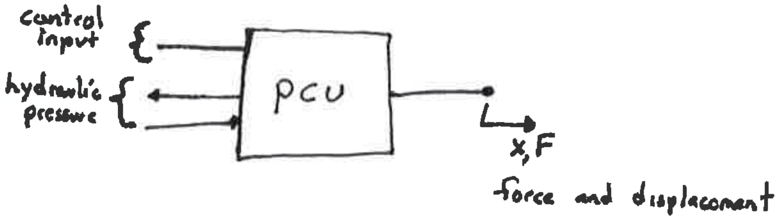
AEM 617

Hydraulics

part 3

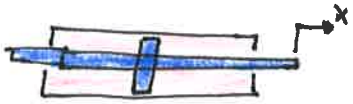
PCU ≡ Power Control Unit



Convert hydraulic pressure and flow to a displacement (with a force), all controlled by an input.

Linear Output:

Unbalanced piston

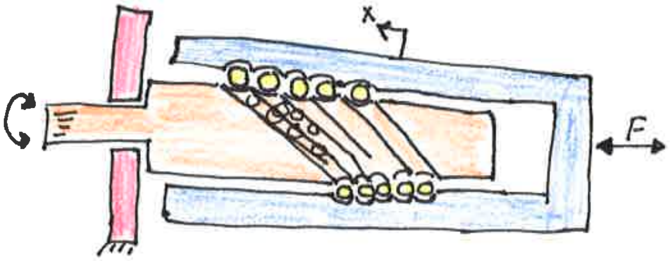


Balanced Piston

Rotary Output

Vane (top view)

This is used in the F-15 rudder.



Boeing research at one point

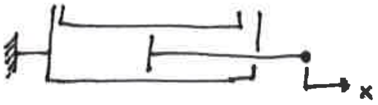
Helical Spline: Converts linear motion to rotational

- Lubrication
- Motion of at least 4 parts.

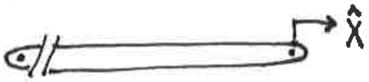
Servo Valves

How can we design a PCU to provide hydraulic gain to an input?

- Output



- Input



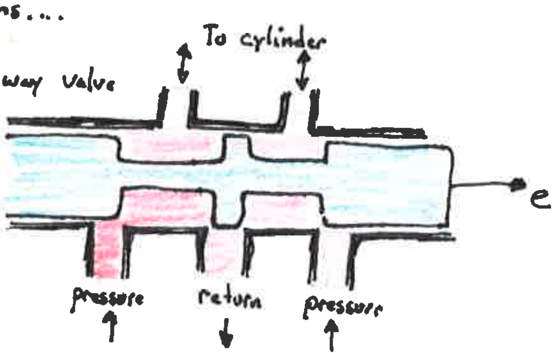
- Error

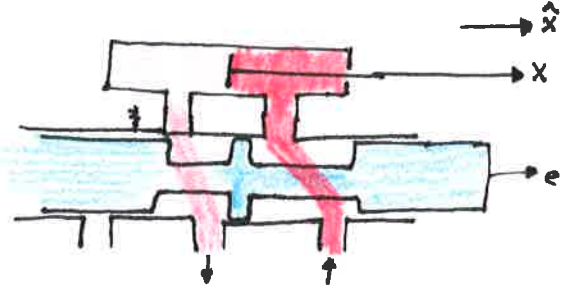
  $e = x - \hat{x}$

- Servo valve that provides a flowrate / pressure proportional to error

  Many designs....

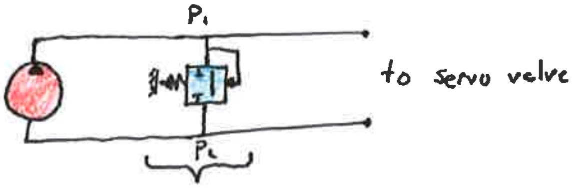
  Common 4 way valve





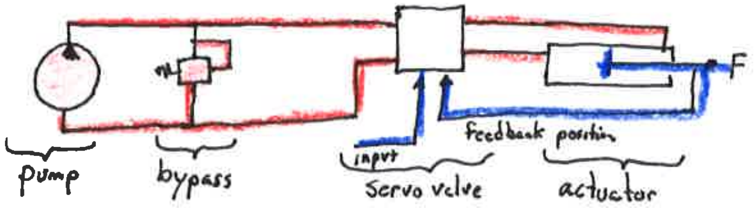
Mechanically connect
$e = x - \hat{x}$
feedback controller

- Constant Pressure Source



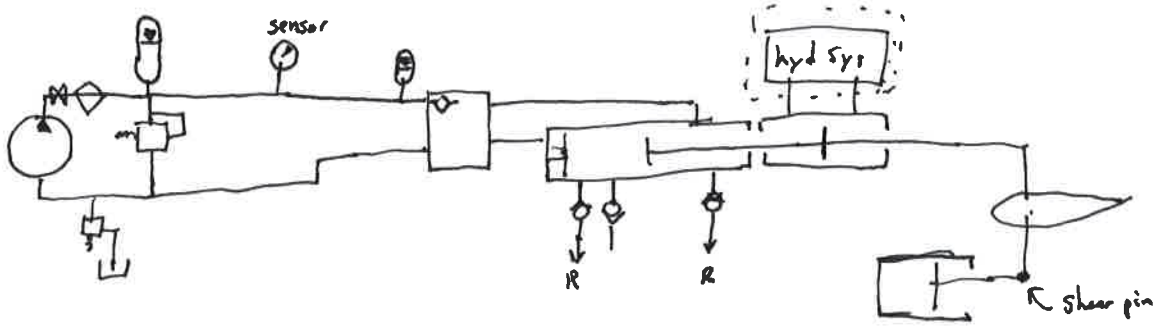
Bypass Valve $\equiv$ hydraulic feedback controlled valve to maintain constant pressure P_1 on supply line. Must be designed to flow full flow-rate when servo valve demand is zero.

- Complete System



Functionally this is complete. Realistically, the system needs additional parts for safety and reliability

- Shock and high Q → accumulator
- Cavitation protection of piston → check valves
- Fluid Contamination → filters
- Fluid charge level → resevoir + check valves
- Redundancy → Dual pistons, dual hydraulic system
- Failure isolation → shear pins + shut off valve
- System Dynamics → Internal damping + spears + etc.



Lap Effects

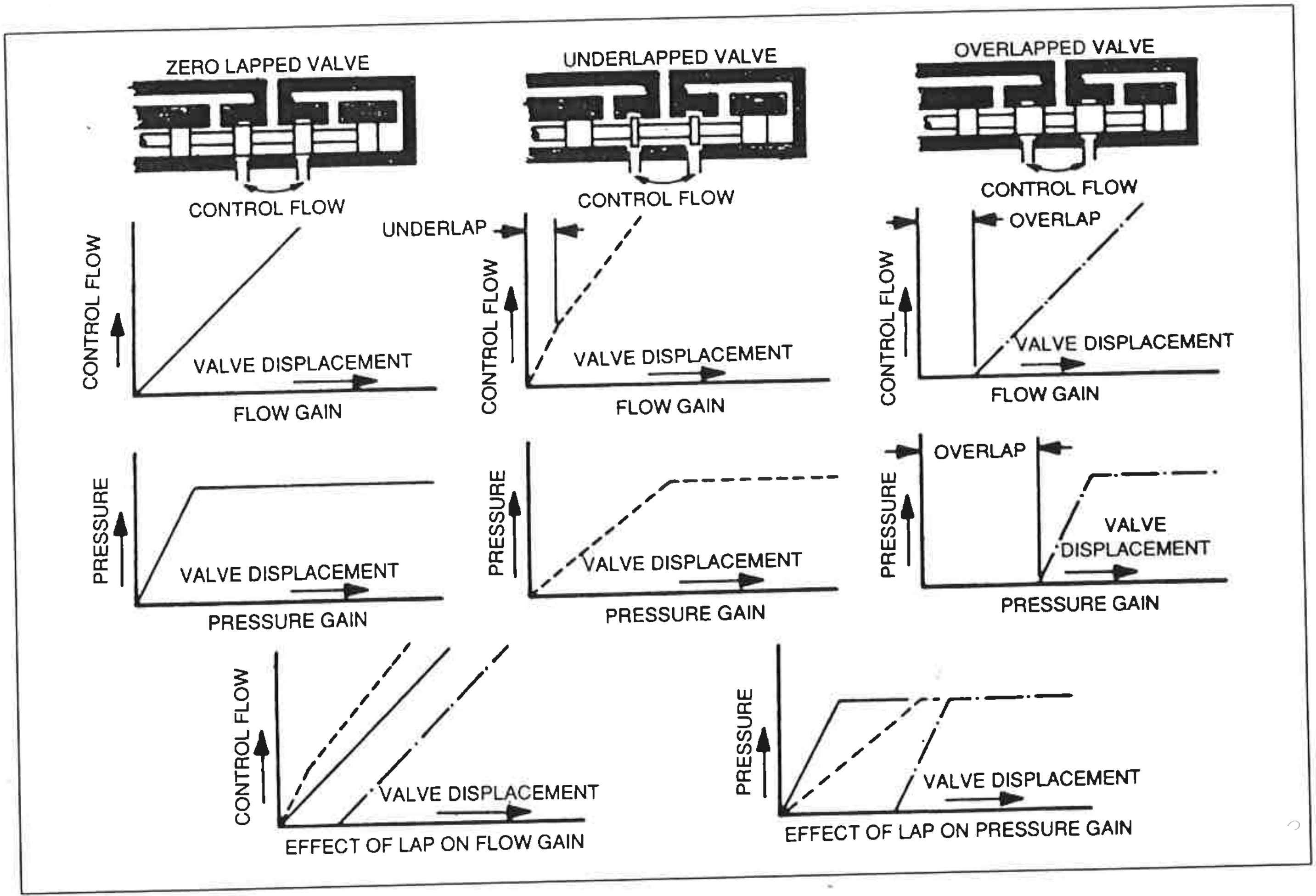
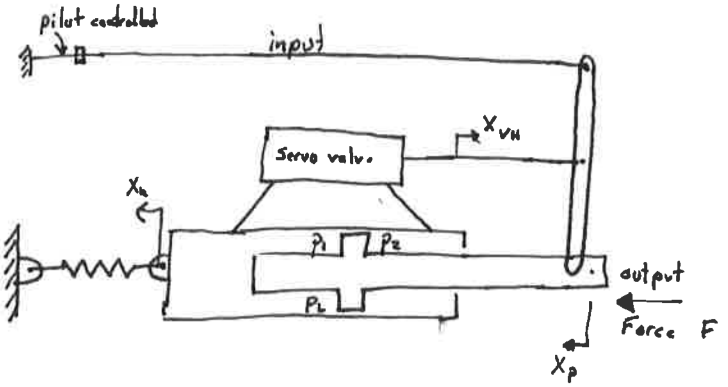


Figure 9-45. The Effects of Lap on a Spool-and-Sleeve Valve.

Dynamics

Source: Aircraft Flight Control Actuation System Design



In the frequency domain, the actuator stiffness is $K(s) = \frac{F(s)}{X_p(s)}$

The linkages are connected such that $X_{VH} = -\underset{\uparrow \text{ ratio of valve to piston displacement}}{R_f} X_p + \underset{\nwarrow \text{ ratio of valve to housing displacement}}{R_H} X_H$

Pressure on piston

$$P_L = P_1 - P_2$$

The servo valve behaves (as a model) $q_V = K_V X_{VH} - \frac{K_V}{K_P} P_L$

The actuator flow rate is $q_A = \underset{\substack{\uparrow \\ \text{piston} \\ \text{area}}}{A} \underset{\substack{\uparrow \\ \text{piston} \\ \text{travel}}}{X_{PH}} + \underset{\substack{\uparrow \\ \text{compressibility}}}{K_c} \underset{\substack{\uparrow \\ \text{pressure}}}{P_L}$ $\qquad K_c = \frac{\text{Volume}}{4\underset{\nwarrow \text{ Bulk modulus.}}{\beta}}$

The resulting force is $F = -A P_L$

The housing moves as $X_H = -A P_L \frac{1}{K_R}$

Combining into a system model gives

$$\begin{bmatrix} AS + K_v R_v & \frac{K_v}{K_{p0}} + \frac{V_V R_H A}{K_R} + S\left(K_c + \frac{A^2}{K_R}\right) \\ 0 & -A \end{bmatrix} \begin{pmatrix} X_p \\ P_L \end{pmatrix} = \begin{pmatrix} 0 \\ F \end{pmatrix}$$

For a transfer function

$$K_A = \frac{F(s)}{X_p(s)} = \frac{A(A \cdot S + K_v R_F)}{\left(K_c + \frac{A^2}{K_R}\right)S + \frac{K_v R_H A}{K_R} + \frac{K_v}{K_{p0}}}$$

$A \equiv$ Piston Area

$S \equiv$ Laplace Freq

$K_v \equiv$ No load valve gain

$R_F \equiv$ Ratio drop' valve to piston

$K_c \equiv$ Fluid compressibility

$K_R \equiv$ Housing stiffness

$R_H \equiv$ Ratio drop' valve to housing

$K_{p0} \equiv$ Pressure gain of valve

When $s \to \infty$ (high frequencies)

$$K(\infty) = \frac{K_R \cdot K_{oil}}{K_R + K_{oil}}$$

when $s \to 0$ (static)

$$K(0) = R_F A K_p$$

$$K_p \equiv \frac{K_{p0}}{1 + K_{p0}\left(\frac{A R_H}{K_H}\right)}$$

$K_{oil} \equiv \frac{A^2}{K_c}$ oil compressibility

Absolute Stability:

$K_A(0) < K_A(\infty)$ for stability

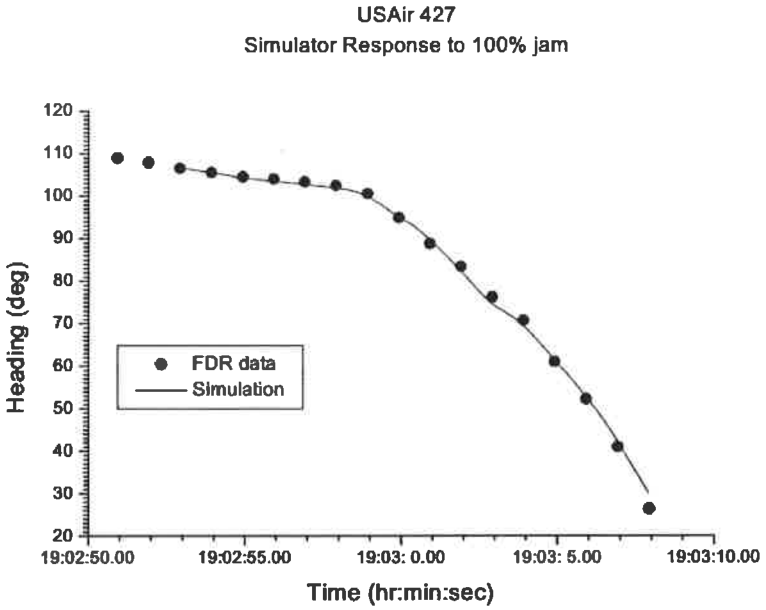


Figure 18d. Heading data for USAir flight 427.

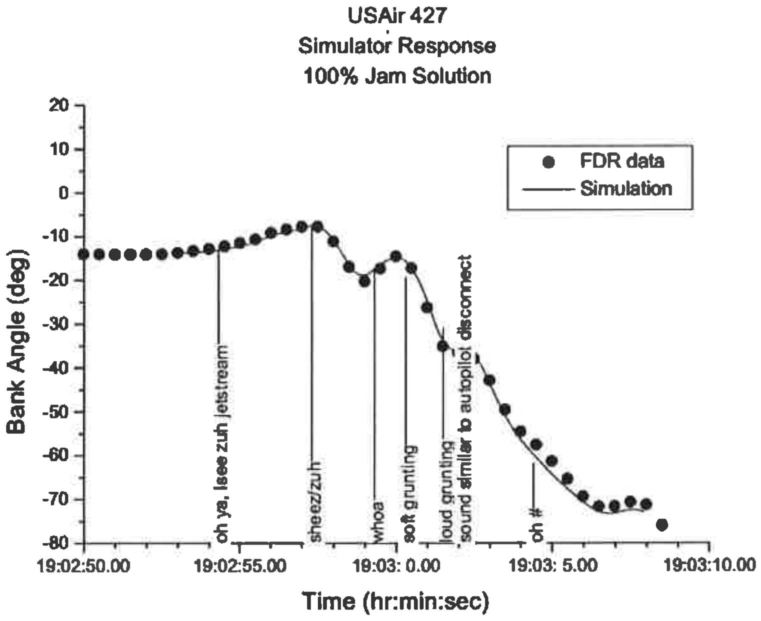


Figure 18e. Bank angle data for USAir flight 427.

Design Mitigation and ADs

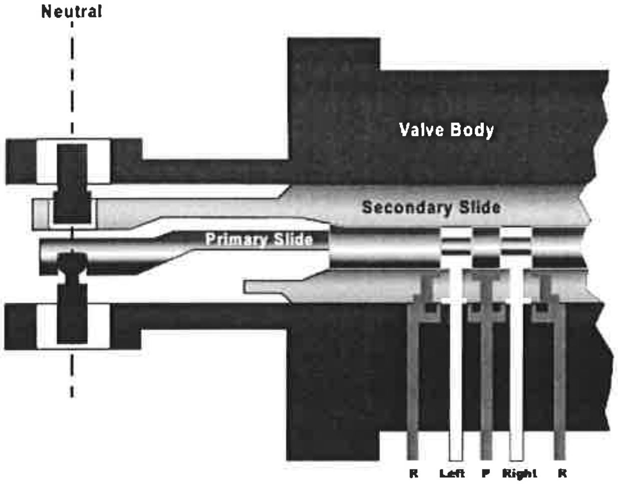
- 1994 Leak test to determine if 2ndary slide was extending two for
  750hr repeating until PCU replaced , AD

- 1996 AD, test every 250 hrs until replaced. Also detects if jam <u>ever</u> occured.

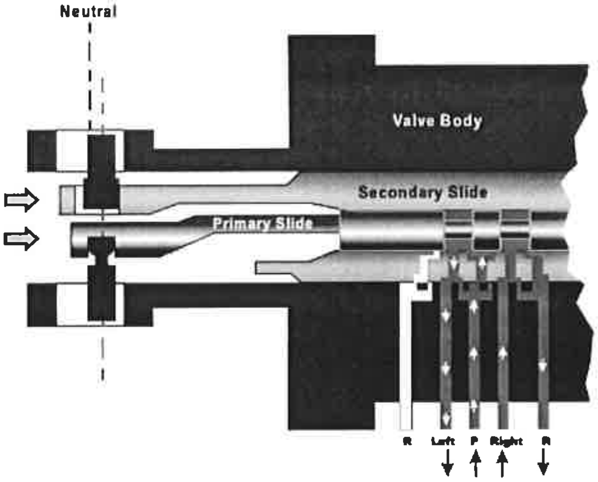
- 1997 AD, Replace PCUs on all 737.
  AD, Replace yaw damper with electromechanical rate gyro
- 1998 PCU redesigned for all new 737s

- 1997 AD, Reduces hydraulic pressure from 3000 psi to 1000psi or 1400psi for only the rudder PCU
  and only during certain phases of flight. (airspeed > 137 kts)

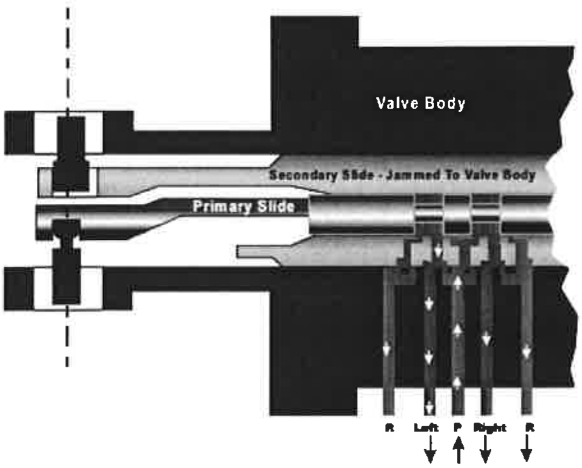
Primary and Secondary Slides at Neutral
Rudder Rate = 0



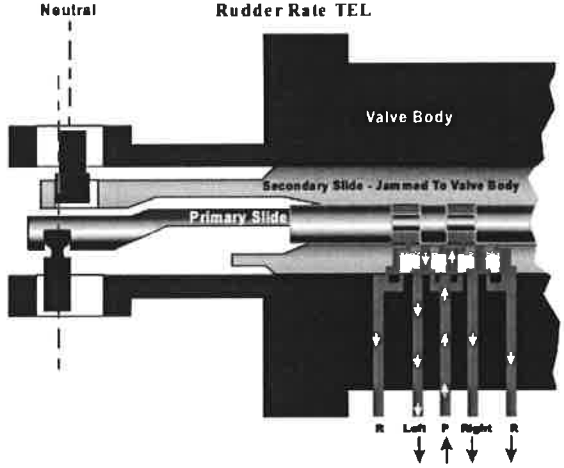
Normal Full Rate Command-
Primary & Secondary Slides Full Open
Rudder Rate TEL

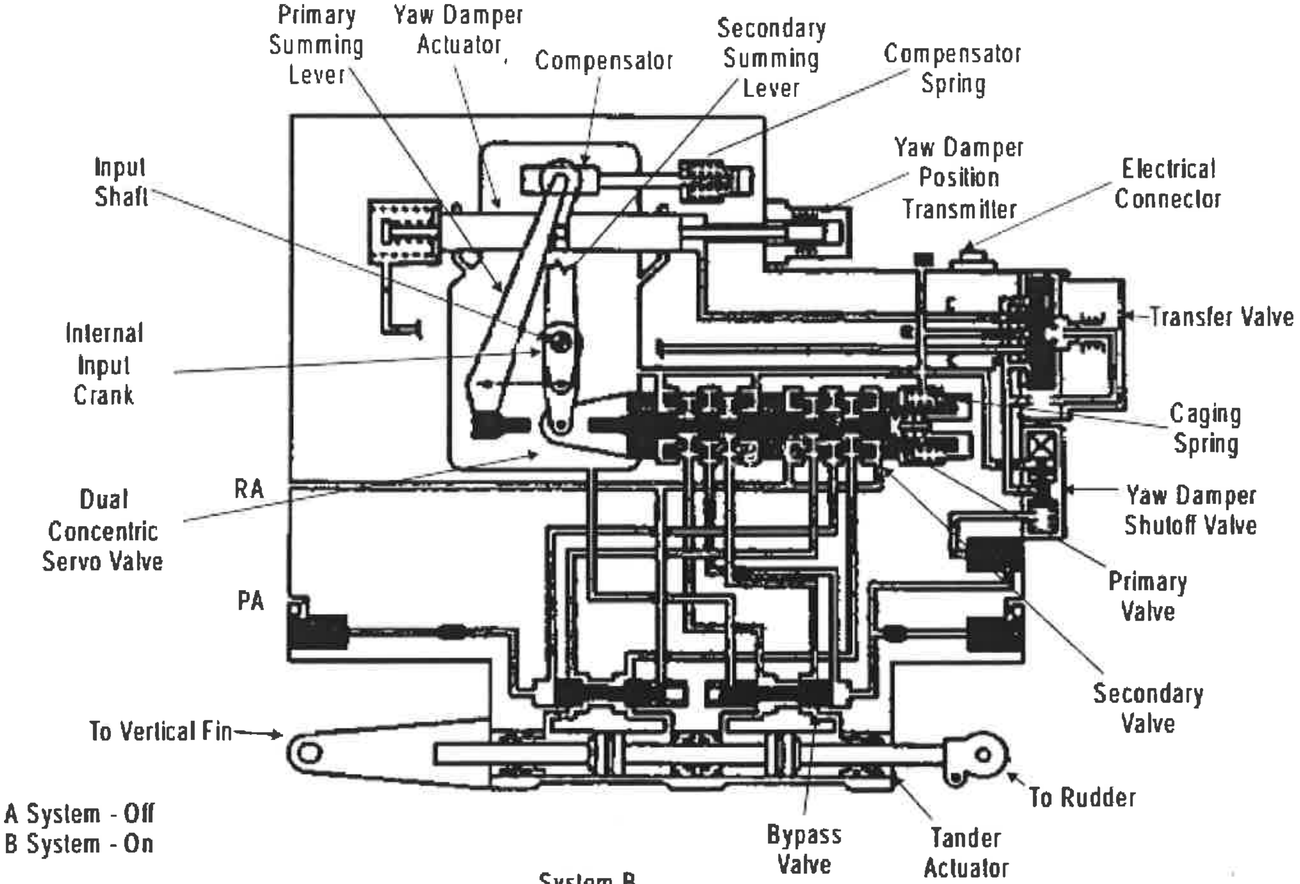


Intended Operation:
Secondary Slide Jammed Full Open, Primary Slide Opposing
(Full Cross Flow)
Rudder Rate = 0

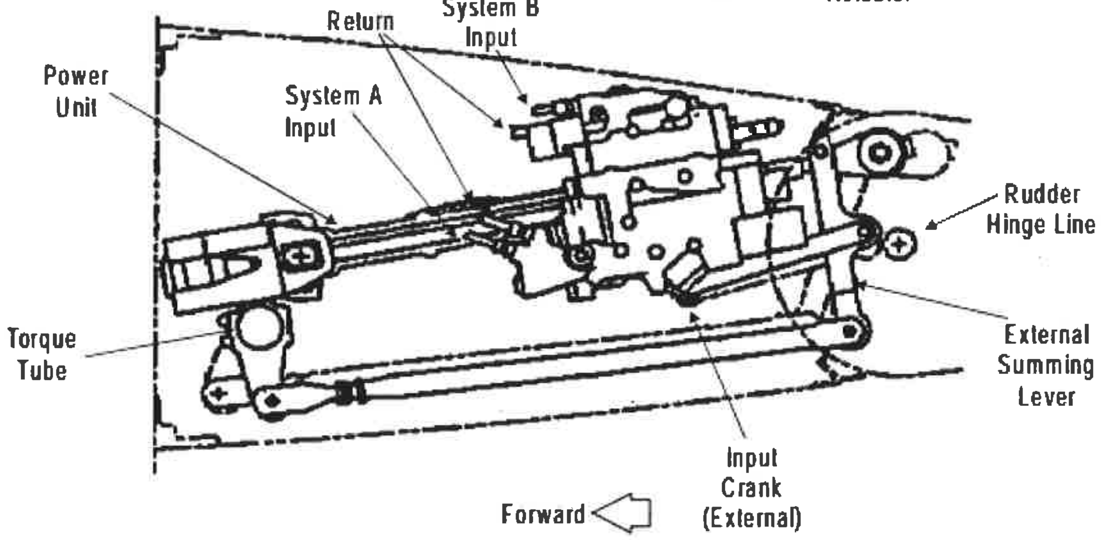


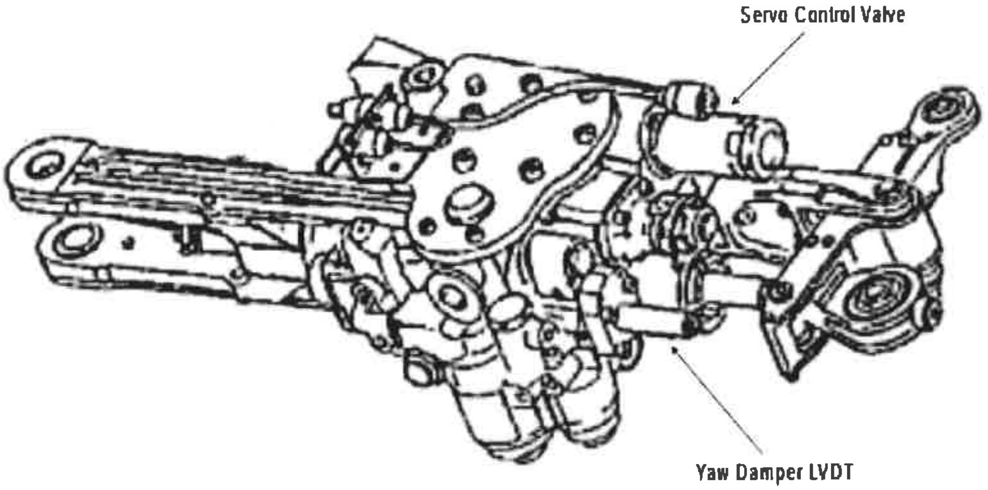
Newly Discovered Failure Effect:
Secondary Slide Jammed Full Open, Primary Slide Over-Stroked
In Opposing Direction
Rudder Rate TEL





A System - Off
B System - On




Servo Control Valve
Yaw Damper LVDT

ADTA , obert

Aerospatiale's SN-600 Corvette prototype has determined that over-trimming of the aircraft's variable-incidence tailplane probably is what caused the twin turbofan business jet to pitch over into an uncontrollable dive.

Aerospatiale officials are convinced the final accident report will clear the basic Corvette design and are accelerating development of two production aircraft and two test specimens. Flight tests with the new models—embodying configuration changes resulting from early prototype flight tests—are scheduled to begin late next year.

The aircraft should be certified by the end of 1973, in time to guarantee production delivery in early 1974. Three crewmen from the French civilian test center (CEV) were killed in the crash of the prototype, which occurred as they were doing high-altitude stalls (AW&ST Apr. 12, p. 53). The aircraft pitched over about 20 kts above normal stalling speed and entered a steep dive.

The only transmission from the pilots was a terse report from one of them that together they were unable to pull the aircraft out of the dive.

After long study of data from flight test recorder tapes, the investigators have determined that the pilot, who was flying the Corvette for the first time, apparently trimmed the tailplane to an excessive negative incidence, nose-up attitude during preparations for the stall tests. No stops had been installed to limit tailplane travel, because that portion of the flight envelope had not been fully explored.

All aircraft with variable-incidence tailplanes could encounter the same problem which caused the Corvette crash, according to several officials. When setting up the aircraft for the stall series, the pilot apparently put it in a configuration which ultimately reversed the action of the tailplane and elevator controls, they said.

The large-span flaps were deployed, creating a relative downward (or nose-up) airflow over the tailplane. While trimming the tailplane, the pilot apparently released back pressure on the control yoke – as is general practice – and the elevator control surfaces moved to a nose-down position opposite that of the tailplane as they streamlined in the relative airflow, they said.

The resultant control surface configuration created a nose-down pitching moment before stall speed was reached, they said, and :the deflected airflow generated by the flaps created aerodynamic pressures on the elevator controls which the pilots could not overcome. The Corvette has straight mechanical linkages without servo-controls in its flight control system.

To recover from the dive, the pilots would have had to move against their automatic reactions and trim the tailplane for nose-down, according to one official. This probably would have re-established the aerodynamic balance of the tailplane, they said. Raising the flaps also might have helped correct the control imbalance, they added.

Aerospatiale test pilots were aware that without stops the tailplane could be over-trimmed, they operated within certain limits while exploring the aircraft's envelope. How the CEV test pilot managed to trim the aircraft past these limits probably will not be determined.

Program officials said production aircraft will be equipped with stops which will make it impossible to establish an imbalanced configuration.

The French accident investigating board has completed a study of the accident and has submitted its report to Aerospatiale and the French flight test center (CEV).

The official report said the cause of the accident was an "aerodynamic anomaly in the horizontal tail" and that the problem has been corrected on the new production design. The problem encountered basically was tailplane stall, according to one source, which was aggravated by a 45-deg. flap setting and high negative incidence setting of the horizontal tailplane. The aircraft pitched down about 20 kt. above normal stall speed.

The problem has been eliminated on production versions through a combination of previously planned lengthening of the fuselage – aimed primarily at improving aerodynamic drag – and smaller limits on movement of the three control surfaces involved.

Travel of the variable incidence tailplane has been reduced from +2 deg and -10 deg to +2 deg and -8 deg.

Elevator travel has been reduced from +25 deg and -15 deg to +20 deg and -10 deg. Flap deflection angle has been reduced from 45 deg. to 40 deg.

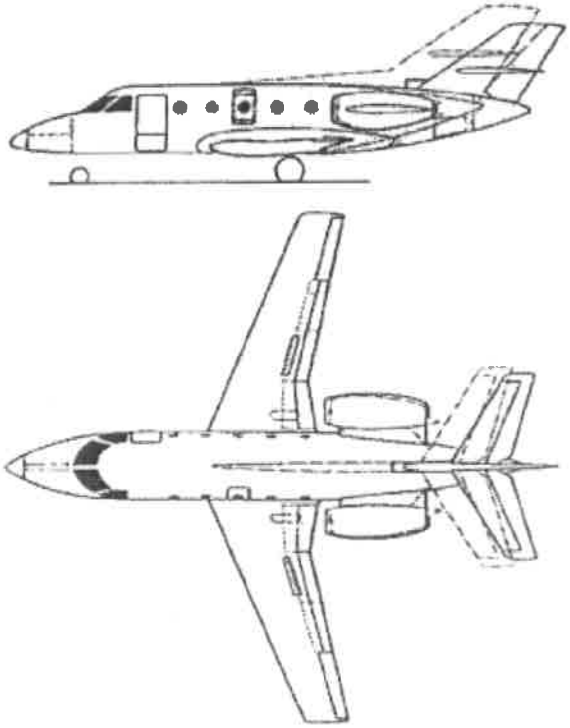


Figure 31.26 - Over-trimming cited in Corvette crash.
Source: Aviation Week and Space Technology, May 31 and October 18, 1971

Hybrid PCU system

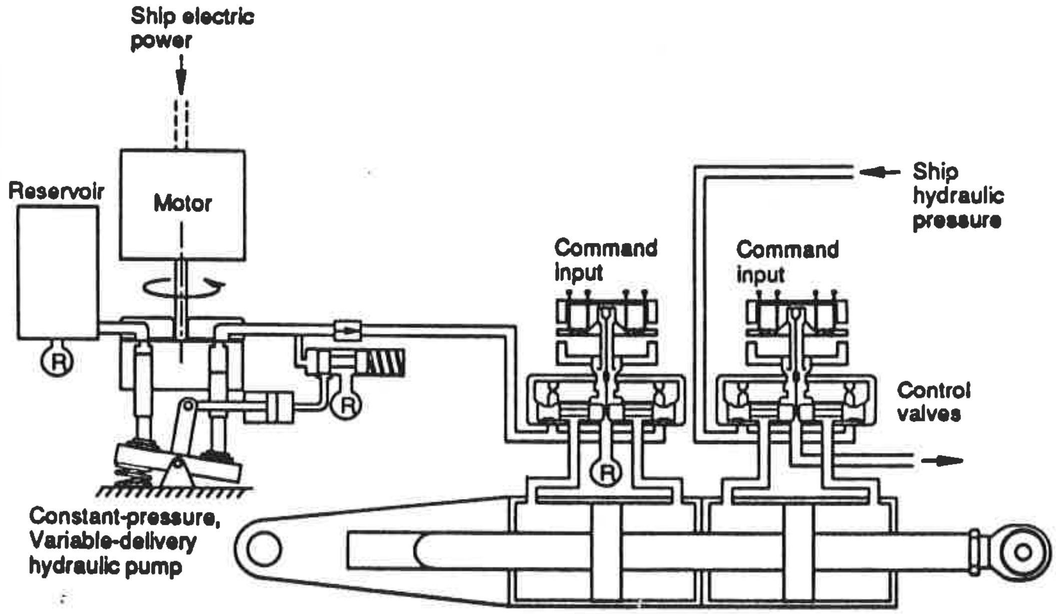
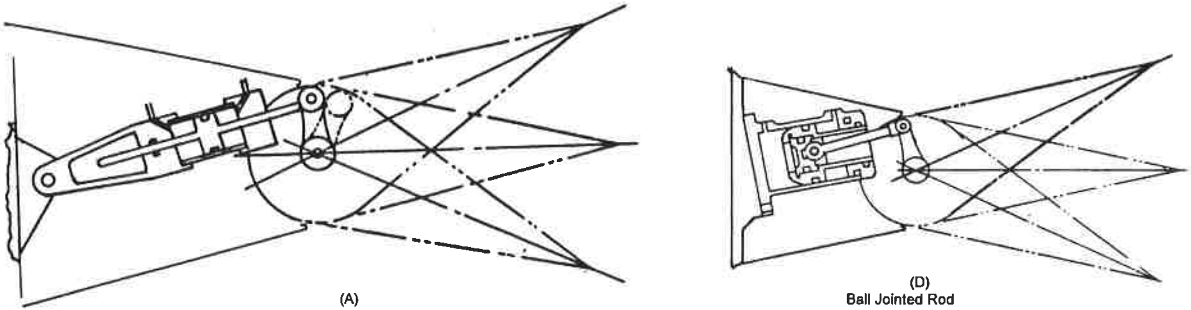


Figure 6-9. Typical Hybrid IAP (HIAP) Arrangement.

Advantages:

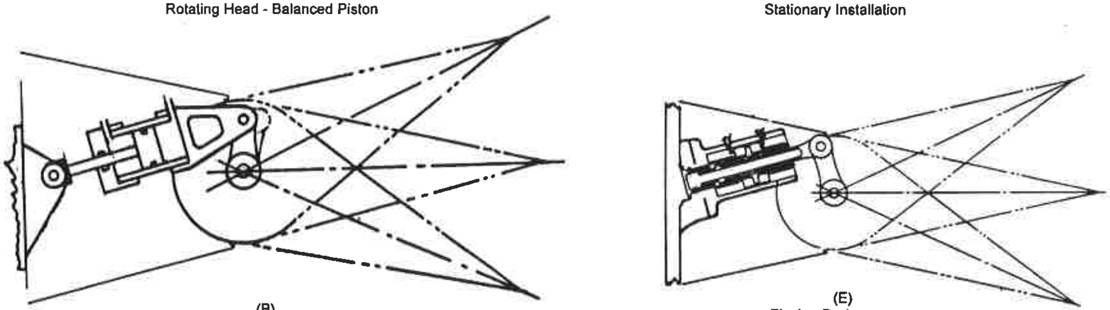
- Independent power sources
  - Electric
  - Hydraulic
- Balanced piston with redundancy
- Independent feedback loops

Connecting PCU to rotating surface



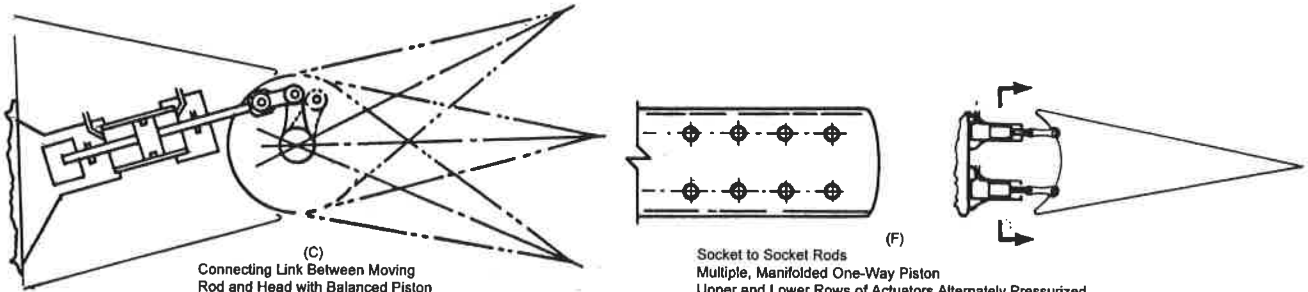
(A)
Moving Piston Rod
Rotating Head - Balanced Piston

(D)
Ball Jointed Rod
Unbalanced Piston
Stationary Installation



(B)
Moving Body
Rotating Rod - Unbalanced Piston

(E)
Flexing Rod
Balanced Piston
Stationary Installation



(C)
Connecting Link Between Moving
Rod and Head with Balanced Piston
Stationary Installation of PCU

(F)
Socket to Socket Rods
Multiple, Manifolded One-Way Piston
Upper and Lower Rows of Actuators Alternately Pressurized
Stationary Installation Intended for Very Thin Surface Vehicles

Figure 9-3. Various Servoactuator Installations.