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9TH AEROSPACE MECHANISMS SYMPOSIUM

Held at
John F. Kennedy Space Center
Kennedy Space Center, Fla. 32899
October 17-18, 1974

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1975

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16. Abstract

This symposium includes presentation of both successes and failures in the design and development of mechanisms for space and aeronautical research programs. Emphasis is given to aerospace mechanisms which have been either flight qualified or flight demonstrated.

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PREFACE

The 9th Aerospace Mechanisms Symposium, held at the John F. Kennedy Space Center, Florida, October 17 and 18, 1974, was sponsored jointly by the National Aeronautics and Space Administration, Lockheed Missiles and Space Company, Inc., and California Institute of Technology. This symposium is devoted exclusively to an interchange of ideas and information on aerospace mechanisms.

Contributions were from NASA Research Centers, U.S. universities, and U.S. manufacturers.

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ACKNOWLEDGMENTS

This report and the conduct of the symposium benefited from the dedicated contribution of many individuals and organizations. In addition to the key role played by the Committee for Aerospace Mechanisms Symposium, I wish to recognize the efforts of the local arrangements committee at the John F. Kennedy Space Center. They include: Barbara M. Westfeldt, Nadine Y. Socks, Fred Christ, Kirby Key, W. Wheeler, W. C. Jones, Norm R. Perry, L. Blocker, W. Munsey, R. Cato, R. Miller, G. Brown, Jean S. String, James M. Taylor, Thurman Killian, F. Markley, Al Lavender, Diana Holden, Beverly Wesche, and Grace Palmer.

O. H. Fedor
Host Chairman,
John F. Kennedy Space Center

9TH AEROSPACE MECHANISMS SYMPOSIUM

MORNING SESSION - October 17, 1974

Chairman: K. A. Faymon
NASA Lewis Research Center

Chairman: E. E. Sechler
California Institute of Technology

AFTERNOON SESSION

Chairman: A. C. Bond
NASA Lyndon B. Johnson Space Center

N76-19173

1. FORWARD BEARING REACTOR MECHANISM FOR TITAN IIIE/ CENTAUR D-1T SPACE LAUNCH VEHICLE

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SUMMARY

This paper describes a load sharing system between the Titan/Centaur launch vehicle and its aerodynamic shroud. The system provides a precise spring constant and is capable of being inactivated during flight. Design requirements, design details, and the test program are discussed. The conventional English system of units was used during this development program for all principal measurements and calculations.

INTRODUCTION

The Titan IIIE/Centaur D-1T is the nation's newest space launch vehicle. The vehicle has recently been developed through the marriage of the newest booster in the Titan III family with the latest version of Centaur, the nation's first high energy upper stage vehicle. The Titan/Centaur vehicle was developed to launch the Viking spacecraft to Mars in 1975. It is also to be used to launch the Helios solar probe payloads and two Mariner-Jupiter-Saturn payloads in 1977. The configuration is characterized by a newly developed bulbous 4.27 meter (14 foot) diameter Centaur Standard Shroud (CSS) which covers the payload, the Centaur, and part of the Titan/Centaur interstage structure. The shroud is attached to and cantilevered from the interstage structure. The Titan/Centaur vehicle is shown in Figure 1.

In order to gain the cost effectiveness of commonality, the Centaur D-1T utilizes the same propellant tanks as those used on the version of Centaur which is flown on the Atlas booster. The propellant tanks, in addition to containing the Centaur propellants, are pressure stabilized in order to react vehicle external loads. For the Atlas/Centaur the loads are normally critical at 1) launch due to payload lateral excitation, 2) at the time of maximum aerodynamic pressure, 3) at booster engine shutdown, and 4) at the various Centaur engine starts and shutdowns. For the Titan/Centaur, those four critical load times are identical to the Atlas/Centaur except for the maximum aerodynamic pressure load. The tanks are not subjected to aerodynamic loads because they are protected by the CSS. However, the other three critical load conditions, which are mainly payload weight originated, cause higher loads in the Titan/Centaur propellant tanks because the Titan/Centaur vehicle has a greater payload weight capability than the Atlas/Centaur. Analyses showed that the common propellant tanks could withstand all the larger Titan/Centaur loads except the launch lateral transient load imposed by the payload. Under this load condition, the aft end of the tanks became structurally critical due to the bending moment resulting from the relatively long cantilever support of the payload.

Two methods to alleviate that situation were considered; first, to increase the tank pressures and second, to provide a lateral load sharing device with the shroud. The first method had the disadvantage of requiring increased tank skin gages, revision to the pneumatic system, and revisions to many other related vehicle components and systems. In short, the propellant tanks would no longer be common. The second method, in addition to the advantage of preserving commonality of the tanks, had a further advantage of supporting the shroud during the aerodynamic load period of flight. Since CSS-to-payload and CSS-to-Centaur relative deflections are critical, CSS weight would be excessive if it had to be designed as a cantilevered structure attached at its aft end. A lateral support for the CSS to share airloads with the Centaur structure reduced the required CSS stiffness and thereby reduced its weight.

Conceptually, the ideal load sharing device would consist of a series of closely spaced springs between the Centaur vehicle and the CSS. This ideal system is shown schematically in Figure 2.

DESIGN REQUIREMENTS

The lateral support system was named the Forward Bearing Reactor (FBR) and the following requirements were established for its design:

A. The lateral support system was to be mounted at the forward end of the Stub Adapter, which is near the forward end of the cylindrical portion of the Centaur vehicle. See Figure 1.

B. The maximum lateral limit load capability of the Centaur vehicle at the station location described above is 88,965 Newtons (20,000 pounds). The maximum allowable deflection at that location is plus or minus 2.54 centimeters (1 inch), based on CSS-to-payload clearance limitations and allowable motions designed into components spanning between the CSS and Centaur. Therefore, a maximum spring constant was established for the FBR system to be 35,293 Newtons per centimeter (20,000 pounds per inch). Additionally, in order to facilitate overall vehicle loads analyses, it was required that this spring constant be constant over the full range of deflection of plus or minus 2.54 centimeters (1 inch).

C. The FBR had to withstand a thermal environment of $-54^{\circ}C$ ($-65^{\circ}F$) to $+71^{\circ}C$ ($+160^{\circ}F$) and a pressure enviroment of sea level to 1 millimeter of mercury.

D. The presence of an FBR during the aerodynamic heating phase of flight is objectionable because of the asymmetric loads introduced into the CSS. Therefore, a requirement was established that the FBR system had to be made incapable of load transmittal after maximum aerodynamic loads were reduced but before significant aerodynamic heating had begun.

E. The FBR system had to provide sufficient clearance so that there would be no "hang-up" or "bumping" during CSS jettison.

F. The system chosen to render the FBR system incapable of load transmittal in flight had to be redundant. The system also had to be self-containing (no debris) and if there was a shock environment associated with the system, the shock levels had to be low.

G. Any material left on the Centaur vehicle after jettison had to either be local and confined close to the vehicle or, if the material protruded outboard, it had to be non-metallic. This was required so as to not cause interference with antenna patterns from the antennas located just aft of the FBR system.

H. The FBR system had to be capable of sustaining an axial deflection of the vehicle moving aft with respect to the CSS of 1.75 centimeters (0.69 inch) at liftoff and 1.47 centimeters (0.58 inch) during the period of maximum aerodynamic pressure. This is caused mainly by cryogenic shrinkage of the Centaur propellant tank.

I. There was a design goal to make the system light with minimum system weight remaining with the vehicle. Since the CSS is jettisoned rather early in flight, the trade-off factor with payload weight is more favorable for CSS weight than for vehicle weight.

CONCEPTS

Several concepts were studied to identify a system to meet the above requirements. The concepts are listed below with a brief description of each.

Struts with Elastomeric Links and Elastomeric Spheroids

These two concepts were basically similar; they both employed elastomeric material to provide the precise spring constant required. However, preliminary studies and analyses indicated that it might not have been possible to design an elastomeric device which would have a linear spring constant over the temperature and load range required. The development program to determine the shape of the elastomeric material, if any, that would satisfy the requirements was considered risky.

Struts with Pneumatic Cylinders

This concept consisted of a pneumatic pressure compartment within a strut to provide the desired spring constant. The disadvantages of this system included its complexity because of the required gas storage provisions, piping, valving, etc. Although not studied in any great depth because of the system complexity, other obvious disadvantages were the difficulties of obtaining a linear spring constant, and possible system leakages which would result in pressure variation. Also, pressure variations caused by the wide temperature range would cause difficulties in providing a precise spring constant.

Pneumatic Tube

This concept consisted of a pressurized rubber "donut" shaped tube which transferred loads by bearing through the use of rollers or teflon slide pads. In addition to the disadvantages associated with pneumatic systems listed previously, it was found analytically that a relatively high pressure was required to obtain the design spring constant. In an effort to achieve a near linear spring constant, tapered tubes and multiple concentric tubes each having a different pressure were considered. There was also a concern that, even though a low friction slide pad was provided, the tube would not maintain its shape when a relative CSS-to-Centaur axial deflection occurred simultaneously with a load transfer. The complexity and development risk were considered too great to choose this concept.

Thin Flat Sheet of Stainless Steel Cut by a Linear Explosive

This system had the advantage of combining the forward annular compartment seal with the load transfer device. However, it was felt that it would be difficult to obtain a precise linear spring constant. This concern would be compounded as the sheet developed shear buckles. The linear explosive device technology existed; however, no developed, tested system could be found which would operate in a plane around a curve. Utilizing a system operating in a series of straight lines had the disadvantages of leaving too large a metallic "shelf" which violated the antenna pattern requirement.

Struts with Conical Washers

This system consisted of a series of struts which contained conical or "Belleville" washers to obtain the desired spring constant, and a pyrotechnic device to inactivate the strut load carrying capability. Due to the length of strut required to package the number of conical washers required plus the pyrotechnic device, it was not possible to use radial struts. Therefore, a series of six struts spanning the CSS/Centaur vehicle annulus at an angle was proposed. This was the system chosen for development and is discussed in detail in the following sections.

FORWARD BEARING REACTOR SYSTEM DESCRIPTION

Total System Description

The FBR system consists of a series of six double acting spring struts located symmetrically around the CSS/vehicle annulus as shown in Figure 3. The struts are located nearly tangent to the Centaur Stub Adapter to facilitate load introduction. Load introduction into the CSS at a much greater angle is acceptable because of the existence of a deep frame located there for other reasons. Two of the struts are located in the plane of the Titan Solid Rocket motors to share the majority of the launch lateral loads developed by the unbalanced thrust buildup of the motors. The quantity of four additional struts was chosen because the strut load magnitudes are small enough to be easily reacted by the CSS and Centaur, preferential load introduction structure is located on the stub adapter at these locations, and it preserved the required symmetry of the system.

The struts are installed with the inboard end 1.60 centimeters (0.63 inches) forward of the outboard end. As the Centaur vehicle moves aft relative to the CSS (due mainly to Centaur propellant tank cryogenic shrinkage) the struts move more into a station plane. Rotation of the strut ends about the attachment fittings is accomplished by use of spherical strut end fittings.

Strut Configuration

The individual struts as shown in Figure 4 are nominally 71.12 centimeters (28 inches) long. The strut has a separation plane inclined 1.4 radians (80 degrees) to the strut centerline. That portion of the strut to the right of the separation plane is the stub adapter mounted inboard portion; that portion to the left of the separation plane is the CSS mounted outboard portion. The precise spring constant is obtained by compressing the stack of 22 conical washers installed in the outboard portion of the strut. The washers are stacked in series rather than in parallel to reduce the frictional losses and non-linearity associated with a parallel stack. If a compression load is applied to the strut, the load is transmitted through the piston to the compression thrust washer. This compresses the conical washer stack against the tension thrust washer, which then transmits the load into the barrel. A tensile load is transmitted through the piston into the cap which loads the tension thrust washer. This in turn compresses the conical washer stack against the compression thrust washer which then transmits the load into the housing.

The conical washer chosen has the following properties:

OD = 8.00 cm (3.15 in.)   t = .4999 cm (.1968 in.)

ID = 4.09 cm (1.61 in.)   Spring Rate K_W = 277,050 N/cm (157,000) lb/in

Therefore: $$\frac{1}{K_{Stack}} = \frac{22}{K_W}$$

Knowing from previous tests that the strut spring constant, K, without the conical washers is approximately 255,875 Newtons per centimeter (145,000 pounds per inch):

$$\frac{1}{K_{Strut}} = \frac{1}{K} + \frac{1}{K_{Stack}} = \frac{1}{K} + \frac{22}{K_w}$$

$$K_{Strut} = \frac{K K_w}{K_w + 22K} = \frac{255,875\ (277,050)}{277,050 + 22\,(255,875)} = \begin{array}{l} 12,003 \text{ N/cm} \\ (6802 \text{ lb/in.}) \end{array}$$

The spring constant of the CSS, K_{CSS}, was determined to be approximately 882,326 Newtons per centimeter (500,000 pounds per inch) and the Stub Adapter spring constant, K_{SA}, was determined to be approximately 1,764,552 Newtons per centimeter (1,000,000 pounds per inch). Extreme accuracy of the spring constants was not required because the total system spring constant is not sensitive to the support structure. Because of the geometrical configuration of the struts, it can be shown that for any direction of shear load the equivalent of three struts placed parallel to the direction of loading will react the load. Therefore, the system spring constant is determined as follows:

$$\frac{1}{K_{SYS}} = \frac{1}{K_{CSS}} + \frac{1}{K_{SA}} + \frac{1}{3K_{Strut}}$$

$$= \frac{1}{882,326} + \frac{1}{1,764,552} + \frac{1}{3\,(12,003)}$$

$$K_{SYS} = 33,932 \text{ N/cm} \quad (19,229 \text{ lb/in.})$$

It can be shown that using 21 conical washers in lieu of 22 exceeds the maximum 35,293 Newtons per centimeter (20,000 pounds per inch) requirement. The linearity of the strut spring constant in tension and compression is shown in Figure 5. This load/deflection curve was obtained by testing one of the struts flown on a recent vehicle. All flight struts are similarly tested and the curves from strut to strut are very uniform. Note that there is very good agreement between the theoretical strut spring constant of 12,003 Newtons per centimeter (6802 pounds per inch) and the test values. The spring constant in tension is less than 2.5 percent low and in compression is less than 0.5 percent low. The strut spring constant without conical washers of 255,875 Newtons per centimeter (145,000 pounds per inch) was obtained by testing an old strut design. It is suspected the present strut spring constant is lower, and this brings the theoretical value even closer to the test values. As an additional data point, tests run on conical washer stacks with spring rates four to five times higher also exhibited good linearity, except for a small non-linear zone near the point where the load shifts from tension to compression.

The two strut segments are held together at the separation plane by use of a pyrotechnically actuated frangible bolt. Since the two redundant pyrotechnic cartridges must be installed late in the launch countdown, pyrotechnic cartridge access holes are machined into the strut body. The mechanically redundant frangible bolt is stronger (and therefore is larger) than required for this application; however, it is a flight qualified device used in many other applications on Centaur and was used in this application to gain the advantages of commonality.

The frangible bolt is shown in Figure 6. Separation is initiated when either or both of the cartridges are actuated generating a gas pressure on the face of the primary piston (3) which applies a force on the elastromeric coupling (6). The coupling amplifies the force, as a fluid would, and loads the secondary piston (7) by a factor of 3.15 to 1. The secondary piston in turn reacts against the secondary piston on the opposite side, which pushes against the insert (5) and subsequently the housing (1), putting the fracture plane in tension. As internal forces build up, the bolt breaks at the fracture plane and the bolt halves are driven apart by the stored energy within the system. The bolt has an ultimate breaking strength of 182,377 Newtons (41,000 pounds) to 204,618 Newtons (46,000 pounds).

Strut tension loads are transmitted directly through the frangible bolt; compression loads, which apply a shear force along the face of the separation plane, are reacted by a pair of shear pins extending across the separation plane. It is undesirable to load the frangible bolt in shear because of its low capability to carry shear through the frangible groove and also because the bolt is clamped on spherical seats in a loose fit hole. When either or both pyrotechnic cartridges are actuated, the bolt fractures through the groove and, as stated previously, a high velocity is imparted to the two halves. The velocity of the half on the inboard end is arrested by bottoming out on a rubber "O" ring. The shear pin assembly is attached to the outboard half and as the bolt half is driven away from the separation plane it withdraws the shear pins. The bolt half/shear pin assembly velocity is arrested by bottoming out on a metallic stop. The possibility of rebound so that the shear pins reposition themselves back across the separation plane is prohibited by use of spring fingers which snap in place after the assembly passes by.

In order to meet the requirement that the FBR cannot transmit load during significant aerodynamic heating, the strut is separated by the frangible bolt 100 seconds after launch. At that time a conservative analysis showed that there could be as much as 20,017 Newtons (4500 pounds) tension or compression load in the struts. It was found during the test program of the original strut design that when the frangible bolt was actuated with that compression load on the strut, it often failed to separate. Due to the large deflection of the strut at this load (approximately 1.75 centimeters)(0.69 inches) the separation plane remains loaded through many degrees of rotation, rather than achieving immediate separation. As a consequence, frictional forces prohibited strut release. The surface finish was a high temperature curing solid film lubricant applied to hard anodized aluminum separation fittings. It was found that after the lube was applied, its surface consisted mostly of a concentration of the phenolic resin binder material. After the surfaces were carefully hand burnished (removing the surface concentration of binder material), acceptable strut separation was obtained. However, this was not an acceptable solution for production parts because of the problem of describing to the factory how much (or how little) to burnish and the improbability of obtaining consistent parts. Too little burnishing would not remove the binder material from the surface; too much burnishing would remove all of the very thin coating (0.00051 to 0.00127 centimeter) (0.0002 to 0.0005 inch). Therefore, a test program was initiated to determine if a surface finish could be found which would guarantee strut separation and would be producible.

Many different bearing surface finishes and lubricants were tested including anodized and hard anodized aluminum alloy, hardened steel with polished finishes, chrome plated steels, teflon coating, and various greases. The test program was accomplished using a set of three plates sandwiched and clamped together. The center plate was pulled while the two outer plates were held. The loads for the center plate to first move, and then to continue moving, were recorded. Based on the relative values so obtained, the best surface finish, by far, was a combination of a special grease consisting of 10 percent by weight of molybdenum disulfide powder mixed with a 90 percent by weight of silicone grease, applied to aluminum alloy separation fittings which had a hard, dense chrome plating electrodeposited on the bearing surfaces.

There are several reasons why this combination was best. The molybdenum disulfide powder has a low coefficient of friction, and also has an extremely high compressive load allowable. The silicone grease is a viscous carrier which flows as the surfaces slide, and it retains this property down to the lower temperature limit of -54°C (-65°F). The effectiveness of the molybdenum disulphide powder was demonstrated during the slip tests. Load values measured with the molybdenum disulphide powder plus silicone grease were only 25% to 30% of loads measured with silicone grease alone. The bearing surfaces were chrome plated to provide hard, smooth surfaces for the powder to act upon. The chrome is applied by an outside vendor using his proprietary method of electrodeposition at a low temperature. The plating thickness is 0.000127 to 0.00127 centimeter (0.0005 to 0.005 inch), has a Rockwell "C" hardness of 70-72, and a surface finish of 12-16 RMS. These properties are similar to those achieved by the conventional high temperature electrodeposited chrome plating per QQ-C-320; however, it does not contain the numerous surface microcracks that the conventional chrome plating does. Another advantage is the absence of warping or the possibility of hydrogen embrittlement (where applicable) inherent in the high temperature process.

The sliding action then occurs due to the sliding of one hard smooth surface upon the other, the surfaces being held apart by, and riding on the low coefficient of friction molybdenum disulphide powder. The relatively fine powder is effective because the surfaces are very hard and smooth and contain no surface microcracks.

Retract System

After the frangible bolt is actuated and the separation plane shear pins are driven away from the separation plane, the strut segments are rotated away from each other. The inboard segment is rotated and held in a position along the Stub Adapter; the outboard segment is likewise rotated and held in position along the CSS. The rotation is sufficient to preclude any further load transfer and to provide sufficient clearance during CSS jettison. See Figure 7 for a structural arrangement of the rotation components.

The inboard segment has a spring looped around the strut body. Upon strut separation, the spring rotates the strut about the spherical end bearing and holds it in place in a saddle mounted on the Stub Adapter. The outboard segment is retracted and held in place by a pair of spring/cable assemblies. The primary system consists of a spring cylinder mechanism mounted on the CSS which is attached to a cable that is routed around a pulley and attached to the strut near the separation plane. The cable of secondary spring/cable assembly is looped around the strut body further outboard on the strut, is routed around another pulley in the opposite direction from the primary system, and is then attached to a stretched spring which is mounted on the CSS. When the strut separates, both systems pull it outboard until it slams into a block of aluminum honeycomb. At that point, the primary system cylinder mechanism locks in place precluding the cable from being pulled back out of the cylinder. The secondary system assists in holding the strut outboard and also applies a forward force to hold the strut up off the annular seal located just below the struts. See Figure 8 for a photograph of one strut installed in flight configuration.

TESTING

Three types of tests were performed on the strut system: component tests on a one-strut configuration, system tests on a complete six-strut configuration, and one flight test to date.

Component Testing

Component tests were performed on one strut and its retraction hardware mounted in a test fixture which simulated the end mounting fittings, the retract hardware mounts, and the annular seal mounted just aft of the strut. When there is a burst pressure acting on the seal, it bears on the struts and applies a forward load. Testing was accomplished at the temperature and pressure extremes, with both tension and compression loads on the strut, with and without pressure on the seal, and by actuating one pyrotechnic cartridge and also actuating both pyrotechnic cartridges. All these tests were successful except the strut failed to separate when the original design was tested when loaded in compression. The solution for this failure has been discussed previously. When the separation plane surfaces were modified as discussed, separation tests when loaded in compression were successful.

"Off limits" testing was also accomplished. These tests included actuation of only one pyrotechnic cartridge which contained 80% of the standard charge, a test at -18°C (0°F) and high humidity which formed ice/

frost, and a test with the grease left off the separation plane surfaces. Both the 80% cartridge test and the ice/frost test were successful; however, the no grease test, when actuated with the strut loaded in compression, was unsuccessful.

Other component tests included structural testing to limit and ultimate loads, and tension/compression cyclic loading. No problems were encountered during this testing.

Systems Testing

Both functional and structural testing was performed on the FBR at the system level using flight configuration hardware. Five functional system tests were performed. All five tests were performed with cryogenics in the Centaur fuel and oxidizer tanks, plus two of the tests occurred while a CSS/Centaur relative shear load was applied. All struts separated and retracted normally on each test as indicated by strain gage and breakwire instrumentation.

Data were obtained on FBR total system load versus CSS-to-Centaur relative deflection during many of the Titan/Centaur system structural test runs. Two types of tests were performed, one in which a shear load was applied only to the CSS, and the other where a shear load was applied to the CSS plus a shear in the reverse direction applied to the Centaur. This latter test was required in order to develop the full 88,964 Newtons (20,000 pounds) shear load in the FBR system. Using only the CSS shear load application to obtain the 88,964 Newtons (20,000 pounds) load at the FBR station would have resulted in overloading the CSS locally where the load was applied.

Typical data from each of the two types of tests are shown in Figure 9. Included in the figure is a plot of FBR total load versus CSS-to-Centaur relative deflection for the CSS shear load only test. These data illustrate the linearity of the system. All other test data were similarly linear. All the data plots like that shown in Figure 9 were generated by computer using strain gage data from each strut. The computer first determined the total system load at various CSS-to-Centaur relative deflections by vector summing the individual strut loads. The CSS-to-Centaur relative deflections were also calculated by the computer using the strain gage data together with the pretest load/deflection calibration data of each strut. Finally, the computer plotted the load/deflection data as shown in Figure 9.

Note that the spring constant calculated from the data in Figure 9 is very close to the analytical prediction of 33,932 Newtons per centimeter (19,229 pounds per inch). As noted in the Figure, the test data is slightly (less than 5%) higher. This was typical of all the test data and was attributed to the spring constant of the support structures (the CSS and Centaur) being a little greater than that approximated in the original analysis.

Flight Tests

The FBR system has flown once to date on the first Titan/Centaur launch vehicle. All telemetry data indicated that the FBR system functioned satisfactorily, and that the maximum in-flight shear load was approximately 31,137 Newtons (7000 pounds) occurring both at launch and during the maximum aerodynamic pressure period of flight.

CONCLUDING REMARKS

The spring strut system described herein is a simple and effective method of sharing load between two concentric structures with a known, precise spring constant. The additional requirement to remove the load transfer capability remotely in flight added complexity. However, the basic spring strut principle can be adapted by the mechanical designer to other load transfer applications where a precise linear spring constant is required of the load transfer device.

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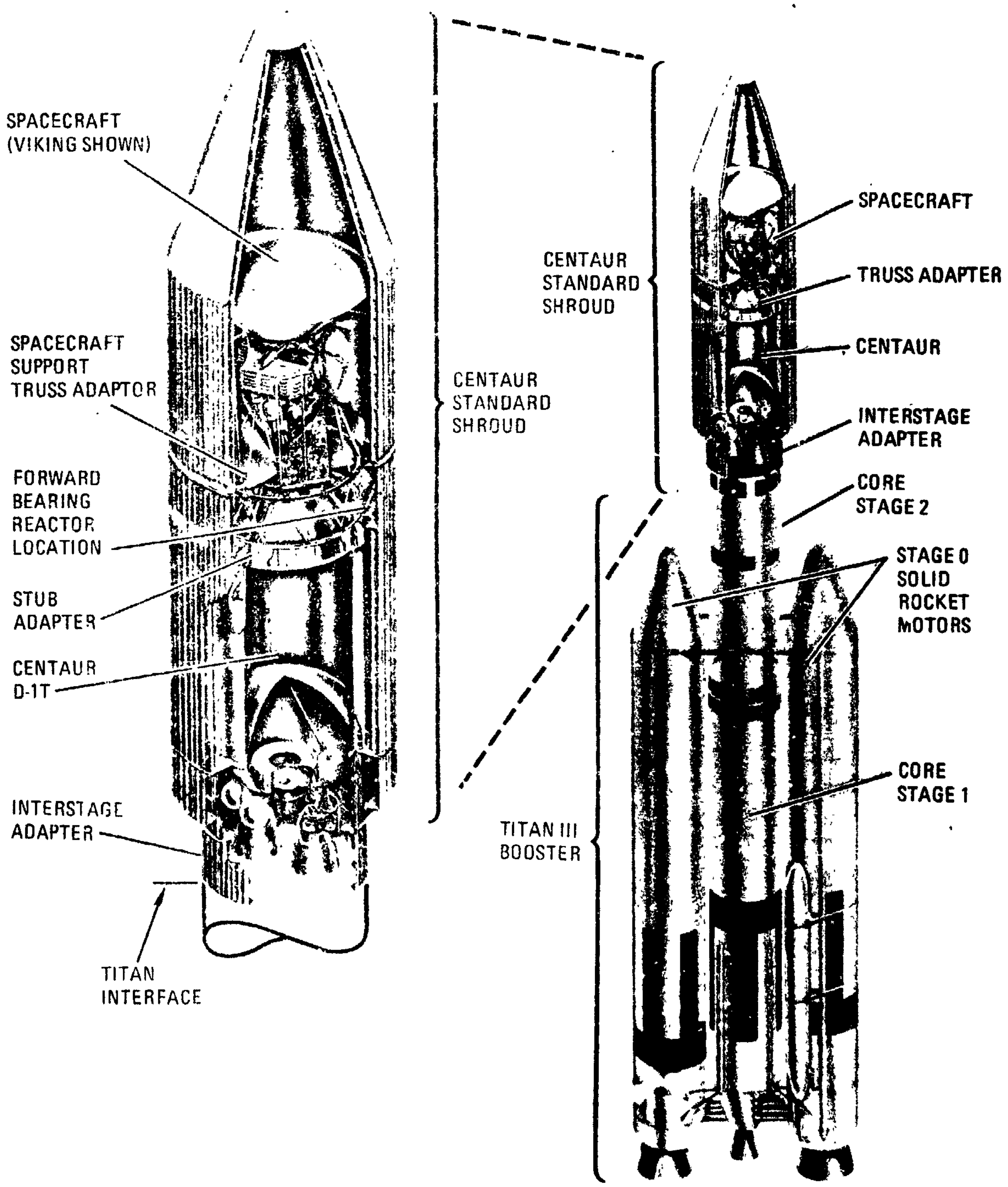

Figure 1. Titan-Centaur vehicle.

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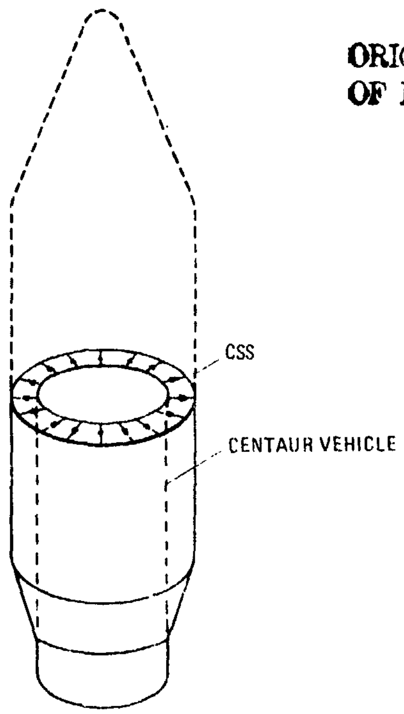


Figure 2. Conceptual ideal load-sharing device.

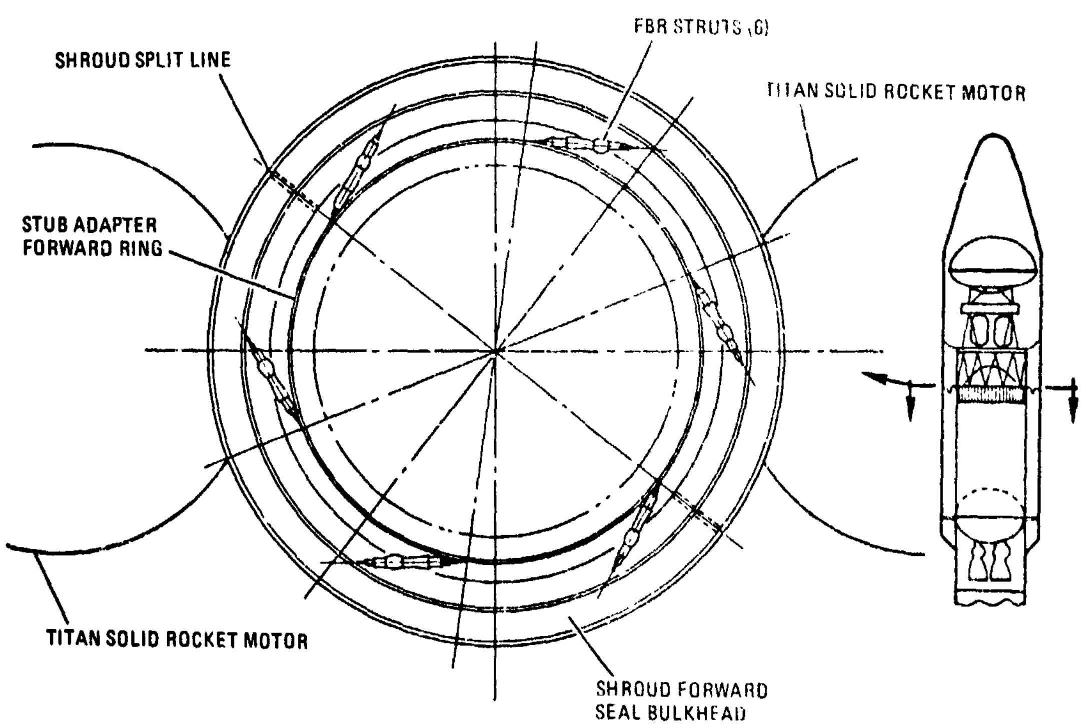


Figure 3. Forward bearing reactor strut system.

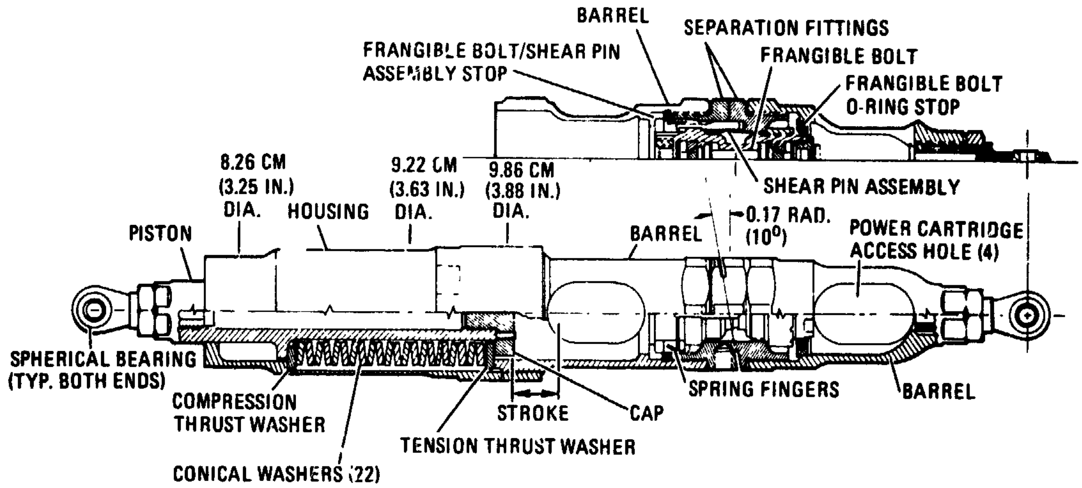


Figure 4. Forward bearing reactor strut configuration.

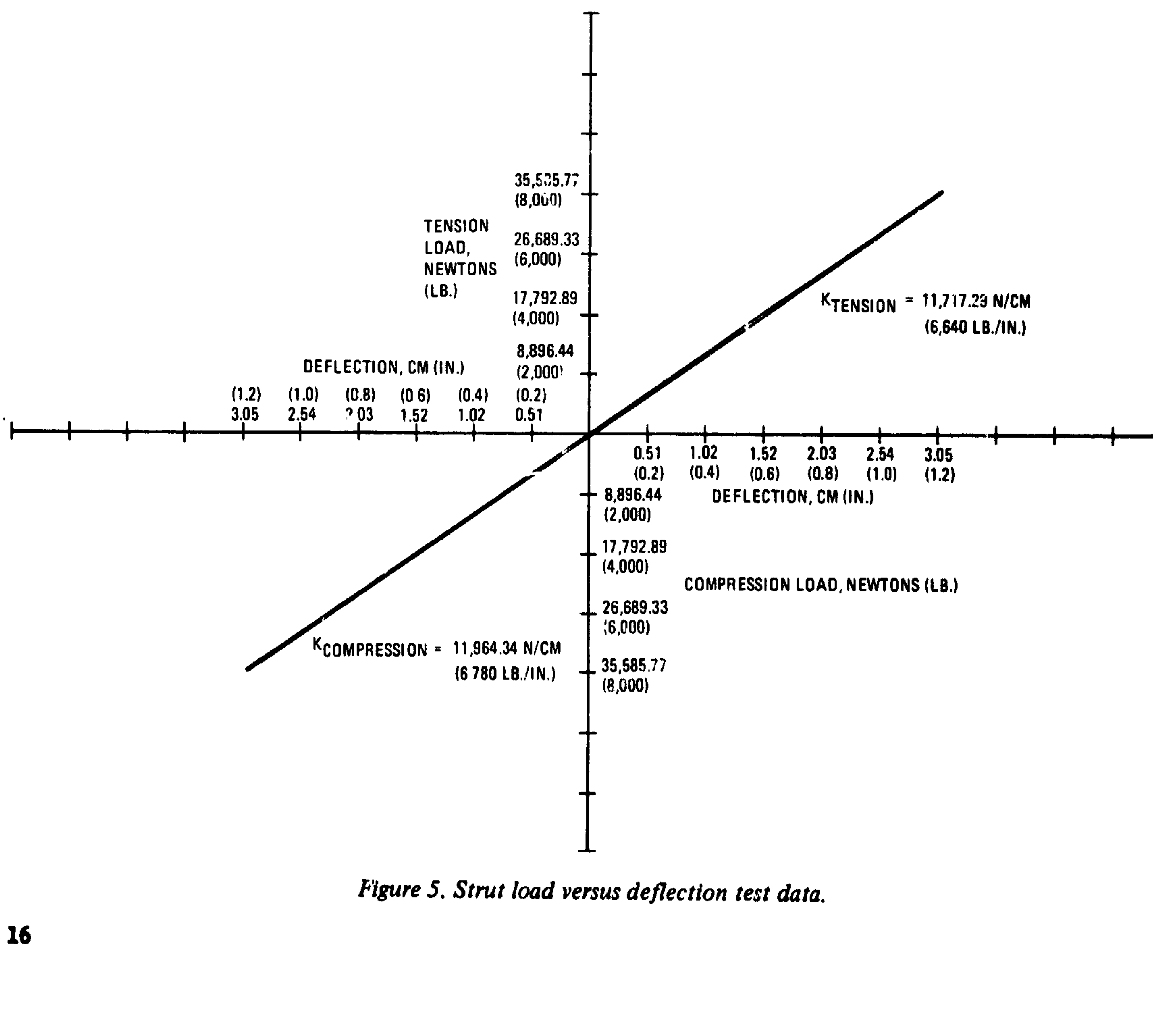
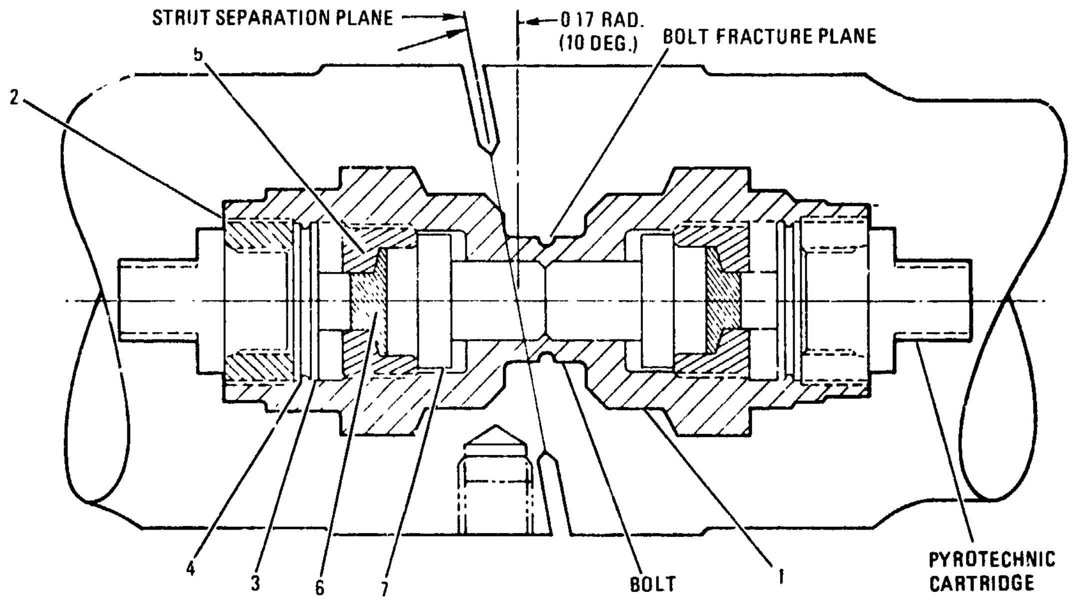


Figure 5. Strut load versus deflection test data.



ITEM NO.	NOMENCLATURE	MATERIAL	QTY./ BOLT
1	HOUSING	4310 STEEL	1
2	RETAINER	MAR. STEEL	2
3	PISTON-PRIMARY	MAR. STEEL	2
4	O-RING	TEFLON	2
5	INSERT	MAR. STEEL	2
6	COUPLER	SILICONE RUBBER	2
7	PISTON-SECONDARY	MAR. STEEL	2

Figure 6. Forward bearing reactor separation bolt assembly configuration.

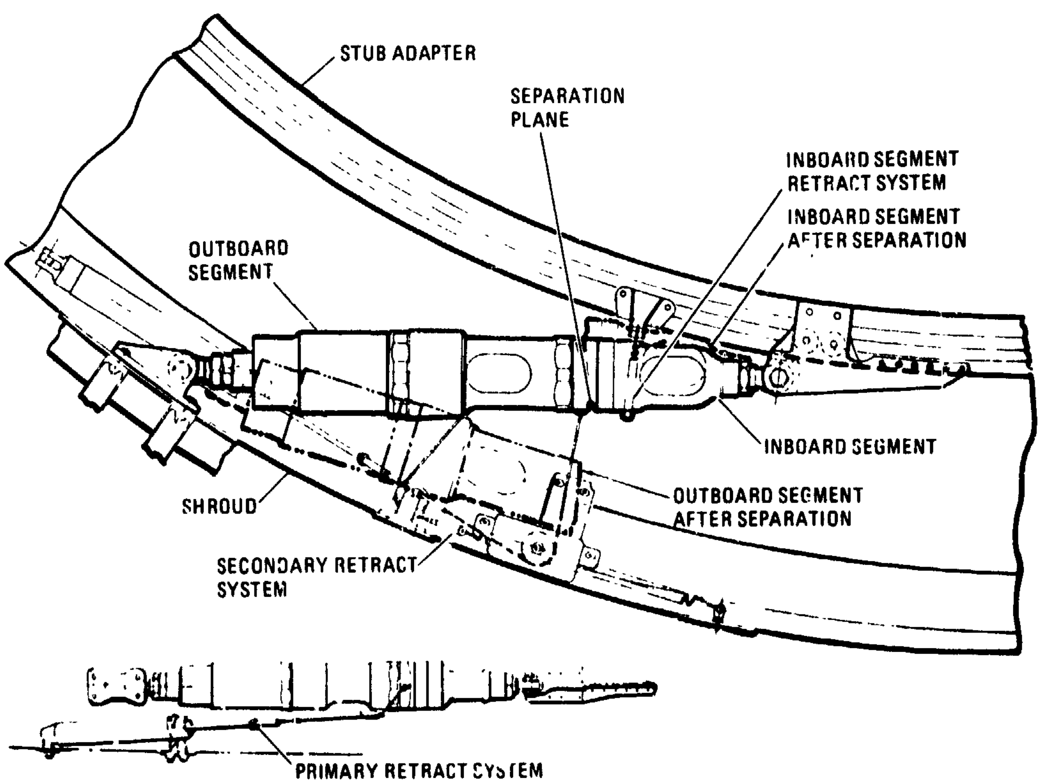


Figure 7. Forward bearing reactor strut retract system.

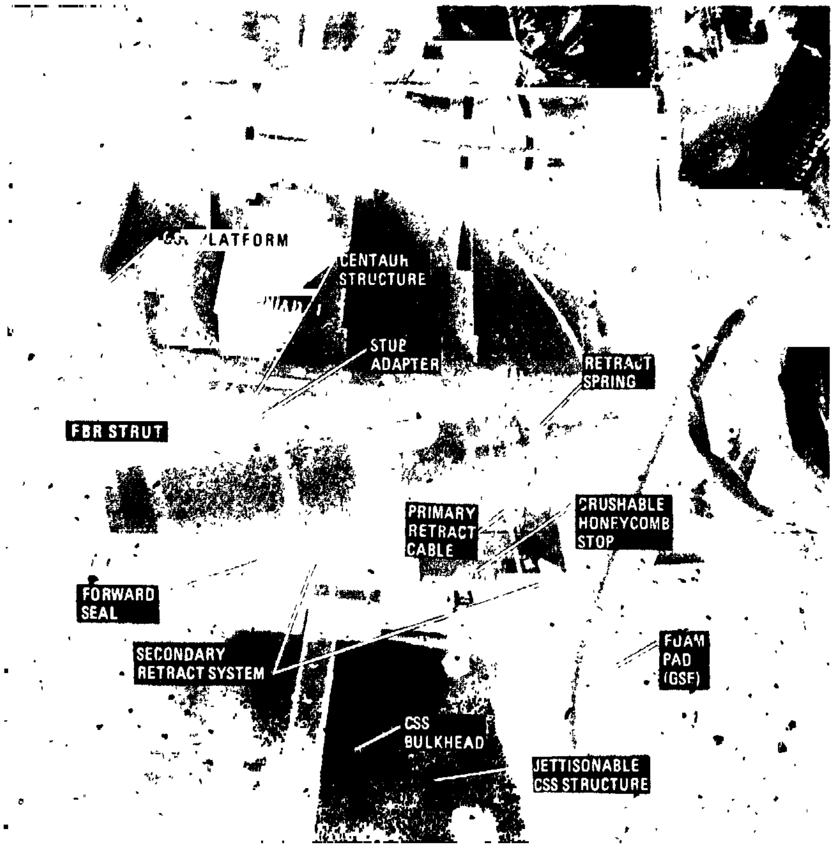


Figure 8. Single FBR strut installed in flight configuration.

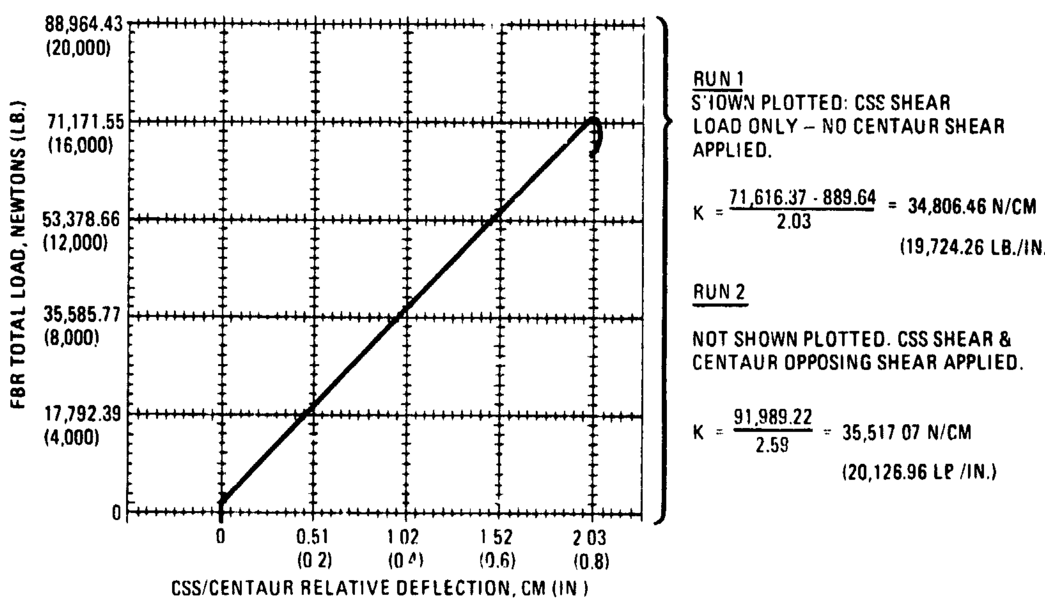


Figure 9. FBR system total load versus CSS/Centaur relative deflection.