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SPACE SHUTTLE ELEVON SEAL PANEL MECHANISM

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ABSTRACT

The orbiter elevon seal panel mechanism controls the position of fairing panels between the orbiter wing and elevon. Early mechanism designs used linkages which approximately matched the panel motion to elevon position, depending on panel deflections to maintain sealing. These linkages were refined during orbiter development to match panel motion to elevon motion more exactly, thus reducing panel deflections, loads, and weight. Changes to the adjacent cove seal resulted in the use of curved tension-compression links. Mechanism temperatures up to 750F (locally) posed difficulties in bearing lubrication. Despite the adverse effect of the many fabrication tolerances, the system has successfully prevented the entry of 1200F hot gases into the wing/elevon joint.

INTRODUCTION

Development of a space vehicle capable of both aerodynamic flight and entry into the atmosphere posed a number of challenges in sealing the moving control surfaces to prevent the entry of hot gases. The orbiter elevons, consisting of an inboard and an outboard elevon on each wing, posed a unique problem at the upper wing surface. The elevon hinge line was established near the lower wing surface, so elevon motion resulted in large changes in the position of the upper elevon forward edge. The structure and systems installations prevented use of a stationary seal riding on a large skin radius.

The gap between the elevons and wing required sealing sufficient to prevent interior heating by the hot entry gases, which reach up to 1200F in that area. These high temperatures would damage the aluminum structure (restricted to 350F maximum), and the hydraulic systems operating the surfaces could not be allowed to exceed 275F. In addition to thermal sealing, the upper wing/elevon junction required a fairing to provide aerodynamic smoothness in an area subject to high vibration, pressure differentials, and buffet/flutter loads.

INITIAL APPROACH

The approach to this challenge was initially developed by Grumman, the major subcontractor for the orbiter wings. A system of overlapping panels made of high-temperature alloys bridged the gap between the wing and the elevon. Each panel had rollers on its trailing edge, and the panels were preloaded to maintain roller contact. Seals between the rollers and at the panel hinges prevented hot gas ingestion.

The use of mechanisms came about in order to maintain contact of the rollers on the elevon surface. Predicted burst/crush loads, dynamic requirements, and magnitude of movement precluded spring loading the panels down. Therefore, at each panel, 2 four-bar linkages were used to cause the motion of the panel to approximately follow that of the elevon.

This initial design resulted in a set of interface points that became fixed for the remainder of the program. As shown in Figure 1, there were 15 panels per wing. A linkage (Figure 2) connected the elevon to a bellcrank (mounted on the rear wing spar) at 17 locations. The bellcrank, in turn, connected with either one or two panels, depending on the location, for a total of 29 connections to panels from the 17 bellcranks per wing. In general, the pivot axis of each bellcrank was skewed relative to the elevon and seal panel hinge lines in an attempt to compromise between the latter two, which were not parallel. Since the panel motion did not precisely follow the elevon motion, the clevis attaching the upper link to the panel was adjustable, and a high preload was put into each linkage by bowing the panel. This allowed the rollers to remain in contact without perfectly matched panel-to-elevon motion.

PROBLEMS WITH INITIAL DESIGN

The initial design was used on OV-101 (The Enterprise) for the Approach and Landing Tests (ALT). The seals and materials were not fully developed for high-temperature use at that time. The ALT program revealed that the high panel preload caused high wear on the interfaces. The rollers would sometimes fail to roll, giving high friction and a jolt at each new motion. The holes in the roller clevises elongated under the high loads, changing the adjustment and spoiling the pivot surfaces.

As a temporary measure to allow completion of the ALT program, the preload on the linkage was reduced. The bushings in the rollers were replaced by needle-type bearings to reduce friction. These measures provided acceptable performance in the low temperature ALT program, but the resulting gaps at the panel trailing edge were not acceptable for operational use. In addition, no anti-friction bearings were available that could meet the environmental requirements of the trailing edge rollers. At this point in the development, the mechanism (linkage) weight was approximately 221 pounds per vehicle.

CHANGES FOR ORBITAL FLIGHT TEST

Following the ALT program, Rockwell International undertook the further development of the subsystem to meet full orbital mission requirements. Primary goals were weight reduction, simplification, and a trailing edge configuration compatible with the high entry temperatures. The approach was to refine the kinematics so that an approximately constant gap would be maintained between the panel trailing edge and the elevon surface throughout the travel. This was envisioned as eliminating the rollers and reducing loads (a high preload would no longer be required to maintain panel trailing edge contact). A new metal seal configuration was developed by the thermal protection system designers to have greater initial deflection and thus tolerate greater variations in trailing edge gap. The lower loads, combined with use of lightweight swaged-end aluminum rod assemblies, gave an anticipated weight savings of 114 pounds per vehicle (52%).

TECHNIQUES USED

The challenge now faced by the designers was the sheer magnitude of the work required. Seventeen (17) lower stages and 29 upper stages had to be kinematically optimized to maintain the trailing edge gap within ± .060 inch over the elevon travel. Since pivot axes, panel sizes, and wing contours were unique at each location, separate kinematic studies were required at each. At that time (1976), no Computer Aid Design (interactive graphics) facilities were available at Rockwell.

The kinematic optimization became a joint effort of the Mechanical Design Group, with Mr. I. Awtamonow as lead designer, and the Numerical Design Group, represented by R. Chu, Supervisor, A. Shapiro, and B. Rivera. The Numerical Design group's primary responsibility was the mathematical modeling of vehicle lines and the programming of large computer controlled plotters to generate lines drawings. Using this background, the analysts developed a geometry analysis program for the main frame digital computer. The program allowed the entry of data on the basic pivot points and lines at each location. The radii and angles of the bellcrank were the only parameters which could be varied without changing the interface points built into the structure. With the chosen values entered, the user could input the elevon angle, and the program would calculate the positions of all the joints and the size of the trailing edge gap.

This program was used at each location to develop the linkage geometry. The designers proceeded much as they would have "on the board," using the original ALT linkage as a start and converging on a satisfactory solution by observing the sensitivity of the gap to each variable at the elevon up, neutral, and down positions. By this process of "enlightened trial and error," the geometry of all the linkages was established in about one year.

DETAIL DESIGN

As a geometry was established at each location, spot layouts were made to assure adequate clearances. However, the resources were not available to allow a detailed check layout of each location. Design of link and bellcrank details followed the establishing of the geometry. Convential aerospace light weight design practices were followed. The most significant obstacle to detail design was the high temperature anticipated at the rod end attaching to the seal panel. A rod end using carbon-graphite-MoS2 bearing inserts was specified in order to withstand the approximately 800F temperature predicted. Bearings of the same material, but in a different configuration, were used in other orbiter systems - e.g., the Payload Bay Door Hinges.

The final loads iteration for the subsystem was completed in 1977, when detail design was well underway. Analysis revealed that the light links had insufficient stiffness based on flutter/buffet criteria. As a result, most tube/link details were redesigned. The larger diameter and wall thickness resulted in a weight increase, but the subsystem weight remained close to the target weight of 107 pounds.

LATER CHANGES

The elevon cove seal on the lower wing/elevon surface was redesigned in 1977. The diameter of the seal increased to the point that the lower links would interfere with the seal as shown in Figure 3. This problem was discovered in spot layouts prior to completion of detail release. Changes in the critical seal were not feasible, so the lower links were redesigned to clear the seal. The resulting curved links added 21 pounds per vehicle to the subsystem.

The body of the curved links was hollow aluminum, the curved and straight portions being one continuous part (Figure 4). The initial fabrication sequence consisted of forming an oversized machined tube to the curvature, chemically milling and machining final dimensions, and heat treatment. Difficulties were encountered due to the higher rate of chemical material removal in the stretched (formed) areas as well as dimensional changes induced by heat treatment. Manufacturing technique development eventually produced trouble free fabrication. The sequence evolved into the following: machining the straight tube to final dimensions; forming the tube to a smaller radius of curvature than the final requirement; and heat treatment, during which the tube straightened out to final dimensions. The amount of overbending required to achieve the correct curvature after heat treatment was determined by experiment.

At some locations, an additional clearance problem precluded the use of the large diameter curved tubes. In these areas, the curved portion of the tube entered a channel fitting with the elevon up (Figure 5). An alternate design was developed as shown in Figure 6. The narrower section and anti-rotation lugs provided the additional clearance required. However, the greater weight of these links resulted in the total subsystem weight increasing to 196 pounds per vehicle. These heavier Inconel 718 links were used at seven of the nine inboard lower stages.

BEARING MATERIAL CHANGE

As described above, the high temperature end of the upper links used a carbon-graphite-MoS2 bearing insert material. This material will withstand temperatures up to 2500F. However, the manufacturer of the bearings found that the spherical ball rod end with carbon-graphite bore presented unanticipated fabrication problems. Cracking of the insert material during fabrication resulted in an extremely high rejection rate. Virtually no bearings were delivered 1-1/2 years after the first order.

In mid-1978, the decision was made to give up on the carbon-graphite inserts. A rod end using a ceramic MoS2 dry film lubricant was specified instead. The new lubricant was restricted to a maximum of 750F for short duration only, which corresponded to the expected environment with no margin. The dry film lubricant was therefore being pushed to perform at its maximum capability. However, experience had been gained by this time with this dry film lubricant in other orbiter mechanisms, resulting in confidence that the life would be adequate.

INITIAL INSTALLATION PROBLEMS

The installation and adjustment of the first operational system occurred on OV-102 (Columbia). Owing to the simplicity of the hardware and its similarity to other orbiter mechanisms, a full qualification program was not performed. Consequently, a number of problems were encountered on the first article. The primary problem was an inability to hold the trailing edge gap tolerances originally targeted. The buildup of fabrication tolerances was enough to force the gap tolerance to increase from ± 0.060 (original) to ± 0.130 (neutral position), ± 0.160 (elevon down), and ± .215 (elevon up). The tolerances involved included those on the elevon moldline (contour), panel details, bellcranks, wing spar fittings, elevon hingeline, and elevon clevis fittings. Adjustments of the link lengths (upper and lower) from nominal were made based on calculated sensitivity until the best results were achieved. Fortunately, the seal design had enough margin to absorb the increased gap variations.

Other first article problems included low clearances to hydraulic lines and fasteners, and rubbing of rod end locking devices against adjacent rod bodies. The problems were considered minor for the first installation of a system without complete check layouts or mockups. R. Holt of Rockwell International was the responsible engineer during the subsystem installation phase.

Installation of OV-099 (Challenger) encountered very few problems. However, many trailing edge gaps were at the low side of the tolerance band, and excessive seal wear was noted on many seals following elevon tests. The damage was found to be caused by rubbing of an area of the seal not intended to contact. A change in the seal mounting geometry solved this problem and avoided any change to the mechanism or the seal itself.

SUBSYSTEM PERFORMANCE SUMMARY

Figure 7 illustrates a typical linkage of the final configuration. The mechanism performance has been satisfactory on all orbital flights. No functional or leakage problems have been encountered. The final design, as developed from the ALT version, meets the original challenge in the intended way - simply and directly.

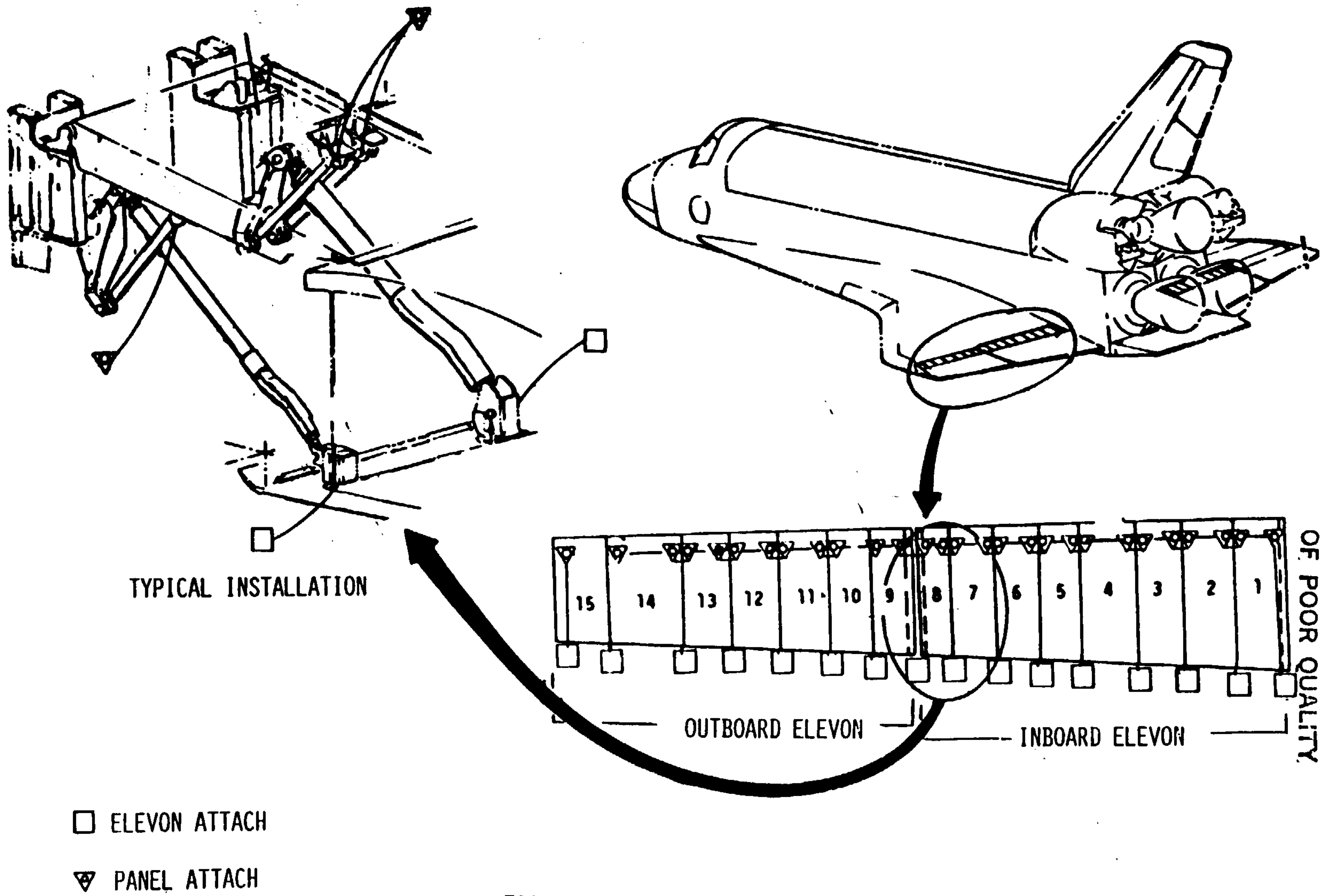

FIGURE 1 PANEL AND LINKAGE LOCATION

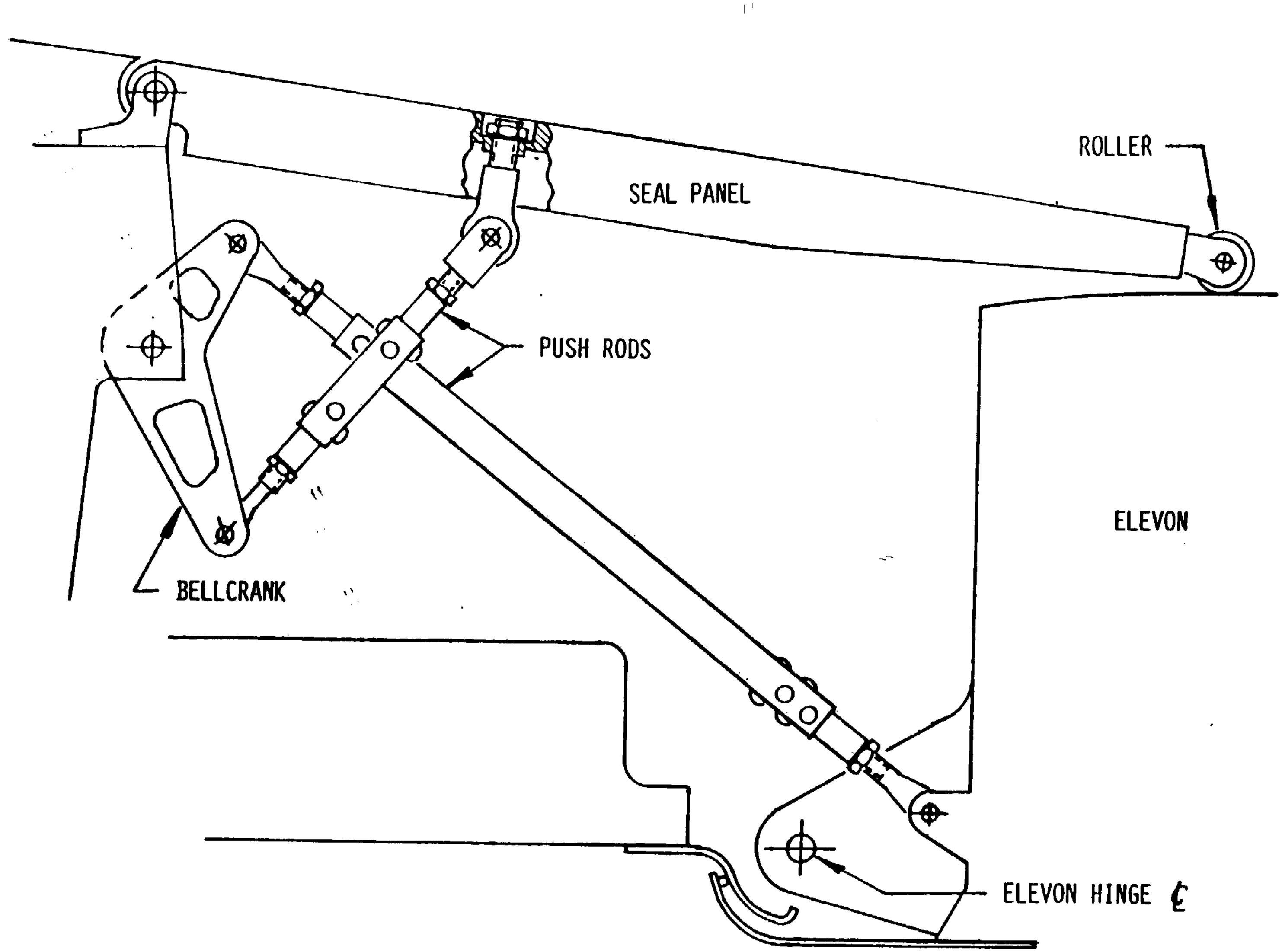

FIGURE 2. ORIGINAL LINKAGE CONFIGURATION (TYPICAL)

ORIGINAL PAGE IS
OF POOR QUALITY

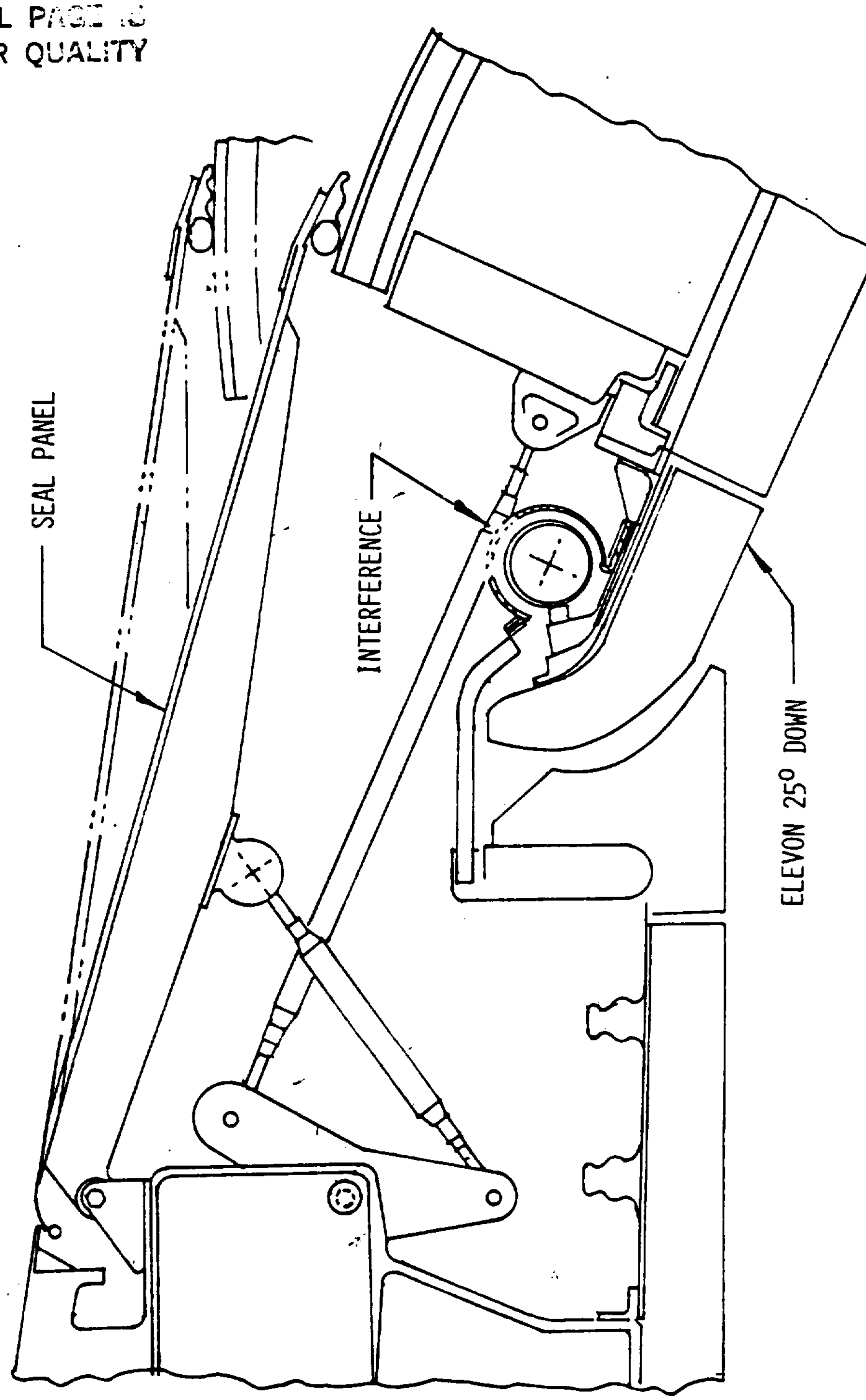

FIGURE 3. INTERFERENCE OF LOWER LINK WITH NEW COVE SEAL

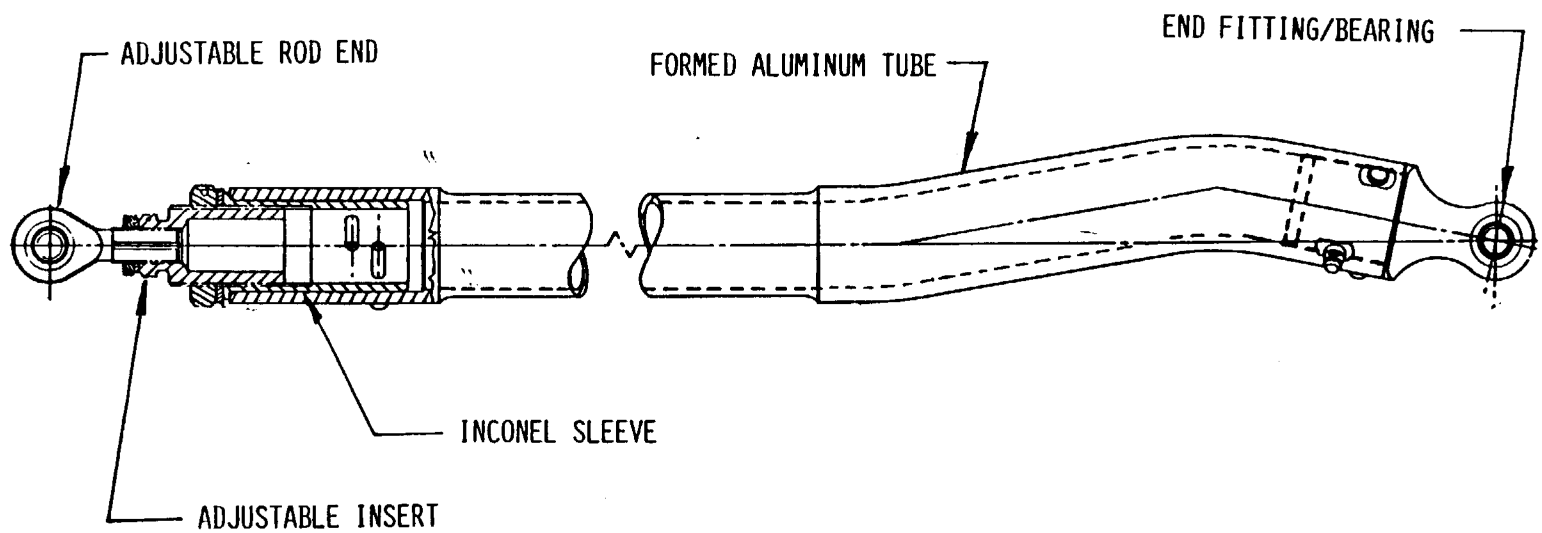

FIGURE 4. CURVED ALUMINUM LINK ASSEMBLY

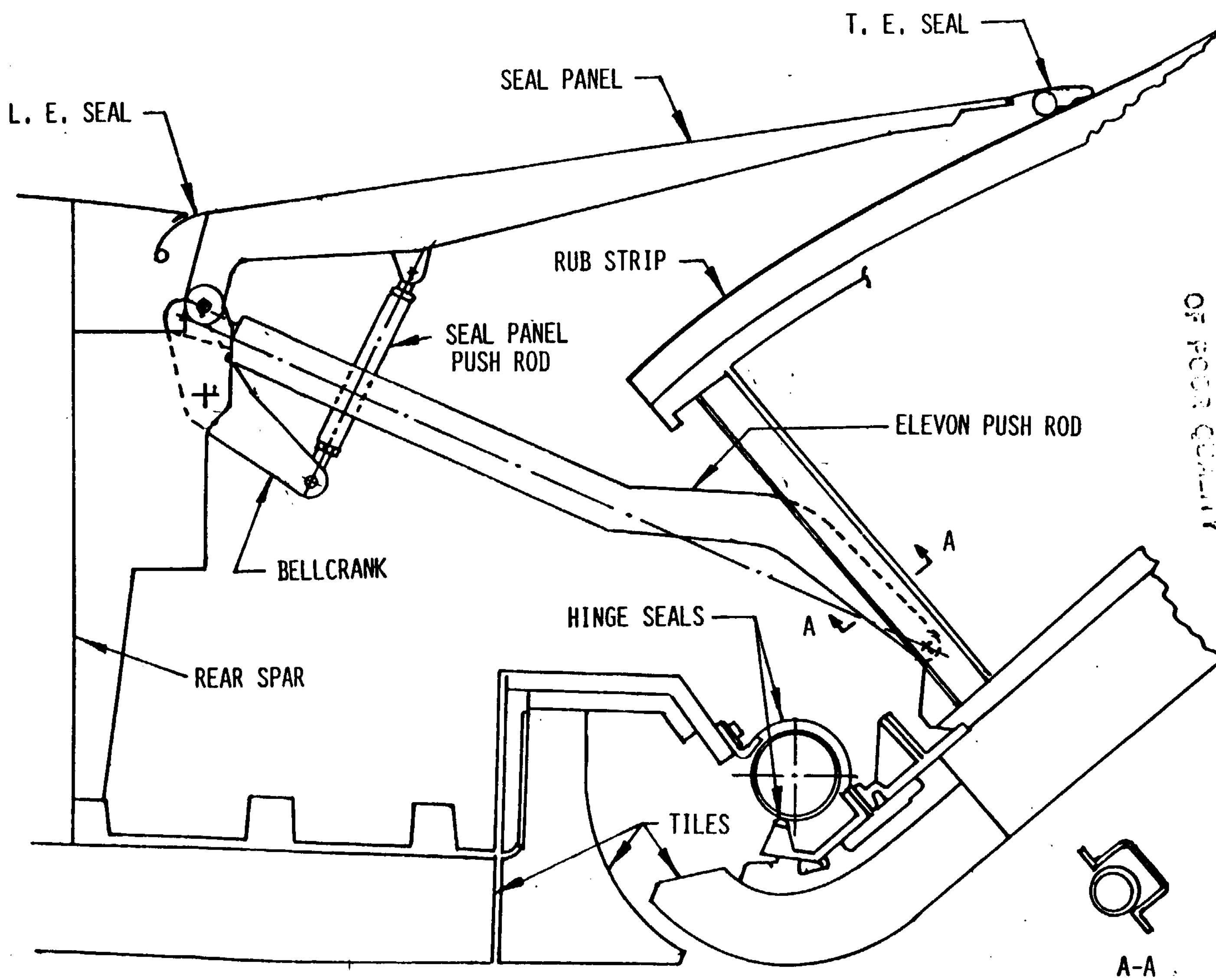

FIGURE 5. CURVED ALUMINUM LINK INTERFERENCE WITH ELEVON STRUCTURE (ELEVON UP)

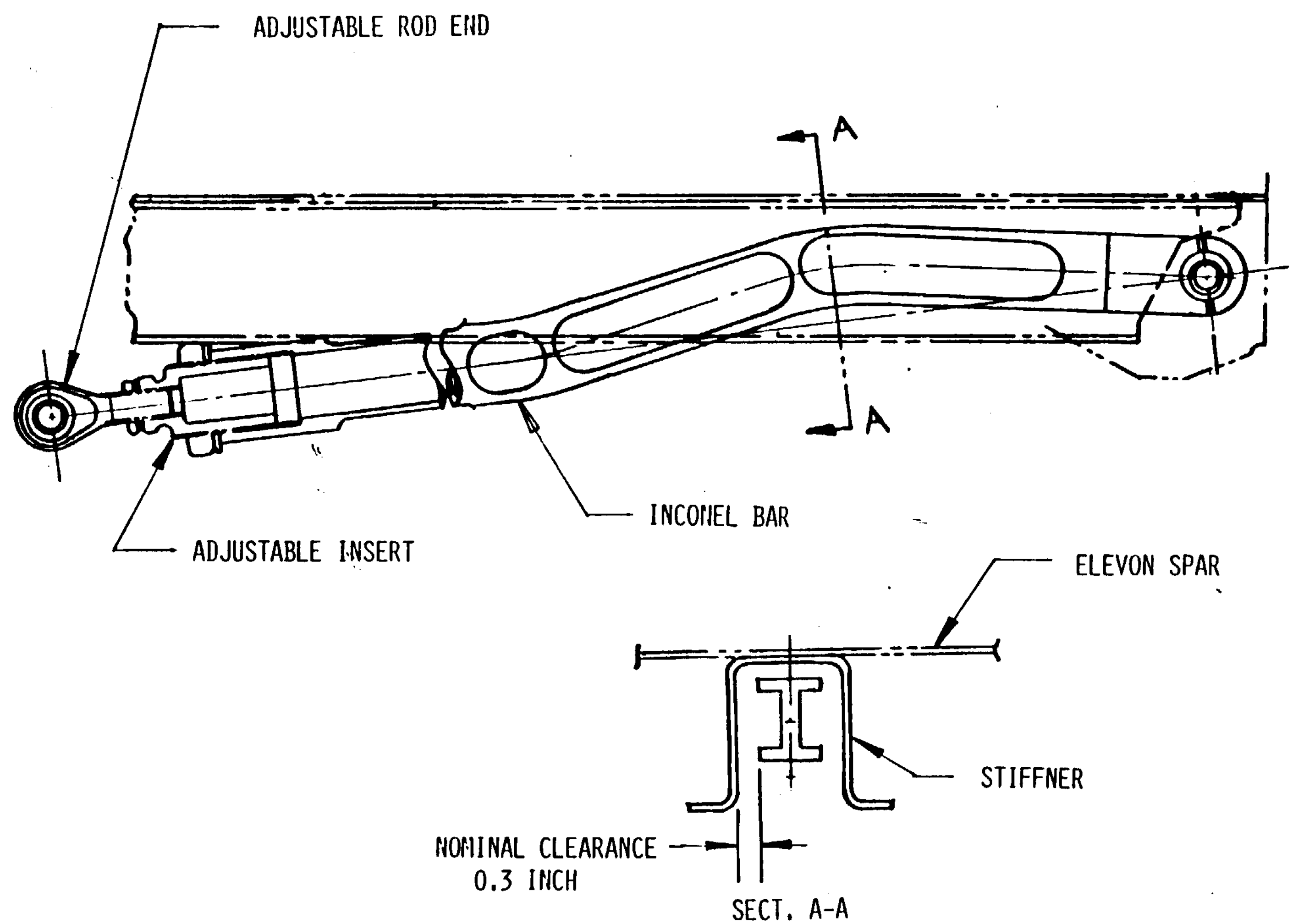

FIGURE 6. CURVED INCONEL LINK ASSEMBLY

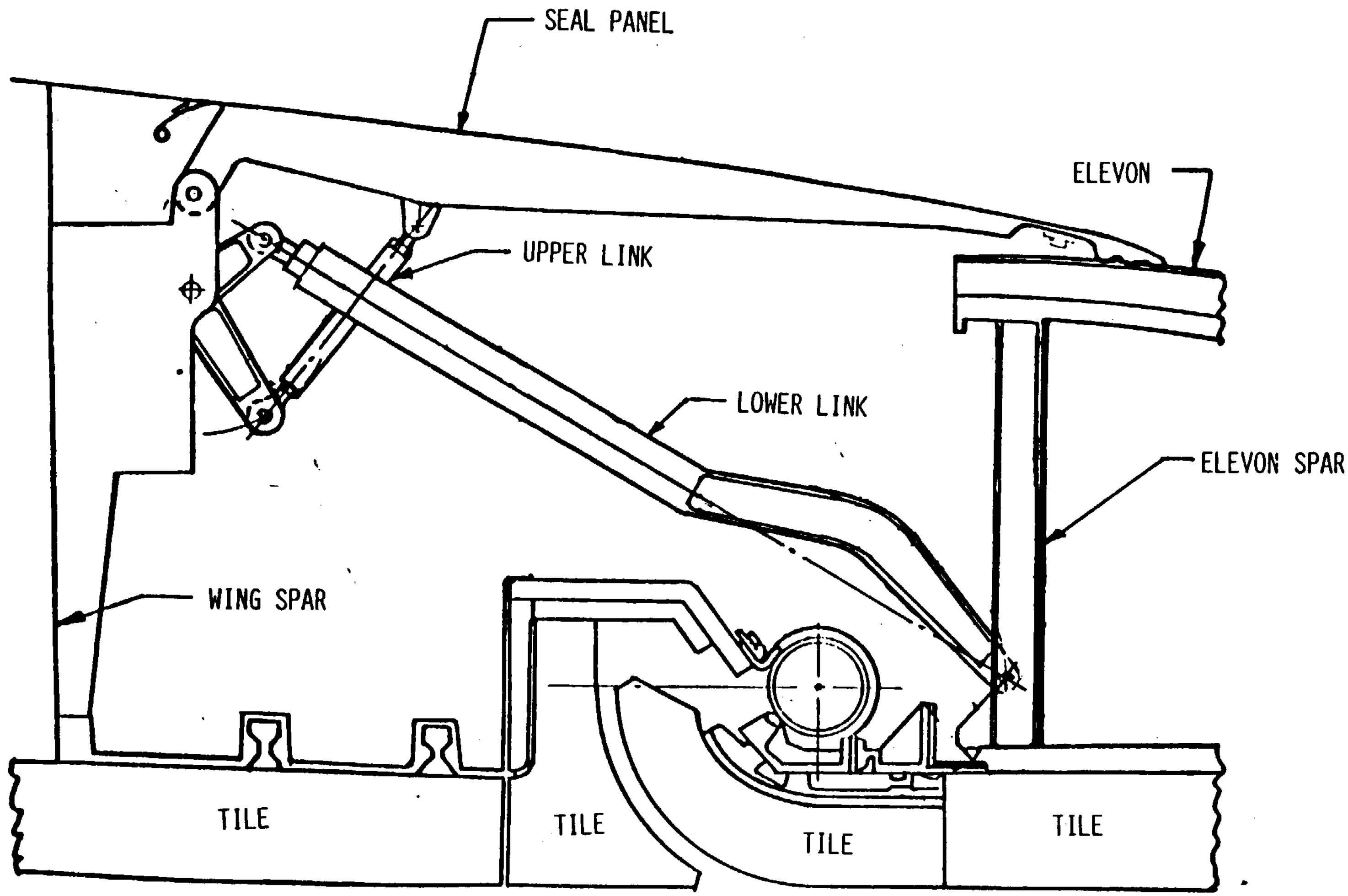

FIGURE 7. FINAL LINKAGE CONFIGURATION (TYPICAL)