NASA TECHNICAL MEMORANDUM

NASA TM X-1147

NASA TM X-1147

BALLOON TANK SKIN STRAIN MEASUREMENTS AT LIQUID-HYDROGEN TEMPERATURE ON CENTAUR FLIGHT VEHICLE

by Tilak R. Lall, Frank A. Maruna, and William F. Lang, Jr.

*Lewis Research Center
Cleveland, Ohio*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1965

NASA TM X-1147

BALLOON TANK SKIN STRAIN MEASUREMENTS AT LIQUID-HYDROGEN TEMPERATURE ON CENTAUR FLIGHT VEHICLE

By Tilak R. Lall, Frank A. Maruna, and William F. Lang, Jr.

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

BALLOON TANK SKIN STRAIN MEASUREMENTS AT LIQUID-HYDROGEN TEMPERATURE ON CENTAUR FLIGHT VEHICLE

by Tilak R. Lall, Frank A. Maruna, and William F. Lang, Jr.

Lewis Research Center

SUMMARY

The Centaur liquid-hydrogen tank at station 402 was instrumented with four strain-gage installations on the Atlas-Centaur AC-3 flight vehicle. These gages were subjected to an extremely severe environment both during vehicle assembly at Cape Kennedy and during flight when the temperature at the gage was -423° F. This report covers the installation of the gages, the signal-conditioning equipment and system calibration, and analysis and evaluation of data obtained from the flight.

In spite of the severe environment both before and during the flight, useful data were obtained to evaluate structural performance. Incremental loads from launch to booster engine cutoff obtained from the strain gages were compared with the values computed from known mass distribution and gravity environment. Of the values at the four gage locations, two agreed almost exactly with the calculated values. Of the other two, one differed by 12 percent and the other by 15 percent. Although bonded gages have been in use in the laboratory at liquid-hydrogen temperatures, this technique on flight vehicles presented many problems. The results indicate, however, though the bonding process is a painstaking one, such gages can be a valuable tool for evaluating flight structural performance.

INTRODUCTION

The use of liquid-hydrogen fuel and a pressure stabilized tank structure presented a unique problem in the measurement of strain on the Centaur vehicle. Bonding techniques developed for normal applications were woefully inadequate at liquid-hydrogen temperature (-423° F). Pioneering work at the Lewis Research Center had developed techniques for bonding strain gages to metal at the very low temperatures of interest. Performance characteristics of several commercially available foil gages had been evaluated at

Lewis. These data included resistance and gage factor as a function of temperature in the range of room to liquid-helium temperature. These data are contained in references 1 and 2.

In the application of these gages to the Centaur vehicle, two problems were immediately apparent:

(1) Application of bonding techniques developed for use under controlled laboratory conditions to relatively uncontrolled conditions in the field

(2) Lack of a suitable location to place a dummy gage in a no-strain environment for use as temperature compensation

The methods by which these problems were resolved are discussed in some depth in this report. Details of the bonding procedure are given in the appendix.

The signal-conditioning and Wheatstone bridge network and the accessory box that contained the electronic equipment were designed and fabricated at Lewis. Calibration of each strain-gage installation was accomplished by Lewis personnel with the vehicle on the launch pad. An attempt was made to check the calibrations during the flight composite and tanking test. Because of the internal pressure limitations of the tank and consequent low strain levels, however, this check was of doubtful value. Evaluation of flight data showed that valid responses were recorded from these gages. → end

SYSTEM DESCRIPTION

Choice of Strain-Gage and Bonding Materials

Success of the entire strain-gage system was dependent on the judicious choice of the foil gage and bonding material to be used on this vehicle. Because of the necessity of calibrating the system at ambient temperature, whereas in the flight environment the gages would experience liquid-hydrogen temperatures, it was desirable to select a strain gage the gage factor and resistance of which were substantially constant over this temperature range. The stabilized Armour D gage (ref. 1) fulfilled these requirements and was selected for this application. Because of the slope of the curve of resistance as a function of temperature at liquid-hydrogen temperature, however, it was considered advisable to provide temperature compensation. As a result of the lack of a suitable no-strain location for the dummy gage, it was decided to locate the dummy gage in the immediate vicinity of the primary gage but oriented at right angles to it. As the primary strain direction of interest was the longitudinal direction, the dummy gage was mounted in the hoop direction. A schematic drawing of this installation is shown in figure 1, and the manner in which these gages were wired together in the Wheatstone bridge is shown in figure 2. It can be readily seen that, at each such installation, the variable being

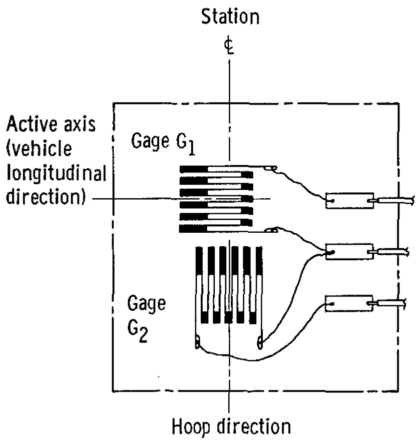


Figure 1. - Strain-gage installation.

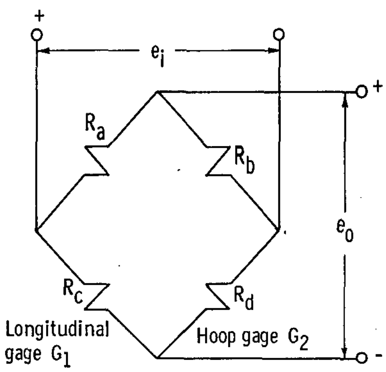


Figure 2. - Wheatstone bridge.

measured was the difference in the longitudinal and hoop strains.

The bonding material selected for installing the strain gages on the tank was GA-5 epoxy cement because of its relative lack of affinity for moisture. Curing the epoxy could be accomplished in the factory by using suitably positioned heat lamps. Affinity for moisture was an important consideration because the environment at the time of installation was such as to preclude any humidity control. One other cement was tried, but its affinity for moisture resulted in failure of the bond when subjected to cryogenic temperatures. Each installation was finally waterproofed with a coating of Ten-X (Gagekote #1).

Installation Details

Four strain-gage installations were used at vehicle station 402, as shown in figure 3. These gages were installed approximately 6 inches forward of the station 408 joint and essentially out of the discontinuity area. Care was also taken to keep them well clear of the longitudinal skin splice. Each set of two locations was placed diametrically opposite each other to facilitate analysis of the data, as is discussed in the section DERIVATION OF EQUATIONS. The liquid-hydrogen-tank insulation panels covered the entire strain-gage instrumentation, though at this station the panels flaired away from direct contact with the tank. Once the insulation panels were installed, it was impossible to gain access to the strain gages. Furthermore, the strain gages first encounter liquid-hydrogen temperatures after the insulation panels are on. Hence, in the event of a preflight failure of any of these gages, corrective action would not be possible. In view of this, great care was exercised during the bonding process to ensure a good bond.

The bonding process was essentially as described in reference 1. Special fixtures were designed to hold the clamps for application of pressure during the curing process. Heat lamps were used to provide the temperature environment, control being effected by use of thermocouples and by varying the distance of the heat lamps. The work was accomplished while the tank was in the assembly dock and concurrent with all other operations and installations necessary to vehicle buildup. As much as possible of the work was scheduled for off-shift hours to keep interference to a minimum. Experienced Lewis

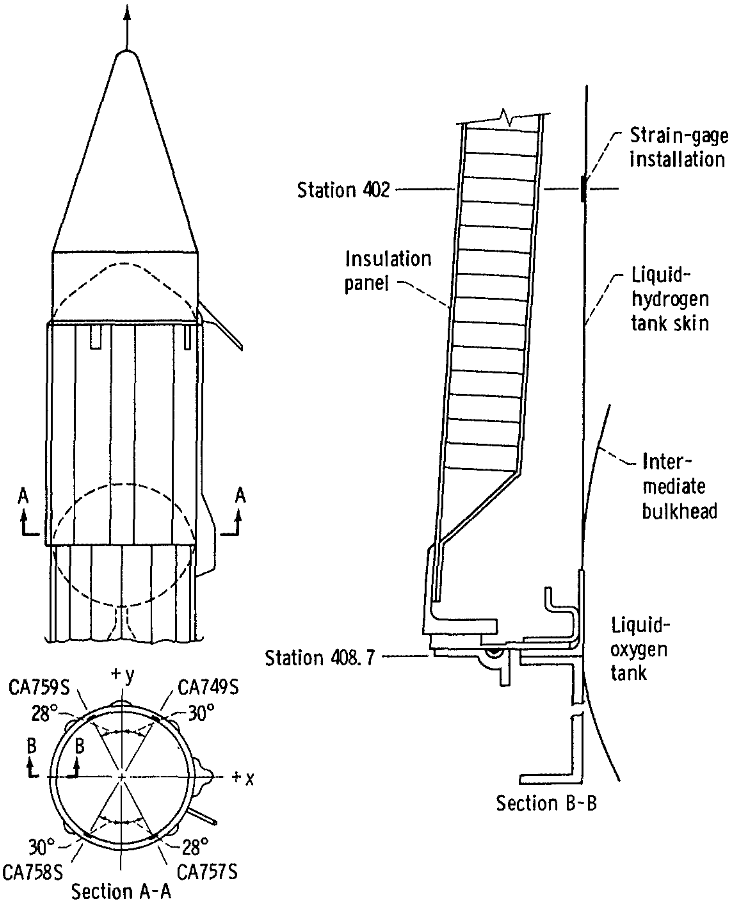


Figure 3. - Installation details of station 402 strain-gage instrumentation.

TABLE I. - RESISTANCE TO GROUND OF EACH STRAIN-GAGE INSTALLATION

Gage number	Location		Resistance, ohms	
	Quadrant	Orientation[a]	Dry	Wet[b]
CA 749S	I	30°	Infinity	Infinity
CA 757S	II	152°	Infinity	7 500 000
CA 758S	III	210°	Infinity	110 000
CA 759S	IV	332°	Infinity	Infinity

[a]Degrees from positive y-axis.
[b]These measurements were made with the vehicle dripping wet with salty water from a fog that had moved in from the sea at Cape Kennedy.

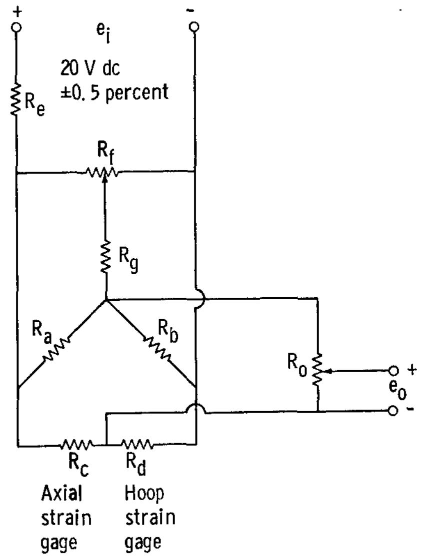
personnel were employed to bond the strain gages to the tank. In general, the task was accomplished quite smoothly considering the difficulties involved. Soldering tabs were used to provide electrical contacts for the harnessing leads. Extreme care was exercised to ensure that the soldering flux did not come in contact with the tank. The flux was neutralized immediately following the soldering.

A satisfactory value of resistance to ground for each gage was measured. These values are shown in table I for dry and salt-water conditions at the launch pad. It is clear that, under the dry helium purge flight environment, the resistance to ground could be assumed to be infinite and the strain-gage installations to be sound. The integrity of the installations was confirmed during the preflight tanking test. The strain-gage bonds were subjected to liquid-hydrogen temperatures and to a varying tank strain due to pressure variations during this test. All four installations yielded satisfactory data and must, therefore, be considered sound.

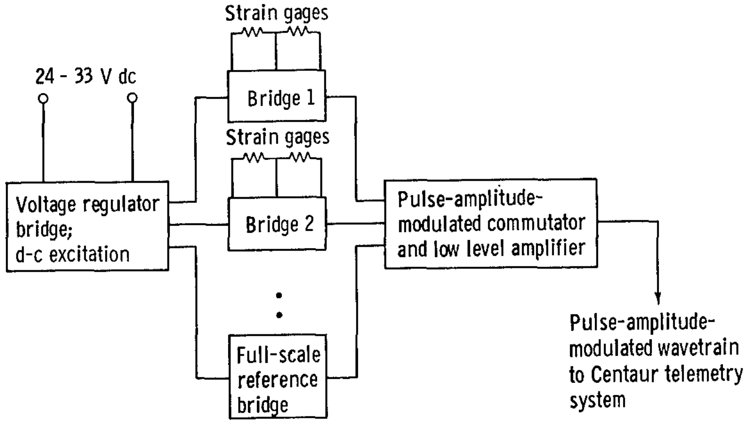
SIGNAL-CONDITIONING SYSTEM

Description

The strain measuring system



(a) Bridge.



(b) Block diagram.

Figure 4. - Typical strain-gage bridge and block diagram of signal-conditioning package.

was the conventional two-active-gage, four-arm Wheatstone bridge with direct-current excitation. The output of each active strain-gage bridge was sampled in time sequence with a low level commutator. The resulting pulse-amplitude-modulated (PAM) wave-train was compatible with the signal input requirements of the Centaur telemetry system.

Bridge Configuration

A schematic drawing of the Wheatstone bridge is shown in figure 2 and was discussed previously. The actual bridge network, as it was wired into the vehicle, is shown in figure 4. It was necessary that the input signal to the commutator (output signal of the strain-gage network) remain of one polarity over the entire strain measurement range. The bridge parameters were chosen to ensure this condition would exist.

The measurement range for these gages was established at

Longitudinal direction	-500 to 3000 microinches per inch
Hoop direction	0 to 1500 microinches per inch

Referring to figure 1 shows that the relation governing the output voltage is given by

$$e_o = \left(\frac{R_c}{R_c + R_d} - \frac{R_a}{R_a + R_b}\right)e_i$$

where

e_o	output voltage
R_c, R_d	strain-gage resistances
R_a, R_b	ballast resistances
e_i	input voltage

It is apparent that, if the polarity is to remain as indicated in figure 2, the ratio $R_c/(R_c + R_d)$ must either equal or exceed the ratio $R_a/(R_a + R_b)$. This was accomplished by establishing the minimum and maximum values of R_c and R_d from known values of each strain-gage resistance and the strain range for each gage. The relation between gage resistance and strain is

$$\Delta R = RG\epsilon$$

where

ΔR	increment of resistance resulting from change in strain
R	resistance of strain gage at zero strain
G	gage factor
ϵ	strain

The resistances R_c and R_d represent the strain gages; the bridge network must be balanced at some point to ensure that all variations of R_c and R_d will result in a positive output voltage.

If the bridge network is zero balanced at the lower strain limit, it must be ensured that the ratio $R_c/(R_c + R_d)$ will increase over its zero-balance value during flight as both R_c and R_d increase in value with increased strain. At a zero-balanced condition

$$\frac{R_c}{R_c + R_d} = \frac{R_a}{R_a + R_b}$$

To ensure that $R_c/(R_c + R_d) > R_a/(R_a + R_b)$ during flight, the lowest possible value of R_c for zero balance must be known, while the highest possible value of R_d for this value of R_c must be known. If the bridge is balanced under these conditions, any change in R_c or R_d will increase the ratio $R_c/(R_c + R_d)$ and result in a positive output.

After the bridge network had been balanced at the lower strain limits to ensure single polarity output, the upper limits of gage strain were determined to provide a full-scale output. This determines the sensitivity or resolution of the bridge network. The full-scale output voltage was divided down to 10 millivolts for full-scale commutator input. Therefore, the full-scale strains had to be chosen to ensure that the resulting output voltage did not exceed the 10-millivolt level. Referring again to the ratio $R_c/(R_c + R_d)$ shows that if full-scale calibration is simulated by substituting a resistance equivalent to the highest possible value of longitudinal strain R_c and the minimum value of strain for the temperature compensating gage for that value of R_c, the output will never exceed the 10-millivolt level.

Auxiliary Signal-Conditioning Package

A block diagram of the signal-conditioning package for these measurements is shown in figure 4(b). The excitation voltage was regulated to 20 volts ±0. 5 percent. The output of the bridges was sampled by an electromechanical commutator. The commutator and a differential input amplifier were contained in a single package referred to as a multi-coder. The input signal of 0 to 10 millivolts produced an international range instrumentation group (IRIG), PAM output of -1. 25 to 5. 0 volts. In addition to the strain-gage bridge cards, provision was made for two cards that would provide a zero and a full-scale reference signal to the commutator. The rate of commutation was 2. 5 revolutions per second. As a result, the actual frequency response of the strain measurements was limited to 1 or 2 cycles per second.

SYSTEM CALIBRATION

Calibration of the strain-gage measurement system was performed in two stages.

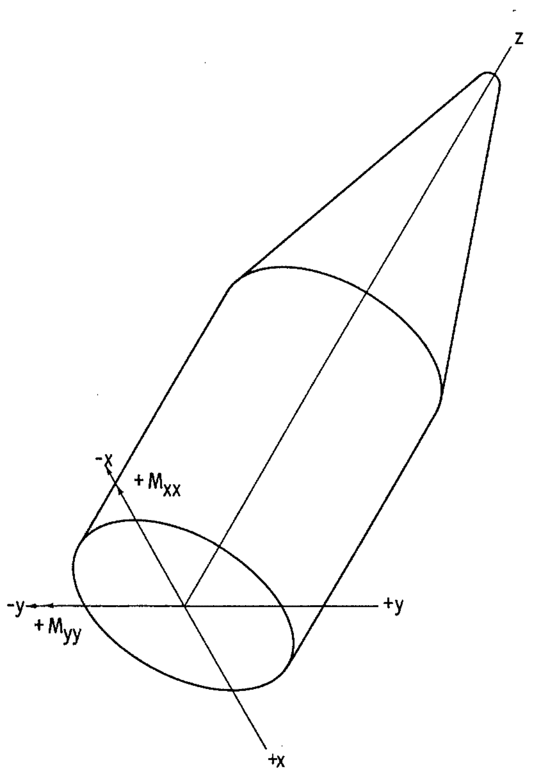


Figure 5. - Coordinate axes and sign convention. View looking forward.

First, the strain-gage auxiliary signal conditioner was calibrated, and second, a system calibration was performed. The signal-conditioning package was calibrated by the use of a special test set that simulated the strain-gage resistance at certain values of strain. The input signal cable from the strain gages was removed and replaced by a signal cable to the test set. The lower limit strain resistance was introduced to each strain-gage bridge; each bridge was then balanced for zero output. The full-scale resistance values were then inserted, and the bridges were again adjusted for a full-scale output of 10 millivolts.

A third set of resistances was inserted that simulated the values of the strain gages under known reference conditions. By replacing the simulator set with actual strain gages under these same reference conditions, a point of cross reference was established.

This calibration procedure was conducted prior to each major test or whenever the reference conditions were changed, such as vehicle erection and mating to the booster stage, installation of insulation panels, and the liquid-hydrogen tanking test. The final calibration was conducted just prior to flight.

DERIVATION OF EQUATIONS

As discussed earlier, each strain-gage installation response was a difference between longitudinal and hoop strains, that is, $\epsilon_1 - \epsilon_2$ where

ϵ_1 longitudinal strain

ϵ_2 hoop strain

Before proceeding with the derivation of the equations, it is necessary to define the sign convention. A bending moment in the pitch plane M_{xx}, that produces compression on the positive y-axis is considered positive. Furthermore, a bending moment in the yaw plane M_{yy} is positive if it produces compression on the negative x-axis. This convention is illustrated graphically in figure 5. In keeping with this convention, the stress field at a point on the cylindrical section of the tank (away from discontinuities) may be defined by the expressions

$$\sigma_1 = \frac{PR}{2t} - \frac{L}{A} - M_{xx}\frac{C_y}{I} + M_{yy}\frac{C_x}{I} \tag{1}$$

$$\sigma_2 = \frac{PR}{t} - \sigma_{2i} \tag{2}$$

where

A	section area, in.^{2}
C_x, C_y	distance of skin element from x- and y-axes, respectively (positive in positive x- and y-directions)
I	section moment of inertia, in.^{4}
L	longitudinal load (positive in negative z-direction), lb
M_{xx}	pitch plane bending moment, in.-lb
M_{yy}	yaw plane bending moment, in.-lb
P	ullage pressure in tank, psig
R	tank radius
t	skin thickness
σ_1, σ_2	stress in longitudinal and hoop directions, respectively
σ_{2i}	tank hoop compressive stress due to insulation-panel interference

Assuming that the values of Poissons ratio μ in the principal directions are equal (verified by coupon test data) gives the strains in the longitudinal and hoop directions:

$$\epsilon_1 = \frac{1}{E_1}\left(\frac{PR}{2t} - \frac{L}{A} - M_{xx}\frac{C_y}{I} + M_{yy}\frac{C_x}{I}\right) - \frac{\mu}{E_2}\left(\frac{PR}{t} - \sigma_{2i}\right) + a_1 T \tag{3}$$

$$\epsilon_2 = -\frac{\mu}{E_1}\left(\frac{PR}{2t} - \frac{L}{A} - M_{xx}\frac{C_y}{I} + M_{yy}\frac{C_x}{I}\right) + \frac{1}{E_2}\left(\frac{PR}{t} - \sigma_{2i}\right) + a_2 T \tag{4}$$

where

a_1, a_2 coefficient of thermal expansion in longitudinal and hoop directions, respectively

E_1, E_2 modulus of elasticity in longitudinal and hoop directions, respectively

Assuming that $a_1 = a_2$ yields

$$\epsilon_1 - \epsilon_2 = \frac{1 + \mu}{E_1}\left(\frac{PR}{2t} - \frac{L}{A} - M_{xx}\frac{C_y}{I} + M_{yy}\frac{C_x}{I}\right) - \frac{1 + \mu}{E_2}\left(\frac{PR}{t} - \sigma_{2i}\right) \tag{5}$$

Equation (5) represents the total response of each strain-gage installation. The primary variables that influence the strain-gage response are ullage pressure, axial load, and bending moments.

The interest in these gages was the calculation of flight bending moments and axial loads. The ullage pressure was measured by an independent pressure transducer. For reasons discussed later, it was considered expedient to measure increments of strain at each gage location from some reference time at which load conditions could be con sidered quiescent. This time was assumed to be T - 10 seconds (i. e., 10 sec prior to launch). At this time the bending moment is zero and the axial load is known from the known mass distribution and 1-g gravity environment. Subscript 0 is used to refer the variables to this time and the subscript t for any other time of interest. There is one strain-gage installation in each quadrant; the gages in quadrants I and III and in II and IV are located diametrically opposite each other. These gages are identified by the quadrant in which they are located by superscripts I, II, III, and IV. From equation (5), the increment of strain response at each location is given by

$$\left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right] = \frac{1 + \mu}{E_1}\left[\frac{(P_t - P_0)R}{2t} - \frac{L_t - L_0}{A} - M_{xx}\frac{C_y}{I}\right.$$

$$\left. + M_{yy}\frac{C_x}{I}\right] - \frac{1 + \mu}{E_2}\left[\frac{(R_t - P_0)R}{t} - (\sigma_{2i_t} - \sigma_{2i_0})\right] \tag{6}$$

Taking the difference in the response in diametrically opposite quandrants gives the following equations:

$$\left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right]^{III} - \left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right]^{I}$$

$$= \frac{1 + \mu}{E_1 I}\left[- M_{xx}(C_y^{III} - C_y^{I}) + M_{yy}(C_x^{III} - C_x^{I})\right] \tag{7}$$

$$\left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right]^{II} - \left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right]^{IV}$$

$$= \frac{1 + \mu}{E_1 I}\left[- M_{xx}(C_y^{II} - C_y^{IV}) + M_{yy}(C_x^{II} - C_x^{IV})\right] \tag{8}$$

There are only two unknowns in equations (7) and (8). All other variables are measured either during the flight or have been previously determined from coupon tests. All pressure terms (ullage and insulation-panel-interference pressures) have been eliminated from the preceding expressions. An equivalent expression for calculating axial load can also be obtained:

$$L_t - L_0 = (P_t - P_0)\frac{RA}{2t} - \frac{E_1 A}{2(1 + \mu)}\left\{\left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right]^{I} + \left[(\epsilon_1 - \epsilon_2)_t - (\epsilon_1 - \epsilon_2)_0\right]^{III}\right\} - \frac{E_1 A}{E_2}\left[\frac{(P_t - P_0)R}{t} - (\sigma_{2i_t} - \sigma_{2i_0})\right] \tag{9}$$

The increment of axial load in equation (9) is a function of the ullage pressure and the interference pressure between the tank and insulation panels.

RESULTS

To enhance the quality of the data obtained from these gages, test specimens were machined from the same roll of sheet material that was used to fabricate the liquid-hydrogen tank. Both longitudinal and transverse specimens were obtained and used to measure the modulus of elasticity and Poisson's ratio. The results of these tests in the two principal vehicle directions are shown in table II. It should be remembered that the rolling direction of the basic sheet material is the hoop direction on the tank.

Aerodynamic loads are the only major source of loads that are wholly dependent on

TABLE II. - SHEET ELASTIC MODULUS AND POISSON'S RATIO FOR

CORROSION-RESISTANT EXTRA-FULL-HARD 301 STAINLESS

Temperature, $^{\circ}F$	Modulus of elasticity, psi		Poisson's ratio	
	Rolling direction	Transverse	Rolling direction	Transverse
Room temperature	25.9×10^{6}	29.2×10^{6}	0.264	0.317
-320	28.6	30.7	.268	.299
-423	31.3	31.5	.301	.296

TABLE III. - COMPARISON OF CALCULATED AND

MEASURED INCREMENT OF STRAIN FROM

LAUNCH TO BOOSTER-ENGINE CUTOFF

Gage number	Measured strain, μin. /in.	Calculated strain, μin. /in.
CA 749S	-1400	-1370
CA 757S	-1230	-1370
CA 758S	-1400	-1370
CA 759S	-1190	-1370

upper altitude wind condition on the day of the launch. Inertial loads can be predicted well in advance and are calculated precisely from trajectory reconstruction data. Hence, there are significant instants of time when the loads are known quite accurately. Two such instants are just prior to launch and at booster engine cutoff (BECO) when the vehicle experiences its maximum longitudinal acceleration. It was possible, therefore, to check the calibration of the strain gages by comparing the increment of strain measured by these gages from launch to BECO to a calculated strain increment based on the known increment of load. This comparison is shown in table III. Two of the gages agree almost exactly with the calculated value. Of the other two, one differed by 12 percent and the other by 15 percent from the calculated value. This agreement between measured and calculated values of strain increment is considered quite good. For purposes of flight-loads calculations, measured values of strain increment were multiplied by an appropriate correction factor based on the assumption that the calculated value of strain increment is the true value.

The strain-gage response histories through the high-dynamic-pressure region of flight were reduced to flight bending moments by equations (7) and (8). These results are shown in figure 6. The liquid-hydrogen tank and the insulation panels form a possible

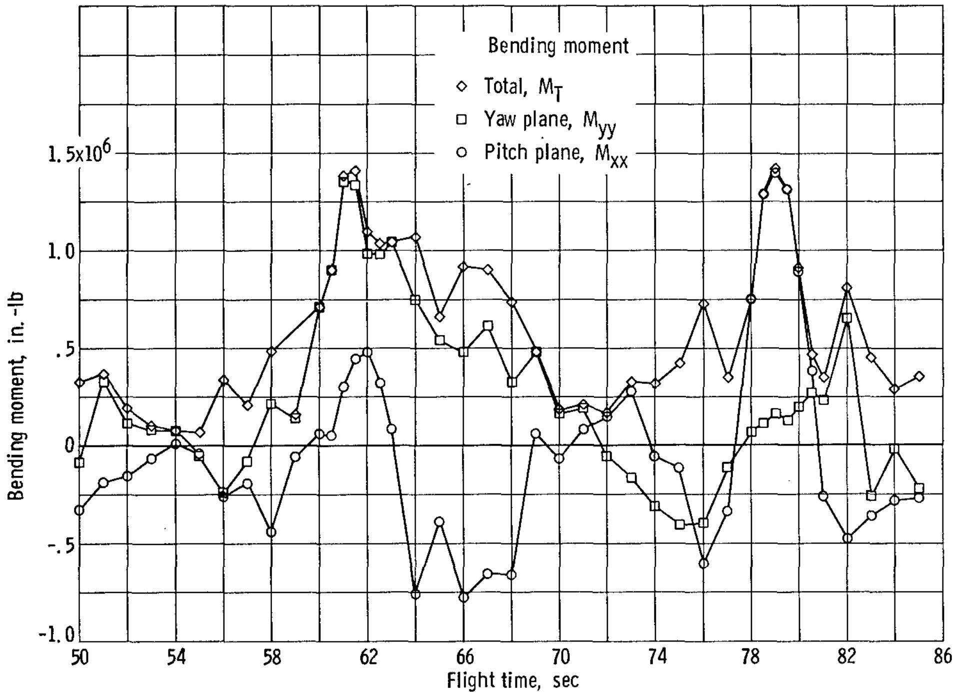


Figure 6. - AC-3 flight bending moment history at station 402 computed from strain-gage response data.

dual load path for flight bending moments. It was of interest to determine the proportion of the load resisted by the tank and by the insulation.

In order to accomplish this, measured angle-of-attack data were used with measured trajectory parameters (dynamic pressure, Mach number, etc.) in a rigid body simulation to calculate gross vehicle bending loads. These loads were then compared with the bending moment history of the liquid-hydrogen tank based on strain-gage data. This comparison is shown in figure 7.

It can be seen that the general trends of the load histories so obtained are in good agreement. The bending moments tend to peak twice during the flight, once at 61.5 seconds and next at 79 seconds. At 61.5 seconds the agreement is not too good, but it should be remembered that, at this time, the vehicle is flying through the transonic regime and a consequent disturbed pressure environment. The sensitivity of the strain-gage network to pressure could explain this discrepancy. It is impossible that the load being resisted by the liquid-hydrogen tank would be greater than the gross vehicle bending. At 79 seconds the loads are in good agreement, 1.55×10^6 inch-pounds from angle-of-attack data compared with 1.43×10^6 inch-pounds from strain-gage data. The difference is relatively minor and within the accuracy of the data. It may, therefore, be inferred that little, if any, of the bending loads is resisted by the insulation panels. Between the two peak loads, the load level is, in general, quite low, and instrumentation and other sources of error form a relatively large part of the total response. No conclu-

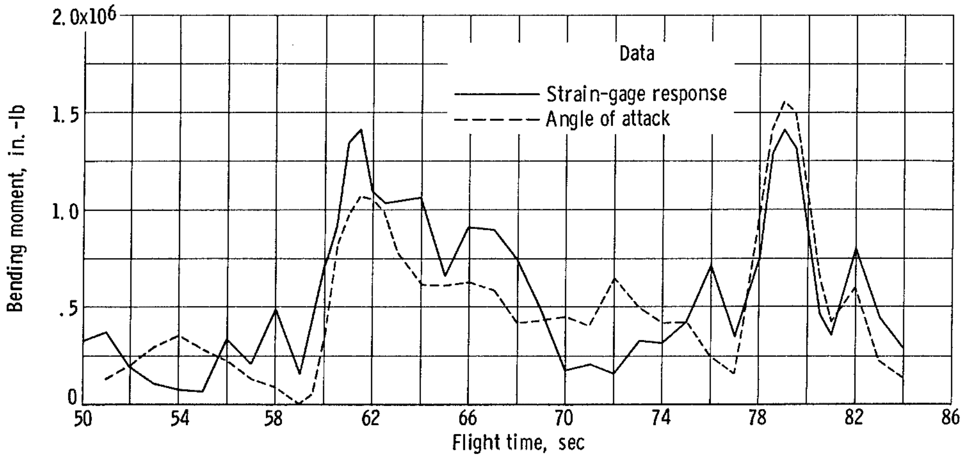


Figure 7. - Comparison of bending moment history obtained from strain-gage-response data and angle-of-attack data through atmospheric flight.

sion can be drawn from this portion of the load history except that the loads were very small.

An attempt was made to calculate longitudinal loads through the atmospheric flight; however, the presence of the tank internal pressure term and the insulation-panel-interference pressure term introduced complications not encountered in bending loads analysis. The forward bulkhead is enclosed by the nose fairing, and the aft bulkhead is enclosed by the interstage adapter. The venting of the cavities during flight results in a complex pressure environment. The longitudinal loads calculated from strain-gage-response data were in error and are not presented here.

CONCLUDING REMARKS

Bonded strain gages can provide a useful tool for the measurement of strain on flight vehicles at liquid-hydrogen temperatures. On the Centaur vehicle, useful information was retrieved from strain-gage-response data. It should be recognized that the process for installation of these gages is a painstaking one that requires considerable skill and patience. In areas where strain gages are essential to evaluate structural performance, however, use of techniques described here and in the references 1 and 2 will result in acceptable strain-gage installations.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 11, 1965.

APPENDIX - PROCEDURE FOR STRAIN-GAGE APPLICATION

The bonding procedure for the application of strain gages to the Centaur liquid-hydrogen tank (corrosion-resistant 301 extra hard stainless steel) is as follows:

(1) Dust the tank in the area of strain-gage locations.

(2) Lay out the strain gage locations and apply masking tape leaving an area approximately 4- by 4-inches surrounding the center of the proposed gage location. Place reference lines on this tape for the exact location. Use 1 inch Scotch flat back masking tape.

(3) Scrub the area within the 4-inch square (2/3 methylethylketone and 1/3 xylene C. P. by volume). Finally scrub with acetone C. P. Do not wipe over tape; stay within the confined area. Do not touch after cleaning.

(4) Carefully apply more tape to reduce the precoat area to the proper size. Cover the area until the next step.

(5) Velvetize the surface to a uniform light gray color holding the nozzle $2\frac{1}{2}$ to 3 inches from work and at an angle of approximately 45°. Catch dust with a vacuum cleaner by using a suitable attachment for maximum recovery of grit:

Equipment: S. S. White Industrial Airbrasive Unit Model C

Supplies : S. S. White Powder #3 and dry nitrogen gas supply at approximately 80 pounds per square inch pressure

(6) Remove inner tape only. Blow off the area with dry nitrogen and retape. Do not touch area. Protect until ready to apply precoat cement.

(7) Mix cement:

(a) Clean all containers with acetone.

(b) Weigh out 2 grams of GA-5 in suitable container that may be covered tightly.

(c) Add six drops of activator.

(d) Weigh out 8 grams of acetone (C. P.) and add to mixture.

(e) Stir mixture for at least 3 minutes with glass rod.

(f) Cover mixture tightly and let set for 1/2 hour.

(g) Keep mixture covered and sealed at all times.

(h) This mixture may be used within 6 hours.

(i) Ambient temperature for use should not be less than approximately 73° F and humidity not more than 70 percent.

(8) Preheat prepared area to approximately 130° F for approximately 5 minutes. Let cool to approximately 100° F and apply first even light coat. Do not dwell on area; make one even pass from top to bottom. Cover and let stand for approximately 15 minutes. Inspect and apply second coat in the same manner the first coat was sprayed; do not reheat. Strive for a total precoat as thin as possible - no more than 0.001 inch.

Equipment: Paasche air brush type H or equivalent and dry nitrogen at 20 pounds pressure

(9) Cover area with a suitable aluminum cover bent to hold away from precoat. This may be held on with green tape.

(10) Let air cure for approximately 2 hours and remove masking tape around area. Replace aluminum cover.

(11) Adjust heat lamp (375 W) to bring temperature up to $180^{\circ} \pm 5^{\circ}$ F for 12 hours continuously.

(12) Inspect precoat for voids, dirt, etc. Check continuity to ground with Simson 260. If precoat is not usable, apply 928400 stripper to gage area for removal and proceed with steps (3), (8), (9), (10), (11), and (12).

(13) Make one single even swipe across precoat area with a clean paper wipe moistened with acetone (C. P.). This should remove the glaze only. If the area becomes sticky, the cure is not complete. Proceed with step (12).

(14) Retape area and extend reference lines from outer tape to inner tape for gage placement. Cover area.

(15) Transfer gages and tabs to cellophane tape. Do not prestress gages. (Trim tabs and wash in acetone (C. P.) before applying. Gage B on tank to be trimmed to dotted line on gage.)

Material: Scotch Brand cellophane tape (width convenient to requirement)

(a) Gages will be selected from package in matched pairs; a variation of 0.2 ohm may be tolerated in matching. Record gage factor, resistance, and lot number.

(b) After transfer, gages should be kept in suitable enclosure prior to installation.

(16) Prepare cement as in step (7).

(17) Preheat area as in step (8), but spray one even coat to place gage.

(18) Place cellophane tape with gages and tabs on sprayed area. Press gages and tabs lightly into place securing the ends of the tape on the dry part of the tank or ring. To avoid placing gage over imperfections in the precoat, gages may be moved ±3/16 inch parallel to both axes only on the tank and ±3/16 inch along the circumference on the ring mounts.

(19) Place a piece of Teflon 0.003 inch thick or less, 2- by 2-inches over gage area. Hold Teflon in place with cellophane tape 1/2 inch wide both top and bottom to hold it smooth over the area.

(20) Place 1/2 inch sponge rubber approximately 2- by 2-inches back up with a piece of aluminum plate approximately 1/16 inch thick 2- by 2-inches. Use a suitable clamping fixture to maintain a pressure of approximately 5 pounds over gage area.

(21) Apply heat as in step (11).

(22) Remove fixture and all padding to cellophane tape.

(23) Apply heat as required to remove cellophane tape from gage and area. Use tweezers and pull tape gently as possible and as close to parallel to the surface as possible.

(24) Wash area with methylethylketone-xylene to remove all tape cement; follow with methylethylketone. Use soft brush and blot with clean wipe. Do not rub.

(25) Make an electrical check on each gage for continuity and check resistance to ground. Use Simson 260 or the equivalent. The resistance to ground should be in excess of 10 megohms.

(26) Wire the strain gage assembly:

(a) Scrape the copper wiring tabs with a clean knife, razor blade, or glass brush.

(b) Clean all proposed solder points on gage and tabs with ethyl alcohol (190 proof).

(c) Tin all copper wiring tabs with a small amount of solder.

(d) Cut a strand of interconnecting wire to a convenient length and solder one end to the copper wiring tab.

(e) Form the wire in a gentle arc to the gage tab. (Use solder - Erson 18 SWG 5 core - 366 flux, 60 percent tin, 40 percent lead - made in England.)

(f) Wet gage tab and wire with flux solution. Keep solution on tab only. Flux solution, 50 percent ortho phosphoric acid (85 percent concentration) and 50 percent distilled water by volume.

(g) Touch gage tab and wire lightly and quickly with a hot soldering iron (Ungar No. 776 with $23\frac{1}{2}$ W heater and needle tip) with a slight amount of solder on tip.

(h) Wet joint with No. 3 Indium flux. Keep flux on the gage tab only.

(i) Touch joint again lightly and quickly with lightly tinned iron to complete connection. Keep joints as smooth as possible. Keep wires flat against precoat.

(j) Neutralize solder joints with ammonia solution (50 percent H_2O and 50 percent ammonia) using soft brush. Wash in the same manner with distilled water. Blot with clean wipe.

(k) Clean all joints with ethyl alcohol (190 proof) to remove all flux. Blot with clean wipe.

(27) With a Wheatstone bridge make an accurate resistance measurement of each gage, A and B, to 0.1 ohm. Record readings. (The resistance of each gage must be matched with mate within 4 ohms.)

(28) With a high-resistance-reading ohmmeter, measure resistance to ground. It should be in excess of 10 megohms. Record reading.

(29) Clear area carefully and thoroughly with methylethylketone-xylene and follow with methylethylketone; keep covered.

(30) Shielded Teflon covered wire is required for the harness to all the gages. It is desirable to run the shielding to 1 inch from the wire solder tab, but for convenience may be cut back as far as 6 inches from solder tabs. All wires should be properly identified so that they can be soldered to their respective gages.

(31) If a wire larger than 26 gage is required (not larger than 22 gage) it will be necessary to remove enough strands from the wire to make it equivalent to 26 gage to solder to the tab. This will be done as follows:

(a) Remove insulation from wire to approximately 1/8 inch from end.

(b) Remove enough strands to make exposed wire equivalent to 26 gage.

(c) Solder the wire at insulation to ensure electrical contact between cut and uncut strands.

(32) After wires are prepared as in step (31), the 1/8 inch exposed wire should be trimmed to a convenient length to fit on the copper wire tab so that the insulation comes to the edge of the copper tab.

(33) Form wires in place, each wire properly identified to these respective gage tabs. Do not solder.

(34) Spot-weld wire holddown strap.

(35) Solder wires in place. Clean joint with ethyl alcohol.

(36) Check complete gage assembly as in step (29).

(37) Mark area with masking tape.

(38) Prepare cement for cover coat as in step (7) and proceed with step (8). Be sure small gage wires are flat against surface.

(39) Continue with steps (9), (10), and (11).

(40) After cure is completed, apply Ten-X water-proofing with small sable brush to all solder joints and connecting gage wires including harness wires. Do not apply to the strain gage element. (The Ten-X compound may be diluted to the proper brushing consistency with methylethylketone C. P.)

(41) Using proper sandwich box, measure total gage and harness resistance with Wheatstone bridge. Record A gage to common and B gage to common. Also record the resistance to ground for each assembly made.

(42) Provide suitable covers for tank gages made from a water-proof material; secure to tank with green tape. Louvers should be designed to give adequate ventilation.

REFERENCES

1. Kaufman, Albert: Investigation of Strain Gages for Use at Cryogenic Temperatures. NASA RP-37, 1963. (See also Exp. Mech., vol. 3, no. 8, Aug. 1963, pp. 177-183.)

2. Kaufman, Albert: Performance of Electrical-Resistance Strain Gages at Cryogenic Temperatures. NASA TN D-1663, 1963.

3. Staff of Lewis Research Center: Postflight Evaluation of Atlas-Centaur AC-3. NASA TM X-1094, 1965.