

# DESIGN AND DEVELOPMENT OF A MOTION COMPENSATOR FOR THE RSRA MAIN ROTOR CONTROL

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## ABSTRACT

The RSRA, an experimental helicopter developed by Sikorsky Aircraft for NASA and the U. S. Army, is equipped with an active isolation system that allows the transmission to move relative to the fuselage. The purpose of the motion compensator is to prevent these motions from introducing unwanted signals to the main rotor control.

Review of motion compensator concepts indicates that most function only for limited motion. A new concept was developed that has six-degree-of-freedom capability. The mechanism was implemented on RSRA and its performance verified by ground and flight tests.

## INTRODUCTION

The Rotor Systems Research Aircraft (RSRA) is an experimental helicopter intended for flight research on advanced rotor systems, designed and developed by Sikorsky Aircraft under the joint sponsorship of NASA and the U. S. Army. Two aircraft have been built. At present one aircraft is in compound configuration, equipped with a variable incidence wing, a moving stabilator and auxiliary thrust fan jet engines (Figure 1). This version will be used for high-speed research on highly loaded or partially unloaded rotors. The other aircraft is configured as a pure helicopter (Figure 2) and will be used for additional research on a variety of rotors. Both aircraft are presently flying with a baseline rotor system virtually identical to the Sikorsky S61 including bifilar vibration absorbers, and the vibrations transmitted to the fuselage are small in all flight regimes. However, it is anticipated that some of the rotor systems that may be mounted on the aircraft in the future will cause vibrations that cannot be alleviated by bifilar absorbers alone. Thus there are provisions for an isolation system that will allow the rotor and its transmission to move on springs relative to the fuselage, so preventing the transmittal of rotor induced vibrations to the fuselage.

The RSRA rotor control is conventional. Cyclic and collective blade pitch are controlled by pushrods attached to a swashplate whose vertical position and tilt about longitudinal and lateral axes are determined by the extension of three hydraulic servo actuators mounted on the transmission base. The signal to each servo actuator is a mechanical displacement transmitted from the cockpit by a set of rods and cranks. When the isolation system is operative, the transmission base is subject to transient and periodic motions relative to the fuselage. With no compensating device these motions would introduce unwanted signals to the servos and so cause collective and cyclic blade pitch changes. Apart from undesirable changes to the flight path, there are obvious possibilities for control coupled instabilities.

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## THE ACTIVE ISOLATION SYSTEM

Various configurations of active isolation were under consideration in the early days of RSRA design. The purpose of the RSRA is to serve as a flying test bed for advanced rotor systems with different dynamic characteristics ranging from two-bladed teetering rotors to hingeless, bearingless, and fully articulated designs. For some applications it was known that extremely soft transmission supports would be required for acceptable isolation, while the total excursion of the transmission under steady loads must be restricted because of the limitations of interfacing systems - in particular engines, tail rotor drive, and controls. The soft restraints were thus provided by 'active isolators' consisting of servo-nulled hydro-pneumatic actuators with displacement feedback to recenter the transmission under steady flight loads while allowing oscillatory motion at the critical vibration frequencies. Other restraints consisted of very stiff pivoted links containing load cells. The number of independent soft restraints determines the number of degrees of freedom of the transmission relative to the fuselage.

During the course of development, a design evolved consisting of four active isolators (two independent) in the horizontal plane, a torque restraint linkage in the horizontal plane, and four load cell links with their axes focused to a point low down on the rotor axis (Figure 3). The active isolation system has been described by Kuczynski and Madden (Ref. 1). This system has two degrees of freedom - or three, when failure modes, e.g., fracture of the anti-torque linkage, are considered.

## COMPENSATOR REQUIREMENTS

The preliminary design of the RSRA control system took place while the isolation system was undergoing many iterations. Many combinations and configurations of soft restraints and rigid links were investigated. The decision was made that the main rotor control would include compensating linkages with a full six-degree-of-freedom capability. Thus the isolation system design could proceed without any consideration of restraint imposed by control system requirements. Also, there would be no inhibition of development and reconfiguration of the isolation system at any future time.

The requirement for a control compensating linkage may be simply described. The input control signal is generated by the pilot commanding a displacement between his stick and the fuselage. The mechanical control system linkage transmits this signal to one of the hydraulic servo actuators that position the swashplate and are mounted on the transmission base. If an isolation system is incorporated, the transmission base can move relative to the fuselage. Thus a mechanical displacement relative to one body must be faithfully copied by a displacement relative to a second body, while remaining unaffected by relative motion between the bodies. In the most general case, the motions consist of translations along three mutually perpendicular axes and three rotations about these axes.

## COMPENSATOR CONCEPTS

If the number of degrees of freedom are limited, then simple solutions are possible. For example, consider two bodies with relative translational freedom along one axis (Figure 4). A linkage consisting of a crank pivoted at each body and a long rod perpendicular to the axis is an effective approximate compensator, since small motions produce little disturbance to the signal in the rod. This simple idea was the subject of a patent in 1971 (Ref. 2). If the restraint between the two bodies is provided by parallel pivoted bars and the control rod is made parallel to the bar and equal in length, then a perfect compensator results.

If the bodies have translational freedom along all three axes but are restrained rotationally about at least one axis, then a solution is possible consisting of a torque tube, universally connected to the control linkage at each end and having a telescopic feature with a splined or scissors link connection. The control signal consists of rotation of the torque tube. This device, subject of a patent by Durno & Dean (Ref. 3), was used in the Sikorsky XH-59A ABC<sup>TM</sup> (Advancing Blade Concept) research helicopter, which had provisions for a passive isolation system while being restrained in roll by torque links (Figure 5).

A simple apparent solution to the problem of transmitting a displacement signal between two bodies with complete freedom of relative motion is to use a flexible push/pull cable operating within a flexible conduit. In fact, the best of these devices exhibits more friction and hysteresis than can be tolerated in a primary flight control.

## COMPENSATOR DEVELOPMENT

Development of the RSRA motion compensator started with consideration of the problem of transmitting a mechanical control signal between two bodies having relative motion in a plane, i.e., translation along two axes and a rotation about a third axis perpendicular to these two. Thus a solution consists of a summing linkage containing two signal paths in parallel planes (Figure 6). One path transmits the control signal, the other a cancelling signal that removes the effect of the relative displacement between the two bodies. If body 2 is subjected to displacements  $d_x$ ,  $d_y$  and rotation  $\theta_z$  while a control input  $c_i$  is made the total displacement of the control output point is  $d_x + c_i$ . Hence the output signal  $c_o = c_i$  and compensation is achieved. This relationship and the independence of the control output displacement on  $d_x$  and  $\theta_z$  is true at the control signal mid-point and very nearly true for small displacements from the mid-point.

If the mechanism is implemented with self-aligning ball type connections, then this device provides compensation for the case where the two bodies also have translational freedom along the z axis and rotational freedom about the x axis (Figure 7). The control output is independent of the displacement  $d_z$  or rotation  $\theta_x$  and is very nearly unaffected by a combination of these two motions. Rotation about the y axis is another matter. If the distance between the signal path planes is h, then a rotation  $\theta_y$  will produce a false output signal  $c_o = h \sin \theta_y$ . It is evident that in order to achieve a full six-degree-of-freedom compensator, it is sufficient to let  $h = 0$ .

The implication of  $h = 0$  is that the two signal paths occupy the same plane. The first development of this idea is shown in Figure 8. The summing beams are separated and connected by rods, and one beam has become shorter than the other to accommodate a bellcrank. Implementation of the idea to a mechanism designed to fit into the space available around the transmission base after the active isolators had been located led to even more complications (Figures 9, 10). Two linkages are installed at the right side of the transmission and one at the left. Local peculiarities of space and alignment imposed an individual approach at each location and there are no common parts anywhere in the linkages. Also a number of compromises had to be made away from the ideal geometry, each introducing another small error. At this time it was decided to make a new start.

The next development reverted to the basic simplicity of the original concept (Figure 11). In order to bring the signal paths into one plane, the summing linkage took the form of an open frame beam, with the other beam centered inside (Figure 12). Likewise, the two rods take the form of concentric tubular members. It was not possible to attach the outer (cancelling signal) rod to the transmission base at the same point that the inner (control signal) rod attaches to its output crank (Figure 13). This introduces an error, but it is extremely small if the rods are long compared to the attachment offset. For this reason, the rods were aligned horizontally and a bellcrank was needed at the output. The motion of the inner rod is limited by being stepped down 2:1 at the input end and stepped up 1:2 at the output bellcrank.

#### IMPLEMENTATION OF THE COMPENSATOR ON THE RSRA

Implementation of the motion compensators on the RSRA followed very closely the lines of this concept. A compromise forced by the limitations of space was the inversion of the summing linkage geometry.

The three linkages are similar in configuration and many common parts are used (Figure 14). A number of innovations were incorporated in the detail design of the summing linkages to make these units compact and prevent the possibility of fasteners slackening off and jamming the controls (Figure 15).

True compensation is achieved with the ideal linkage and for small control signal displacements about neutral. The compromises that had to be accepted introduced small errors. Also effective compensation was required over the whole range of control displacements. A criterion was set that the error in output should not exceed 2% full stroke at any control position while the transmission base was subject to motions in any direction up to the maximum stroke of the active isolator (+9 mm) taken in the worst combination of possible configurations. A geometric motion analysis was performed by computer program and performance within specification was determined.

The compensating linkage described was installed on both RSRA aircraft (Figures 16, 17). Only the second aircraft has been configured with the active isolation system operative, and tests of the compensator performance were conducted on this aircraft. The test consisted of setting a control input with a fixed stick in the cockpit and driving the transmission base to extremes of travel on the isolation system, while observing motion at the control output points. The results of these tests confirmed the predictions of analysis.

#### CONCLUSIONS

The RSRA has made many flights with the isolation system action and records indicate that the motion compensators have functioned to completely eliminate any measurable spurious control signals.

#### REFERENCES

1. Kuczynski, W. A., and Madden, J., The RSRA Active Isolation/Rotor Balance System, Paper No. 18, Fourth European Rotorcraft and Powered Lift Aircraft Forum, Stresa, Italy, September 1978.
2. Dueweke, J. E., U.S. Patent 3,563,499, Mechanism to Transfer Engine Torque and Control Motion Across Helicopter Rotor Vibration Isolator.
3. Durno, R. A., and Dean, J. C., U. S. Patent 3,908,399, Primary Flight Control With Isolated Gear Box.

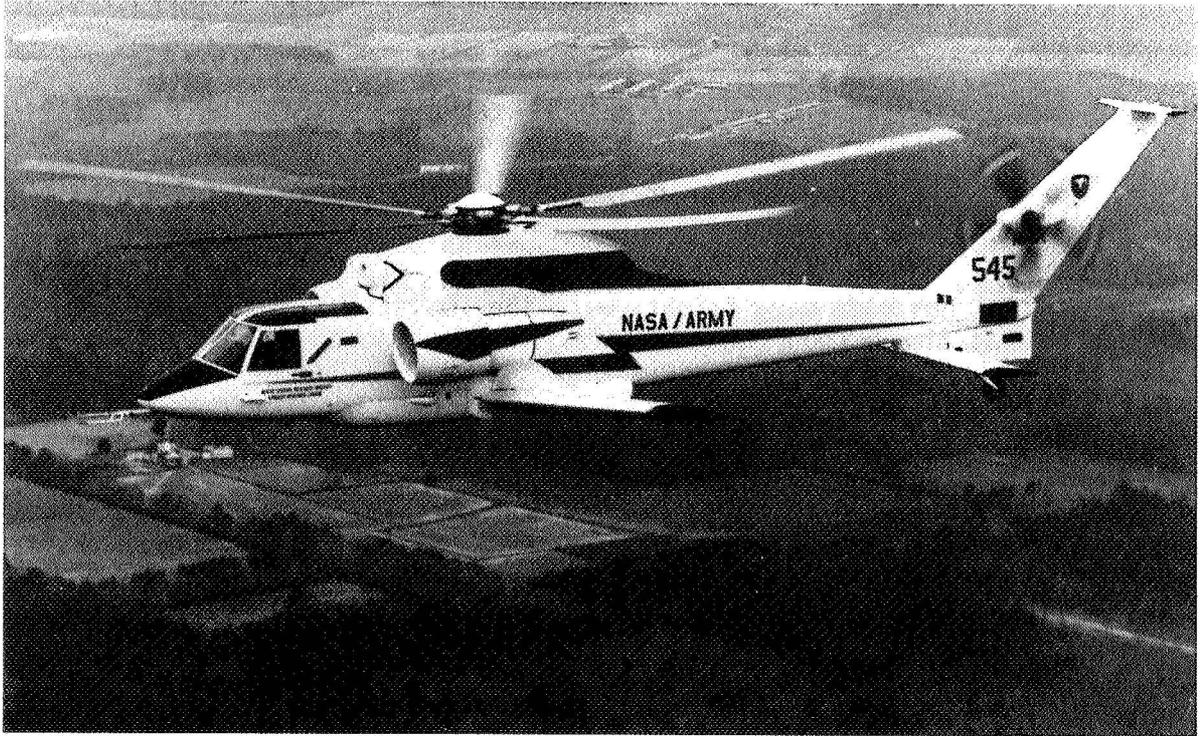


Figure 1 RSRA Compound Configuration



Figure 2 RSRA Helo Configuration

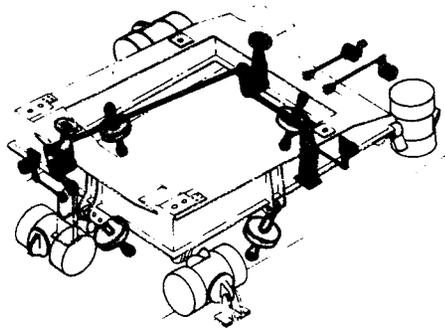


Figure 3 RSRA Transmission Active Isolation System

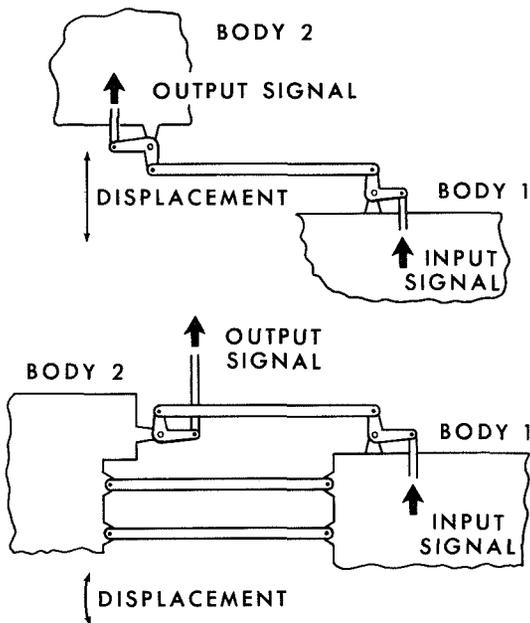


Figure 4 Compensator Concept - Linear Motion

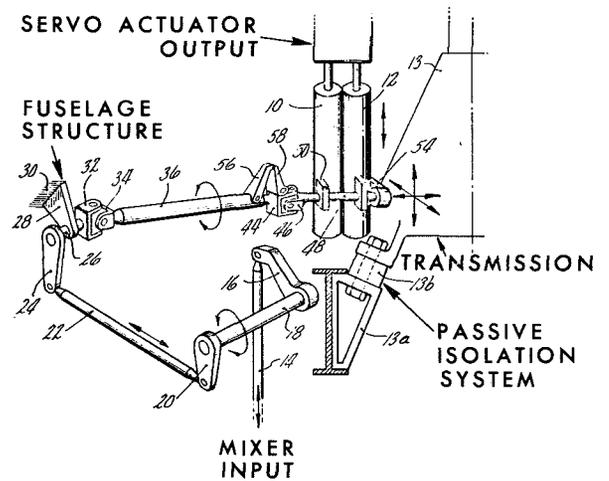


Figure 5 Controls Motion Compensator on Sikorsky ABC

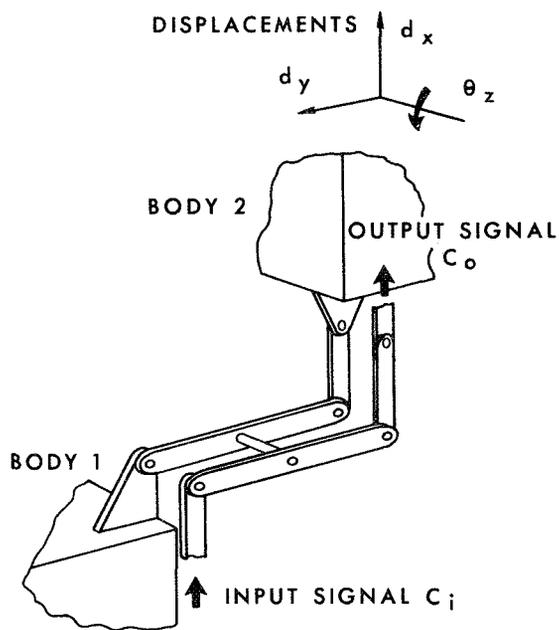


Figure 6 Compensator Concept - Plane Motions

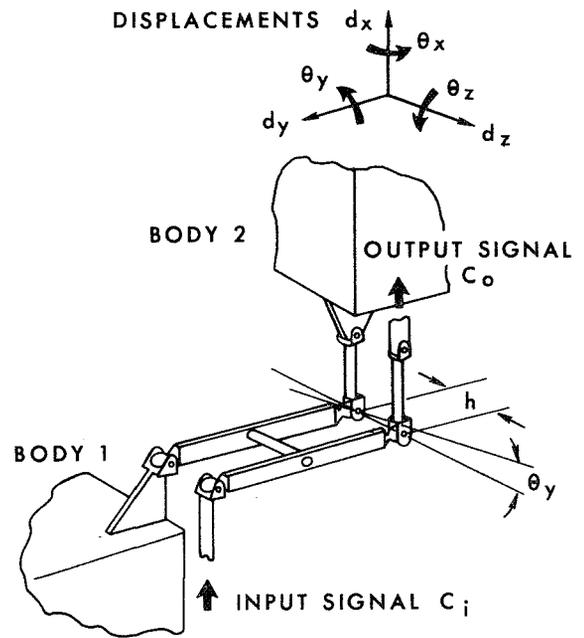


Figure 7 Compensator Concept - General Motions

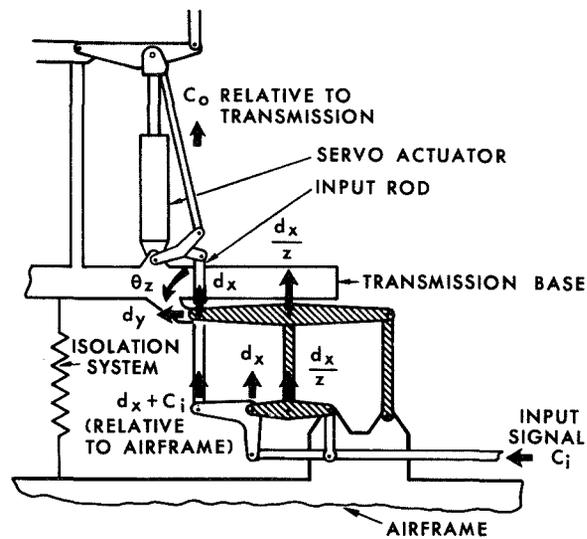


Figure 8 Compensator Concept Applied to RSRA

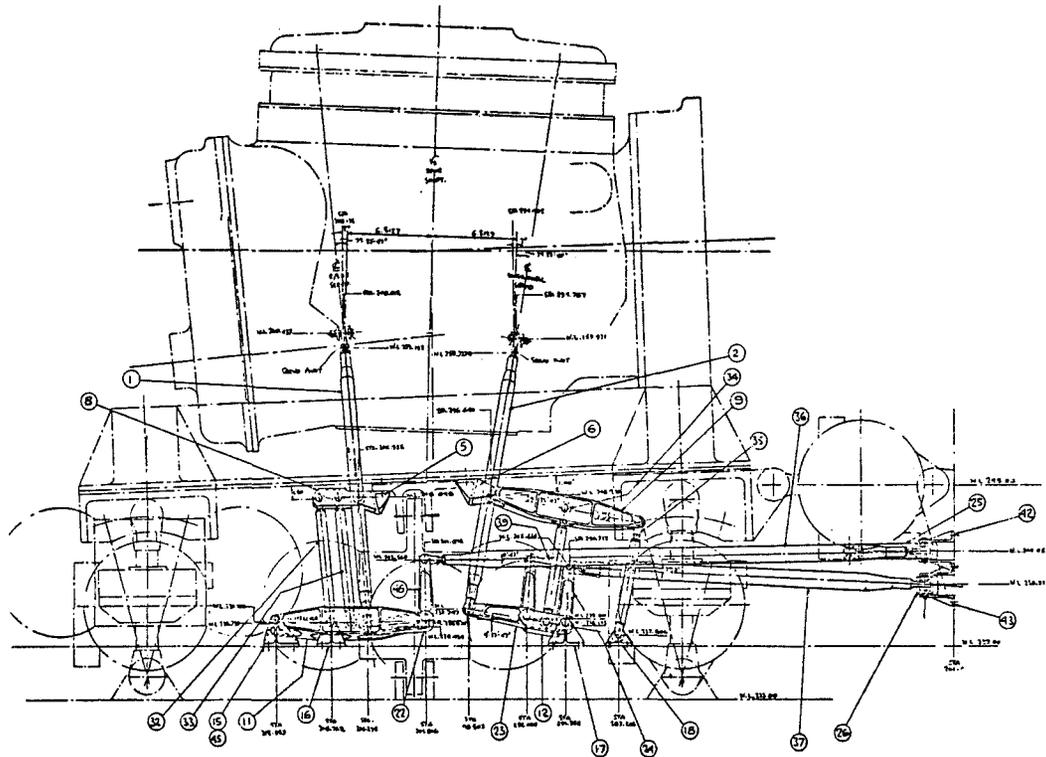


Figure 9 Preliminary Design for RSRA Motion Compensator - Right Side

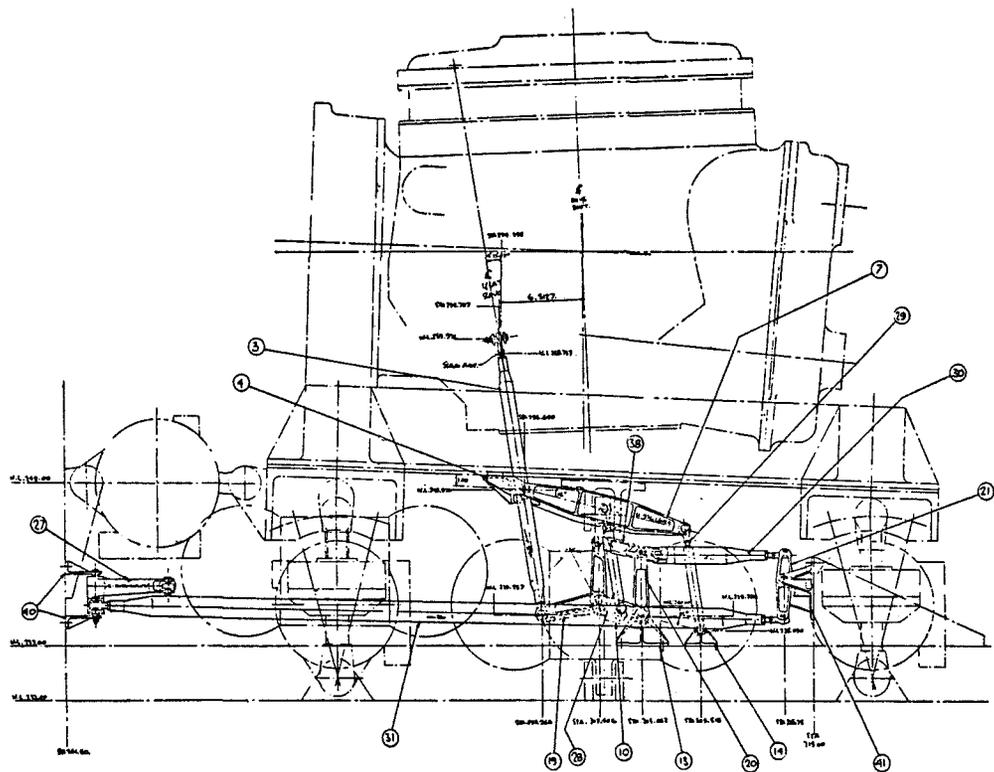


Figure 10 Preliminary Design for RSRA Motion Compensator - Left Side

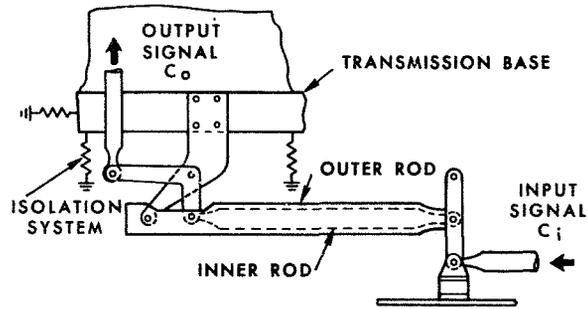


Figure 11 Revised Concept for RSRA Motion Compensator

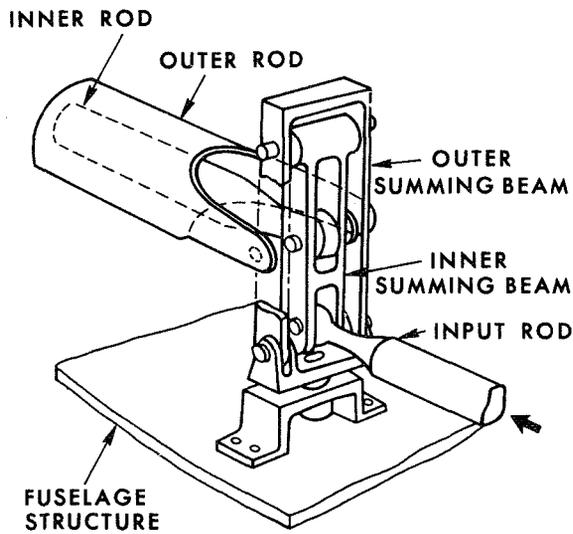


Figure 12 Revised Concept for RSRA Motion Compensator - Input and Summing Linkage

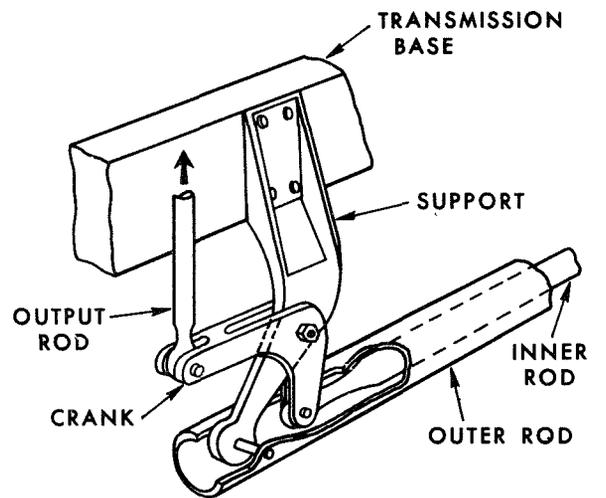


Figure 13 Revised Concept for RSRA Motion Compensator - Output Crank

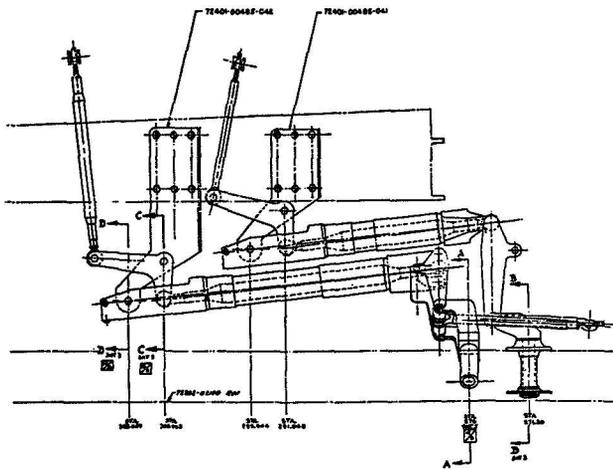


Figure 14 Final Design - RSRA Motion Compensator

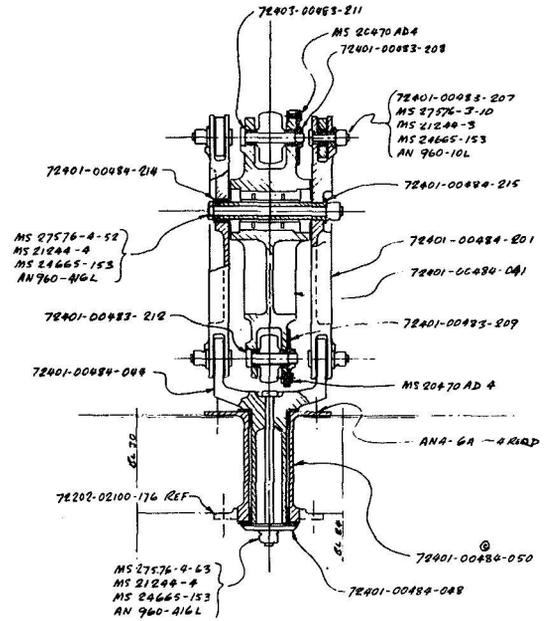


Figure 15 Final Design - RSRA Motion Compensator - Detail

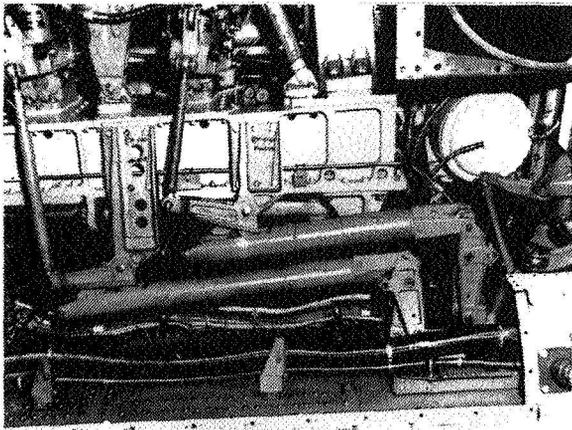


Figure 16 Motion Compensator Installation on RSRA

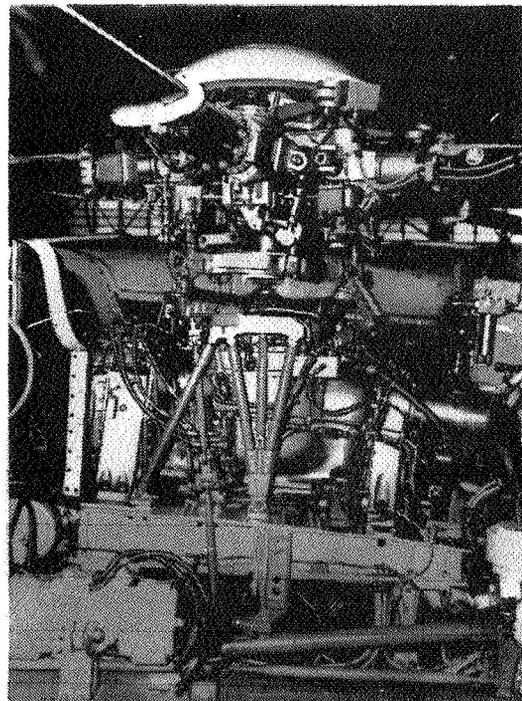


Figure 17 The RSRA Main Rotor and Transmission, Isolation System, and Flight Controls