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SPACE SHUTTLE RUDDER/SPEEDBRAKE ACTUATION SUBSYSTEM

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ABSTRACT

An electro-hydro-mechanical actuation system for control of the rudder and speedbrake aerosurfaces of the Space Shuttle orbiter was developed to meet the strict operational requirements imposed on this mission critical function. (Reference 1) The re-entry and landing portions of the Space Shuttle mission included a set of environmental and operational requirements which presented a significant engineering challenge. The design solutions derived during this effort served to provide a reliable, safe-life actuation system and to provide technology that will be useful in future engineering challenges.

INTRODUCTION

The Rudder/Speedbrake (R/SB) Actuation Subsystem supplied by the Sundstrand Corporation for use on the NASA Space Shuttle Orbiter is an electro-hydro-mechanical system which provides the control and positionary capability of the orbiter aero-dynamic primary flight control surface. The system is located in the vehicle's vertical stabilizer. The Geared Rotary Actuators provide a power hinge feature of the split panel rudder. Actuation of both panels in the same direction provides conventional rudder control; actuating the panels differentially provides a speedbrake function intended to control both speed and pitch. The commands may be superimposed on one another.

The system consists of one Power Drive Unit (PDU) which responds to quadredundant avionic signals to generate a rotary output, four Geared Rotary Actuators, which develop rotary position and torque as outputs, and ten torque transmitting Drive-shafts. (See Figure 1)

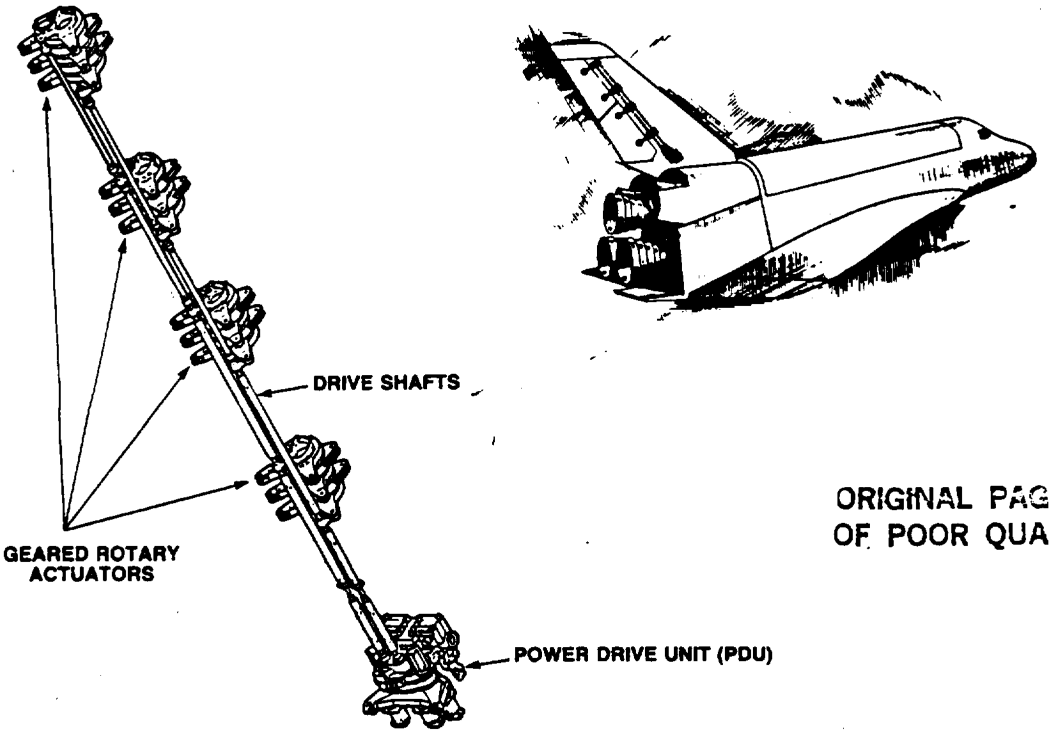

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Figure 1
Rudder/Speed Brake Actuation System

The Power Drive Unit (PDU) responds to electrical command signals that operate electrohydraulic servovalves. The servovalve operation ports hydraulic pressure to hydraulic motors which in turn provide rotary power to PDU gearbox. The PDU is presented schematically in Figure 2.

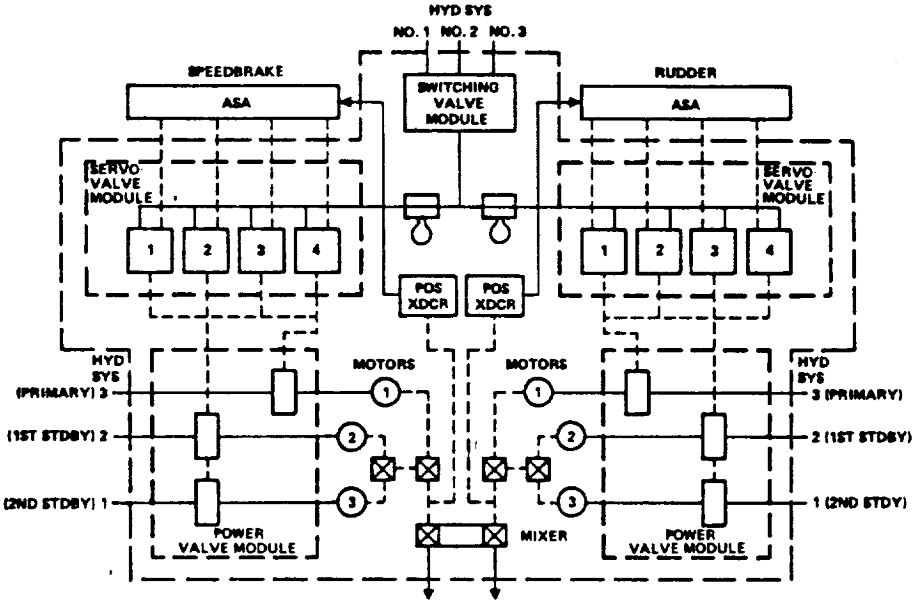

Figure 2
Power Drive Unit Schematic

Within the PDU design, the areas of engineering challenge to be discussed in this paper include the following:

1. Electrical/Hydraulic Fault Detection and Isolation,
2. Gearbox design to mechanically mix the rudder commanded movement with speedbrake commanded movement.

The Geared Rotary Actuator shown in Figure 3 presented a significant challenge on its own. As in all flight control systems, weight and volume are critical factors in determining the actuating mechanism package. This results in the use of highly stressed gears to accomplish the task. This gear design required refinement of the analytical technique and extensive testing.

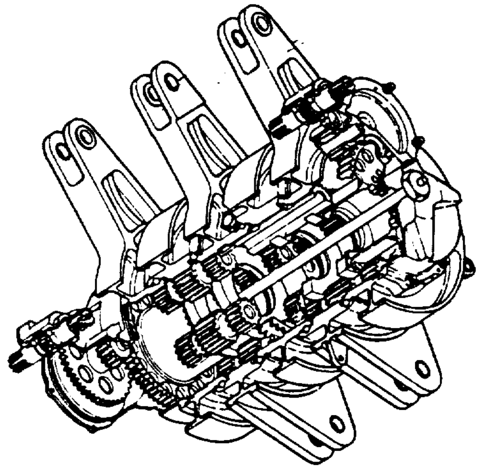

Figure 3
Rotary Actuator

FAILURE DETECTION AND ISOLATION

The operational capability of the R/SB system is critical to the successful completion of the orbiter mission. Therefore considerable design emphasis was placed on electrical and hydraulic system redundancy and further fault detection and isolation. Referring to Figures 2 and 4, the electronic input commands are quadredundant, coming to the PDU from four independent avionic sources. These four commands act on four separate electro-hydraulic servovalves within the PDU. Pressures from the servovalve second stages act on areas of a single structural power spool valve, causing it to move from its null position. This movement opens ports that supply hydraulic pressure to the three hydraulic motors providing rotary power to the PDU gearbox.

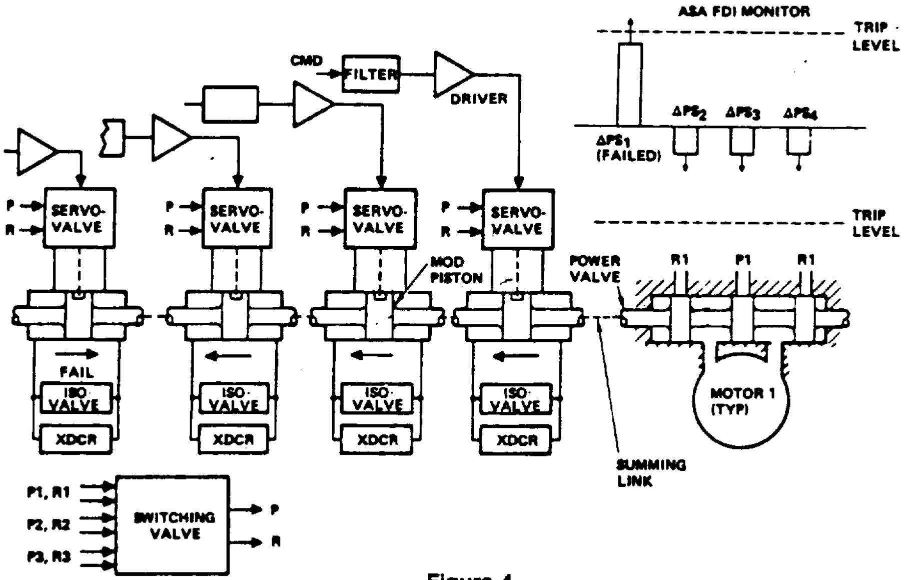

Figure 4
Channel Fault Detection

Should a servovalve output to the power valve be significantly different from the other three (due to failure of the valve, or its associated avionics, for instance), the second-stage differential pressure of that servovalve will rise as it force-fights the three opposing good servovalves. This rise in pressure (Figure 4) is monitored by second-stage pressure transducers, and, when a trip level is attained indicative of a failed channel, a solenoid valve is commanded to open, bypassing the failed channel. The PDU, meanwhile, continues operating normally in response to the commands of the three good channels. Should a second servovalve failure occur, a similar two-versus-one vote would result in its bypass. In this way, the PDU is tolerant of two avionic failures while maintaining full performance.

During early development testing of the PDU, it was found that channel failure and isolation, while the PDU was operating at a high output rate, could result in very high internal pressure pulses as a result of transfer of kinetic energy to potential energy by compressing the oil as a spring between the motor and the valve. This problem was resolved by making several system modifications, including avionic command filtering, elimination of a power valve positioning linkage, and strengthening of pressure passages within the PDU.

A hydraulic system failure is monitored by and managed by the switching valve. This pressure actuated valve is arranged to accept the three on-board independent hydraulic systems. The valve automatically switches from an out-of-tolerance hydraulic source to a standby source. Isolation of motor pressures is maintained.

MECHANICAL MIXER

The Space Shuttle Orbiter combines in the rudder flight control system two functions: conventional rudder operation and a speedbrake function. In order to produce the desired output of the functions the PDU gearbox design was required to accept the power inputs of either or both the rudder and speedbrake controls and integrate and deliver those inputs to the geared rotary actuators.

A combination of gears and differentials was selected to perform this PDU function (See Figure 5). In the first series of gears/differentials the three motor outputs of each flight control system (rudder or speedbrake) are speed summed into a single shaft entering the mixer. In the final series of gears/differentials, the mechanical mixer algebraically sums the rudder and speedbrake motor outputs and delivers the resultant to the aerosurface via the system drive shafts and actuators. Successful design and development of this mechanical mixer concept has greatly reduced the system complexity and weight while permitting simultaneous rudder and speedbrake motion.

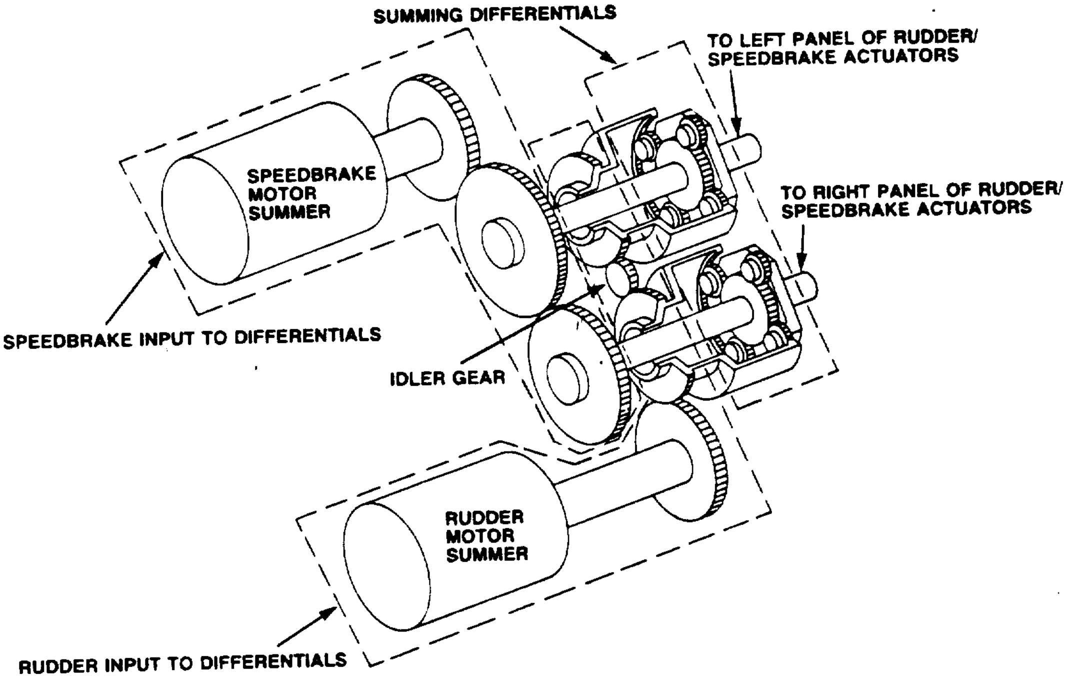

Figure 5
Mechanical Mixer

PLANET GEAR DESIGN

The Geared Rotary Actuator is a planetary-type gearbox with a 474-to-1 gear reduction system. The unit acts as a power hinge for the aerosurfaces. Within the system there are two basic sizes, with barrel diameters of 8.8 in. and 11.4 in. The two sizes are designed for maximum load capacity of 338,000 in lb. and 732,000 in lb.

The planet gears in the actuator assembly are the critical, life limiting component. These gears are designed to withstand high stresses in order to minimize weight and envelope. During early program testing a problem was encountered with root cracking in these highly stressed gears. This test result lead to extensive evaluation of material and manufacturing processes as well as load distribution analysis and cumulative damage analysis.

The material and manufacturing processes' evaluation lead to requirements for additional shot peening of the gear roots to increase precompression and for a new process: grit-blasting of gear roots to remove the presence of intergranular oxidation. The absence of these two items was not considered the cause of initial failure but provided added reliability to final design configuration.

Considerable test work and analysis was conducted to study the effect of load distribution on the planet gears. Testing revealed that under maximum load conditions the relatively long planet gears deflected several thousandths of an inch, resulting in a considerable load concentration on the inside corners of the gear teeth. Using the test information the analytical model was reviewed and after several iteration a solution was recommended. That solution required optimizing the gear tooth thickness and providing a crown on the mating ring gear so that under loaded conditions the planet would deflect into a more uniform gear contact. These changes were thoroughly tested and verified before implementation into production.

The ability to predict the fatigue life of a gear critical actuation system became the subject of concern. It was determined that a more detailed model of the mission load spectrum was required. In studying this design, Dr. Philip S. Oyoung developed a method to synthesize the load spectrum for the Rudder/Speedbrake mission profile so that actuator life capability could be calculated. The method, applicable to general fatigue analysis, provides a much improved accuracy to gear life prediction.

Conclusion

All of the design challenges of the Rudder/Speedbrake Actuation Subsystem, and specifically those addressed in this paper, have been met and solutions derived that yield a highly reliable actuation system. The channel self test features of the PDU and its ability to isolate bad control channels and to switch hydraulic power supplies combine to give a depth of redundancy that is unique to a flight control system. The mechanical mixer provided a light weight, simple gear system that permits simultaneous rudder and speedbrake operation. Safe-life design concepts for primary load carrying components were utilized to maximize output potential for given weight and envelope.

Successful test programs and, now, successful operational status of the orbiter vehicle are the evidence of meeting the challenge this aircraft has presented the technical community.

References

1. Technical Report Woolhouse, Dwight: Space Shuttle Orbiter Rudder/Speedbrake Actuation System. STS 81-0231

2. Technical Report Oyoung, Shio-ping Philip: Fatigue Life Optimization for Gear Critical Actuation Systems by Load Spectrum Synthesis and an Algorithm for S-N-R Curve Generation