with rubber precured to the metal were about equal to the results for the uncured rubber specimens. The results indicate uncured 139WH45 in 0.010 inch thickness gives higher bond strengths than the other two rubber compounds. Failure analysis indicates the heavier gauge rubber compounds have a tendency to fail in the rubber stock. This is more prevalent in the asbestos-filled rubber compound than in the other two compounds tested. The 0.030 inch samples appeared to fail prematurely because of ply delamination. This test is being repeated with limited specimens for this reason.

g. Increasing the bond line thickness of the rubber stock from 0.010 inch to 0.030 or 0. 100 inch did not result in a marked increase in bond strength. The thicker samples of precured 39322 did show some increase in bond strength; however, this increase was not obtained with the uncured rubber specimens. Failure analysis of the specimens indicates the reason for low strengths of 0.100 inch rubber may be porosity of the rubber stock adjacent to the primer. This condition was not present in the 0.010 inch rubber stocks. Failure at the interface between the rubber and the epoxy primer in a large percentage of specimens indicates this is a problem which should be investigated. Adhesion of the rubber insulator to the fiberglass has also been a problem with some A-2 motor cases. Data for the single lap shear specimens are given in tables I, II and III.

Table I. Single-Lap Shear Specimen Test Data, 39322 Rubber Compound

| Sample No. | Rubber Precured to Metal Pound load at failure | | | Uncured Rubber to Metal Pound load at failure | | |
|---|---|---|---|---|---|---|
| | 0.010 ga. | 0.030 ga. | 0.100 ga. | 0.010 ga. | 0.030 ga. | 0.100 ga. |
| 1 | 730 | 366 | 780 | 690 | 320 | 490 |
| 2 | 652 | 440 | 960 | 780 | 260 | 550 |
| 3 | 782 | 572 | 925 | 510 | 200 | 600 |
| 4 | 692 | 468 | 790 | 600 | 270 | 610 |
| 5 | 516 | 308 | 915 | 610 | 340 | 530 |
| 6 | 374 | 386 | 960 | 630 | 510 | 510 |
| 7 | 488 | 354 | 715 | 570 | 420 | 560 |
| 8 | 516 | | 745 | 600 | 420 | 610 |

## 5. TEST ON SUB-SCALE CHAMBER 823-10

a. This is a continuation of the sub-scale chamber test series described in Report No. 2. The port reinforcement for this chamber is illustrated in Figure 2. A spiral wound ring was positioned between plies of unidirectional tapes which were placed tangential to the port opening. The reinforcement was constructed to extend over the tangent point for a distance of one inch. The same resin system was used to wind the chamber and to fabricate the port reinforcements.

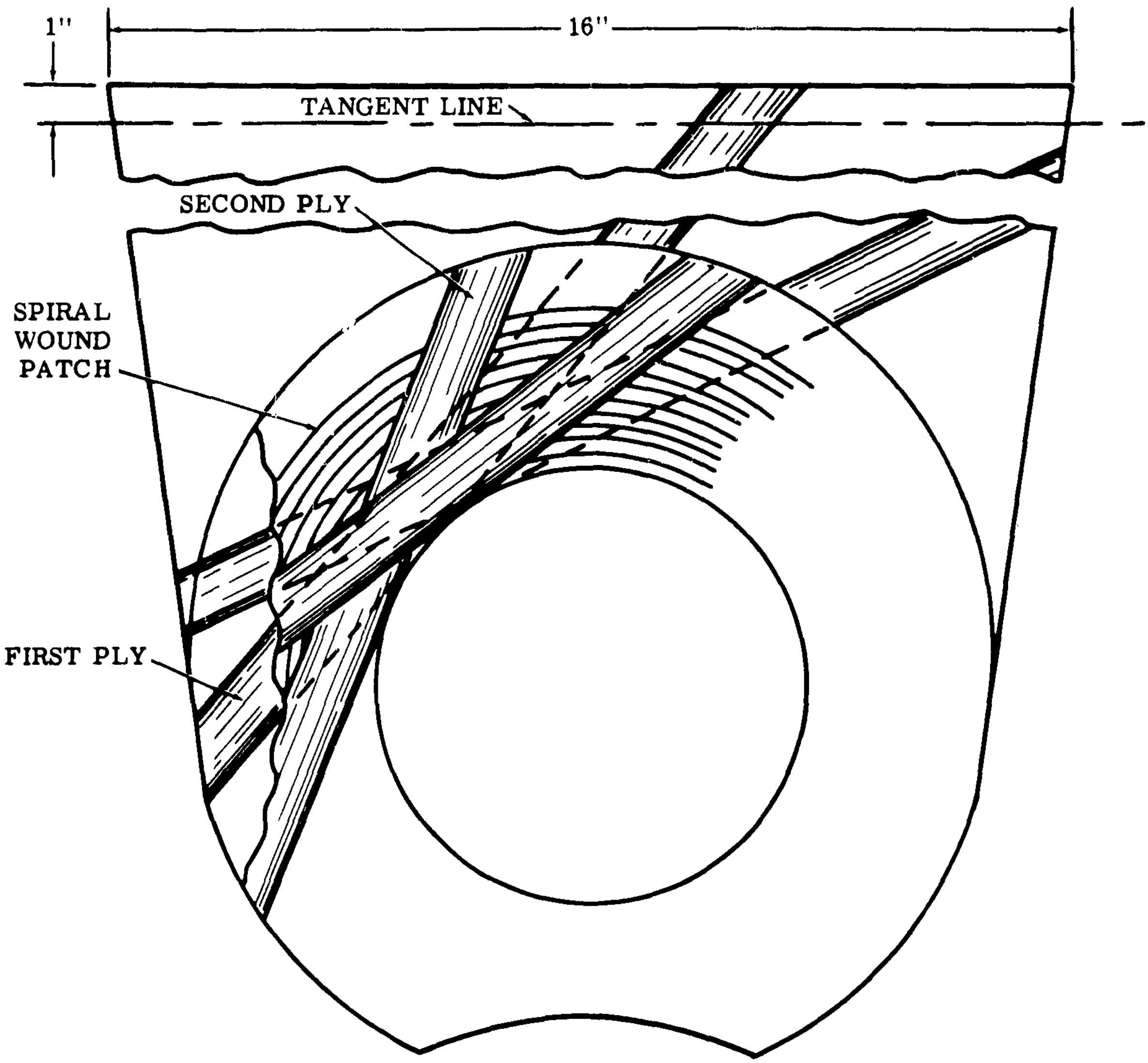
Table II. Single-Lap Shear Specimen Test Data, 139WH45 Rubber Compound

| Sample No. | Rubber Precured to Metal Pound load at failure | | | Uncured Rubber to Metal Pound load at failure | | |
|---|---|---|---|---|---|---|
| | 0.010 ga. | 0.030 ga. | 0.100 ga. | 0.010 ga. | 0.030 ga. | 0.100 ga. |
| 1 | 574 | 610 | 680 | 1310 | 360 | 790 |
| 2 | 460 | 690 | 612 | 890 | 340 | 700 |
| 3 | 672 | 512 | 580 | 630 | 420 | 710 |
| 4 | 582 | 684 | 672 | 920 | 290 | 890 |
| 5 | 542 | 530 | 802 | 640 | 580 | 600 |
| 6 | 504 | 676 | 690 | 650 | 330 | 890 |
| 7 | 554 | 540 | 590 | 1100 | 400 | 530 |
| 8 | 470 | 822 | 628 | 1140 | 350 | |

Table III. Single-Lap Shear Specimen Test Data, V-52 Rubber Compound

| Sample No. | Rubber Precured to Metal Pound load at failure | | Uncured Rubber to Metal Pound load at failure |
|---|---|---|---|
| | 0.030 ga. | 0. 080 ga. | 0.080 ga. |
| 1 | 700 | 686 | 330 |
| 2 | 690 | 482 | 400 |
| 3 | 640 | 726 | 370 |
| 4 | 732 | 766 | 280 |
| 5 | 1032 | 806 | 570 |
| 6 | 782 | 768 | 480 |
| 7 | 676 | 552 | 420 |
| 8 | 832 | 582 | |

b. Analysis of port reinforcements indicates one cause of failure may be due to differences in cure rates of the resin system in the port reinforcements and the longitudinal winds. The resin used for winding the chamber has a shorter gel time than the resin in the port reinforcement; thus the resin on the longitudinal winds gels first, preventing uniform flow of resin from the port reinforcement. This causes a film of resin to form between the port reinforcement and the longitudinal fibers. This film of resin is the weak point in the wall of the motor case because of low shear strength in the resin film. The stress induced in this resin film by shrinkage during cure may also contribute to failures at low stress levels. The flow of resin from the port reinforcement through the semi-cured longitudinal fibers has a tendency to move the fibers out of their natural position over the dome, causing distortion in the fibers and flaws in the case wall. This can result in failure of the rocket case at low stress levels.




Chamber No. 823-10

Notes:
1. Patch is made of 28 BFG preimpregnated Tapes 1" wide by 0.007" thick.
2. Patch is placed between first and second revolution.
3. Weight = 0.22 lbs.
4. Spiral wound patch made of ECG 150 1/0 1. OZ. yarn 0.020" thick.

Figure 2. Chamber 823-10 Reinforcement

c. The difference in cure rates of the Scotch Ply 1009 resin and the aromatic amine cured Epon 826 used to wind the motor case appears to be the cause of poor interlaminar bonding between the port reinforcement and the longitudinal winds. Chamber 823-10 was fabricated to test this theory of resin cure compatibility. The unidirectional tape was made by coating the fibers with resin as they were drawn from the bushing. This made it possible to use the same resin system for the port reinforcement and to wind the chamber. The spiral wound ring on port number two was cut in the area adjacent to the center boss to allow this ring to conform to the surface of the case. The resin in this ring was "B" staged excessively making it difficult to form the ring to the contour of the chamber.

d. The chamber failed at port number two at a pressure of 255 psi. The shear lines originated at the point where the spiral ring was cut and ran in a meridional line outside the edge of the port reinforcement to the point of tangency. The bonding of the port reinforcement to the longitudinal winds was good, indicating the compatibility of cure rates for the resins is important. The other three ports show no sign of strain or shear lines. Refer to table IV.

6. TEST ON SUB-SCALE CHAMBER 823-11

a. To obtain a direct comparison of the two types of aft metal fittings, rigid and flexible, a chamber was constructed using the SM-1, design 4, aft cluster fitting with no port reinforcement. This was done to determine the effect of the rigid metal fitting on the burst pressure due to bending forces at the edge of the fitting.

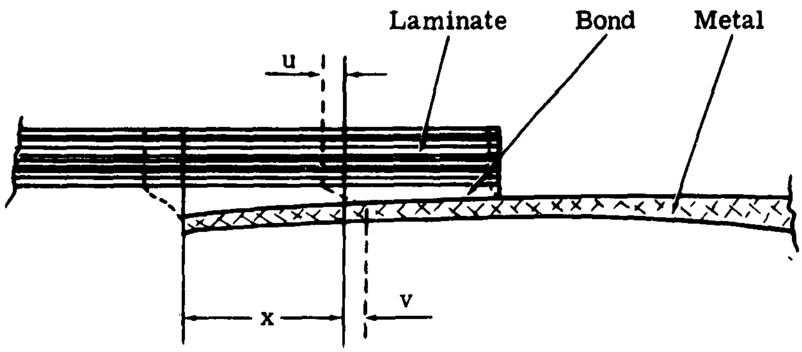
b. The chamber failed at 135 psi pressure as predicted. This was a lower burst pressure than obtained with the flexible metal fitting. Chambers 823-1, 2, 3, and 4 with the semi-rigid aft adapter failed at 220 psi. The type of failure was the same for all cases. The cause of early failure is believed to be local bending of the laminate at the edge of the aft cluster fitting. This condition would probably be minimized if the aft cluster fitting was made slightly flexible at the outer edge.

7. BOND STRESS STUDY

a. It is desirable to spread the adhesion load between glass laminate and aft cluster fitting over a reasonably large area of bond, in order to achieve maximum bond strength. The strength will depend on how uniformly the bond load is spread over the available area. It is possible that significant increases in bond strength can be achieved by tapering the metal fitting, or by tapering the bond thickness, or both.

Table IV. Burst Test Data

| Chamber No. | Type Aft Adapter | Location of Adapter | Type Port Reinforcement | Number of Reinforcements per Port and Weight | Burst Pressure | Point of Failure |
|---|---|---|---|---|---|---|
| 823-10 | Design SM-1 No. 4 Aluminum adapter, rigid. | Underside of Fiber-glass. | Placed between revolutions 1 and 2. (See figure 2) | 0.22 lbs | 255 psi | Tensile failures along shear line, lifting the reinforcement. |
| 823-11 | Design SM-1 No. 4 Aluminum adapter, rigid. | Underside of Fiber-glass. | None | None | 135 psi | At the port opening along shear lines, parallel to the meridian through center of port. |




Dotted lines show deflected position.

Figure 3. Deflections at Bond

b. In the simplified theory we assume that the shear modulus of the laminate (interlaminar) and of the metal are very large compared to the shear modulus of the bond material. The meridional extension of both the metal and the laminate and the shear deformation of the bond were considered but any effects of bending or of shrinkage or expansion in the hoop direction which may result from pressurization were neglected in this phase.

c. Let X be the distance along the meridian from the edge of the aft cluster fitting in the unloaded chamber, and let L be the bond length so that the bond extends from X = 0 to X = L (see figure 3). Let u be the displacement of the glass laminate under load, and v be the displacement of the metal, measured in opposite directions, with respect to the edge of the cluster as a reference point. Let $W_1$, $W_2$, $W_3$ be the respective thickness of laminate, bond material, and metal. These are considered functions of X. Let $E_1$ and $E_3$ be Young's moduli for the laminate and metal, and let G be the shear modulus of the bond material. Let F be the bond load per unit of circumference.

Glass strain $= \frac{du}{dx}$ Glass Stress $= -E_1 \frac{du}{dx}$

Metal strain $= \frac{dv}{dx}$ Metal stress $= E_3 \frac{dv}{dx}$

Glass tension (per hoop inch) $= -W_1 E_1 \frac{du}{dx}$

Metal tension (per hoop inch) $= W_3 E_3 \frac{dv}{dx}$

Total tension $= F = -W_1 E_1 \frac{du}{dx} + W_3 E_3 \frac{dv}{dx}$

Shear strain in bond $= (u + v)/W_2$

Shear stress in bond $= G(u + v)/W_2$

Equations for load transfer:

$$\frac{d}{dx}\left(W_1 E_1 \frac{du}{dx}\right) = G(u + v)/W_2$$

$$\frac{d}{dx}\left(W_3 E_3 \frac{dv}{dx}\right) = G(u + v)/W_2$$

Boundary conditions:

At $X = 0$, $v = 0$, $\frac{dv}{dx} = 0$, and $W_1 E_1 \frac{du}{dx} = -F$

At $X = L$, $\frac{du}{dx} = 0$, $W_3 E_3 \frac{dv}{dx} = F$

Solutions for these equations are now being sought to determine whether or not a significant improvement in bond strength may be hoped for if the bond material or the metal or both were to be tapered. The results will be indicated in a later report.