General Approach to FCS Actuation System

- Utilize Experience From F-4 SFCS Program and F15
  - Force Summing Single-Stage EHSV
  - Failure Monitoring

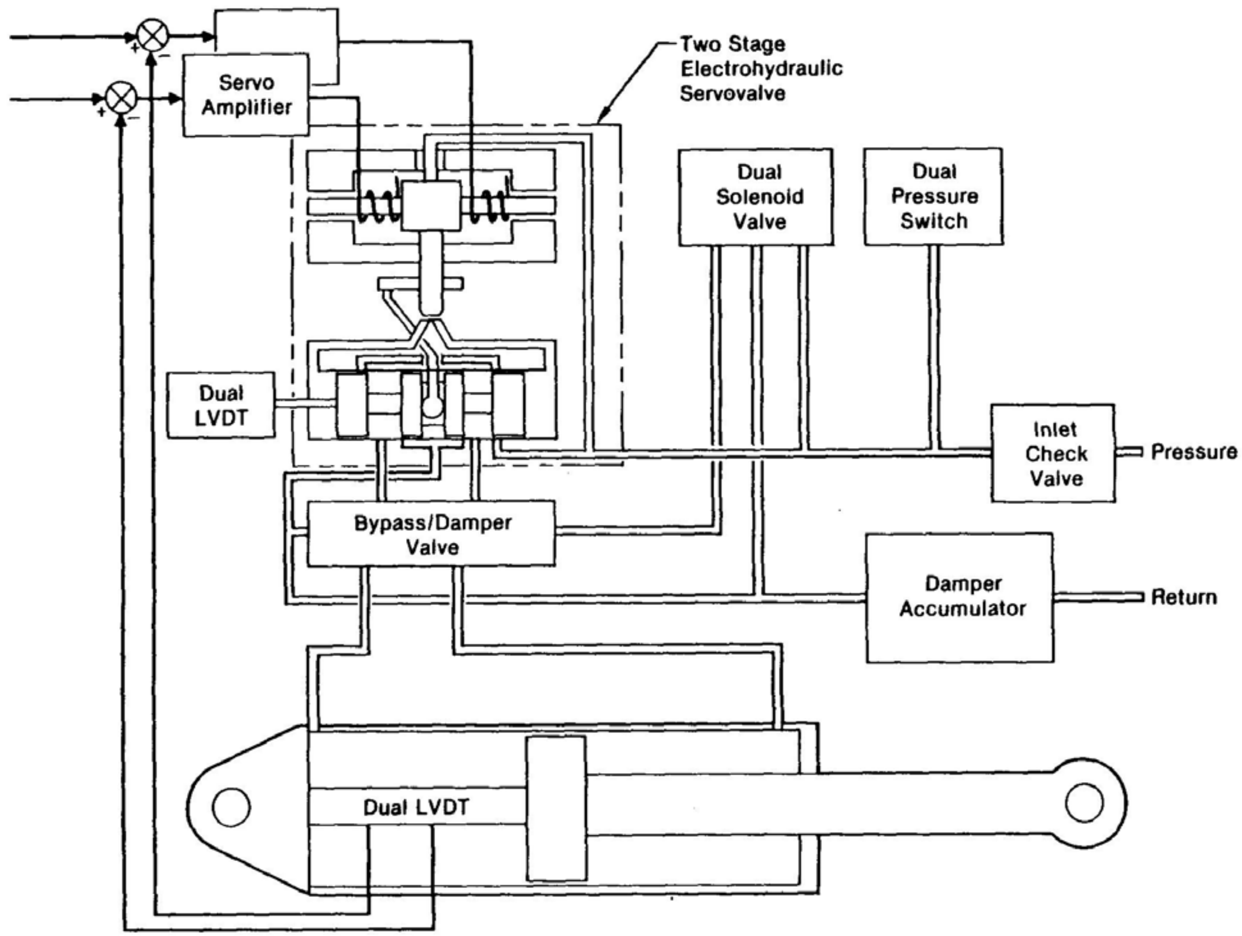
- Thin Wing and Vertical Tail Limit Envelope for Aileron and Rudder Actuators

- Analysis and Simulation Indicated No Carrier Landing Problems With One Aileron or Rudder Inoperative

Aileron and Rudder Actuator Design Rationale

- Redundancy Requirement Fail-Operate/Fail-Safe
- Fail-Safe Defined as Actuator in Flutter Damper Mode
- Envelope and Weight Penalty Precluded Dual Piston Actuator
- Study Select Actuator Configuration
  - Single Piston/Cylinder
  - Single Electrohydraulic Servovalve (EHSV)
  - Dual Servo Electronics
  - Electronic Channel Force Summing in Coils of EHSV Torque Motor
  - Dual Hydraulic Supply via Upstream Switching Valve

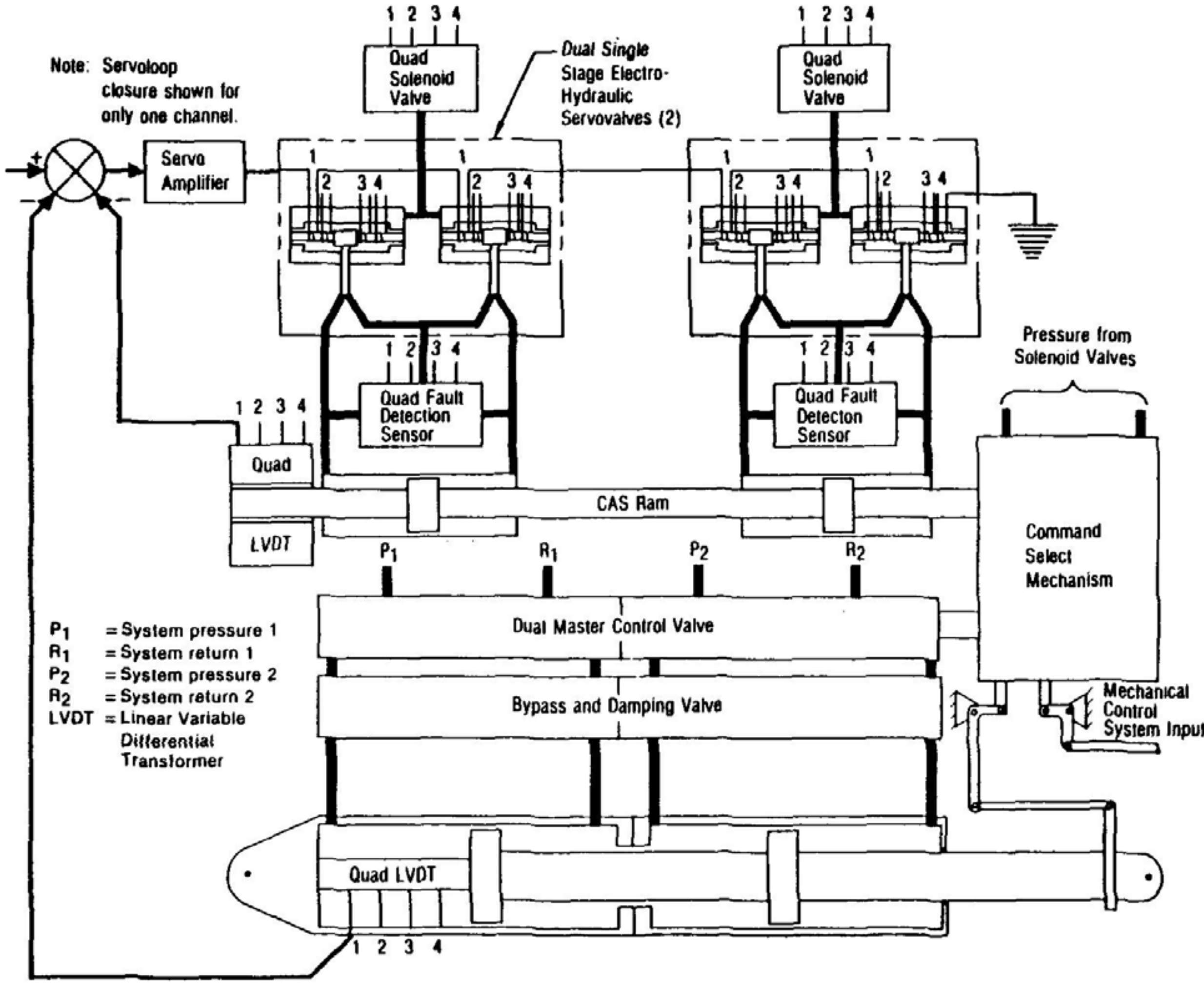
F/A-18A Aileron Actuator



F/A18A Stabilator and Trailing Edge Flap Actuator Design Rationale

- Redundancy for Both Actuators is Two-Fail-Operate/Fail-Safe
- Fail-Safe for T.E. Flap is Retract to Neutral
- Fail-Safe for Stabilator is Switch to Mechanical Mode
- Design Issue - Interface of Quad Electronics With Dual Hydraulics
- Electronic Channel Force Summing in Coils of EHSV Torque Motors
- Normal Dual EHSV Coils Separate to Produce 4 Independent Coils
- Force Fight of EHSV Pressures Needed to Minimize Failure Transients
- Servo is Driven by Two Pair of Quad Coil Single-Stage EHSVs
- EHSVs Arranged as “Siamese Pairs” With One Port of Each Valve Connected the Servo Ram and the Other to a Differential Pressure Sensor for Failure Monitoring

F/A-18A Stabilator Actuator



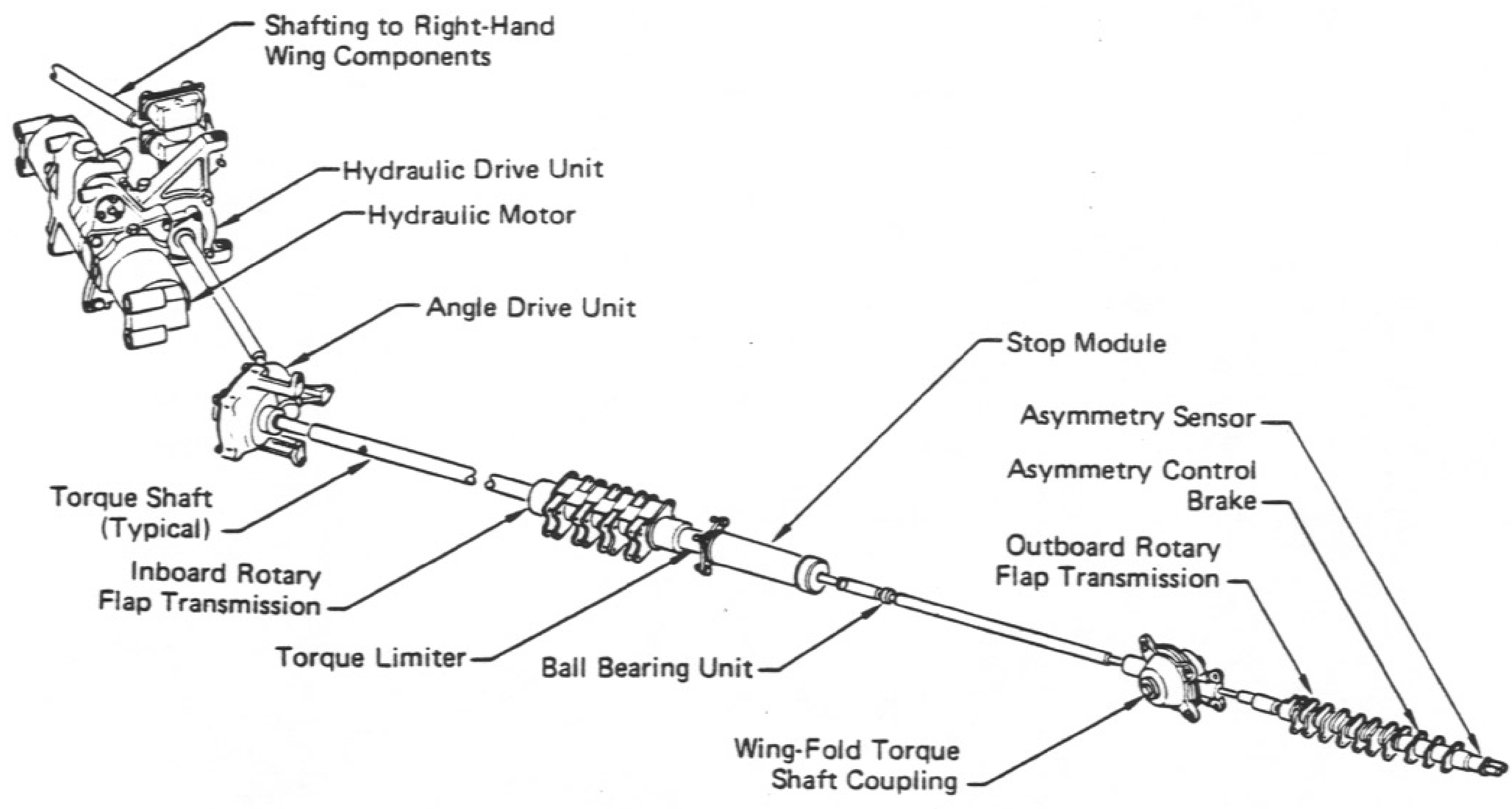
F/A-18 Leading Edge Flap System
Design Rationale

- Thin Wing Cross-Section Was the Design Driver
- Wing Fold Requirement Complicated the Installation Problem
- Needed Actuation Device on Inboard and Outboard Panels
- Rotary Mechanical Drive Was Selected Because It Fit Inside the Wing (also it worked well on the YF-16)
- Planetary Gear Type Transmissions Power Inboard and Outboard Flaps
- Transmissions are Connected to Hydraulic Drive Unit With Torque Shafts
- Mechanical Torque Shaft Coupling/Swivel Solved the Wing Fold Problem

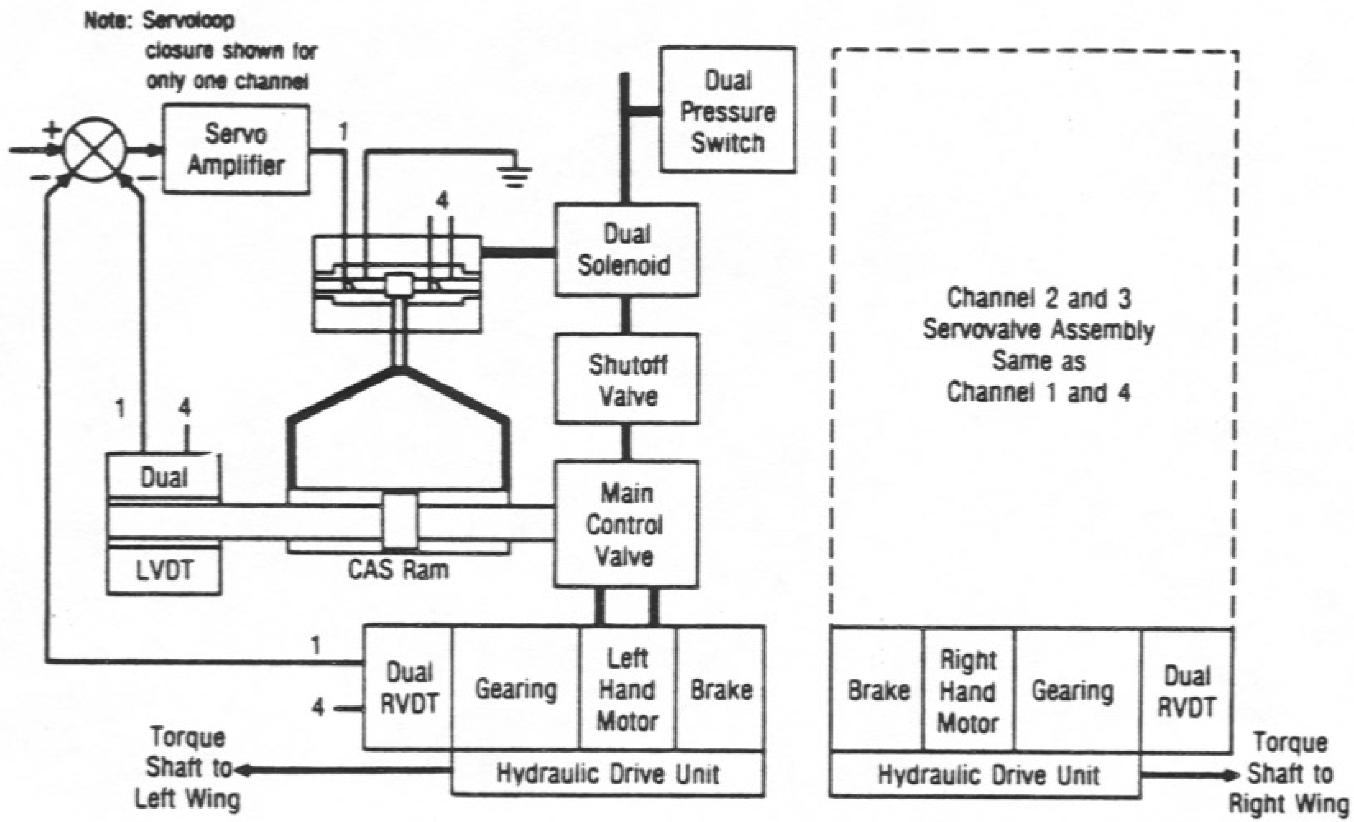
F/A-18 Leading Edge Flap System

- Leading Flap System Redundancy is a Fail-Operate/Fail-Safe
- Fail-Safe is Defined as Locked in Last Position
- A Backup Hydraulic Supply is Provided by a Upstream Switching Valve
- The System Provides Individual Control of the Flaps on Each Wing
- The Servos Which Control Each Flap are Dual Coil Single-Stage EHSV Driving a Servo Ram With Electrical Position Feedback
- The Servo Ram Controls Hydraulic Flow to the Hydraulic Motor that Power the Flap Drive Transmissions
- Asymmetry Control Units are Installed on the OUTBD Transmissions
- Asymmetry Monitor Compares Hydraulic Drive Unit with Asymmetry Control Unit

F/A-18 Leading Edge Flap Drive System



F/A-18 Leading Edge Flap System
Servovalve Assembly



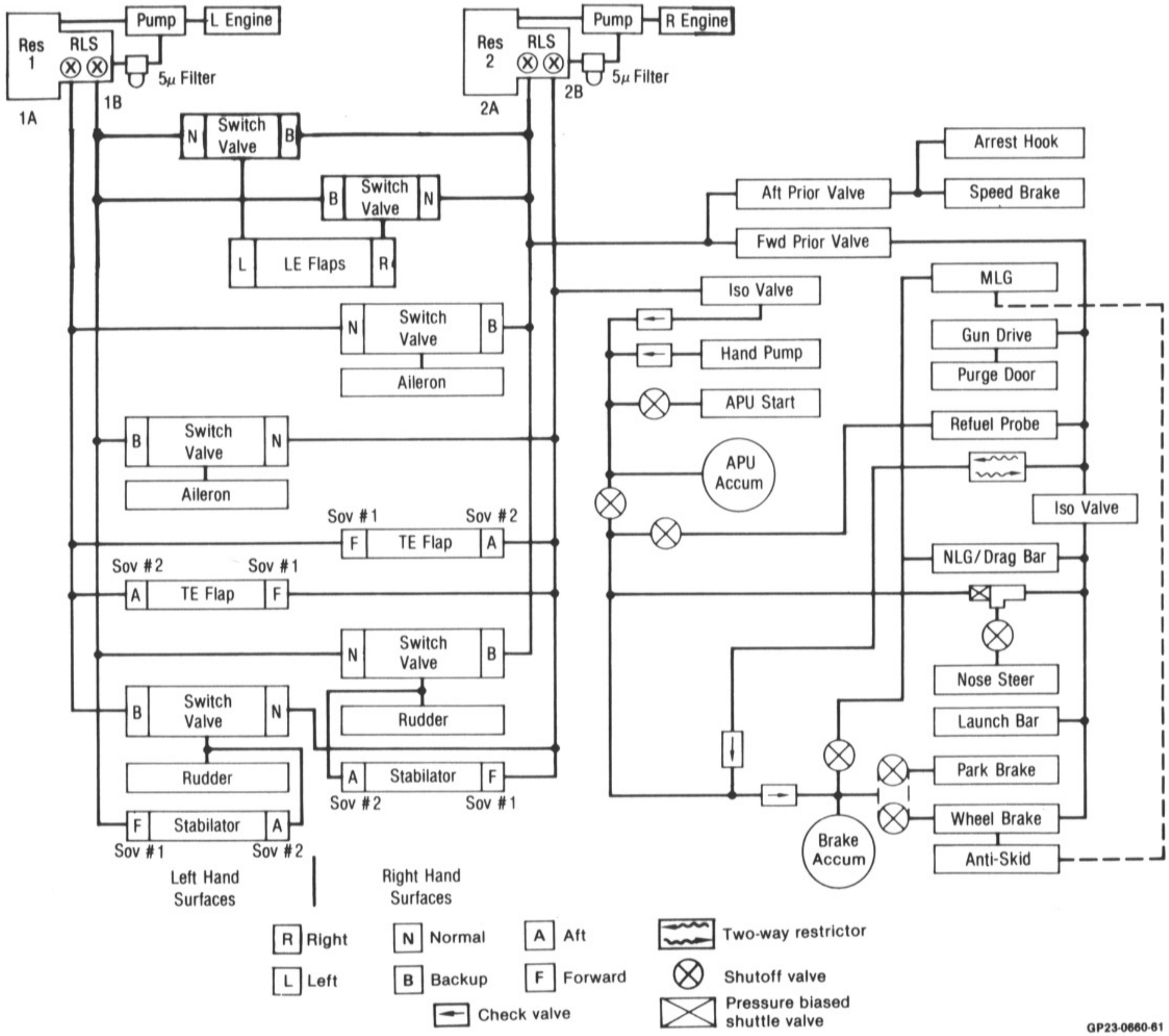
F/A-18A Flight Control System
Interfacing Systems

The Design of Interfacing Systems Must Support the Flight Controls Reliability and Survivability Requirements

- The Hydraulic System Has Redundancy and Separation
  - Reservoir Level Sensing - Separate Branches
  - Switching Valve Provide Backup Supplies

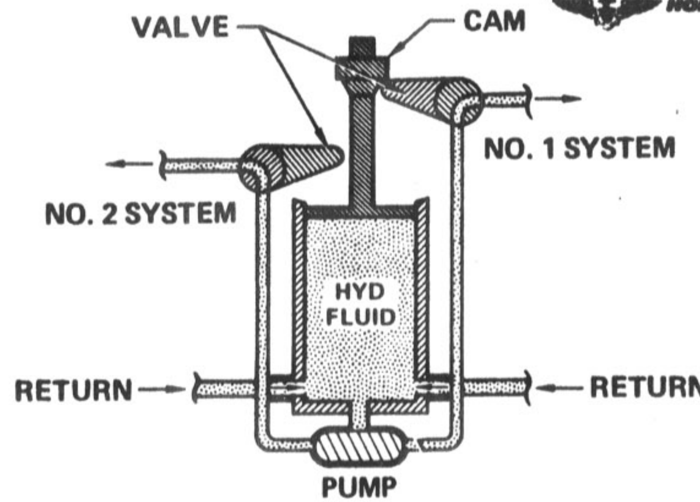
- The Electrical System Has Redundancy and Separation
  - Bus Switching
  - Battery Backup

F/A-18A Hydraulic System Arrangement



HYDRAULIC SYSTEM CIRCUIT BREAKER RESERVOIR LEVEL SENSING (RLS)

BASIC PRINCIPLE SCHEMATIC

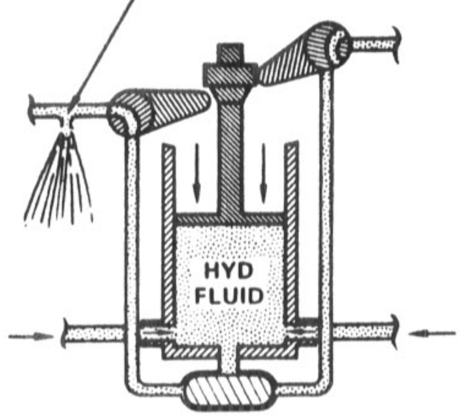


SEARCH

PISTON FOLLOWS LOWERING LEVEL OF RESERVOIR. AUTOMATICALLY SHUTS SYSTEMS SEQUENTIALLY BY CAM OPERATION OF VALVE. RESERVOIR LEVEL DROPS AS LONG AS LEAK IS NOT ISOLATED

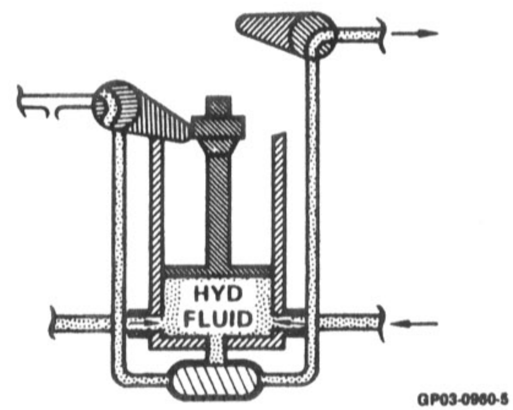
LEAK

RESERVOIR LEVEL BEGINS TO DROP



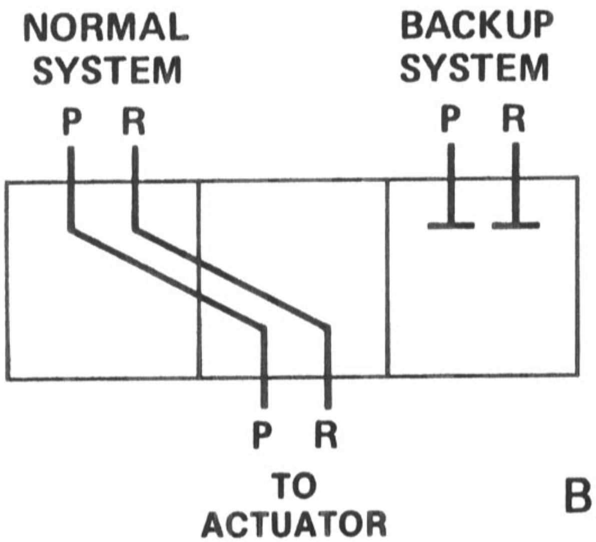
ISOLATE

WHEN LEAKING SYSTEM IS ISOLATED RESERVOIR LEVEL STABILIZES

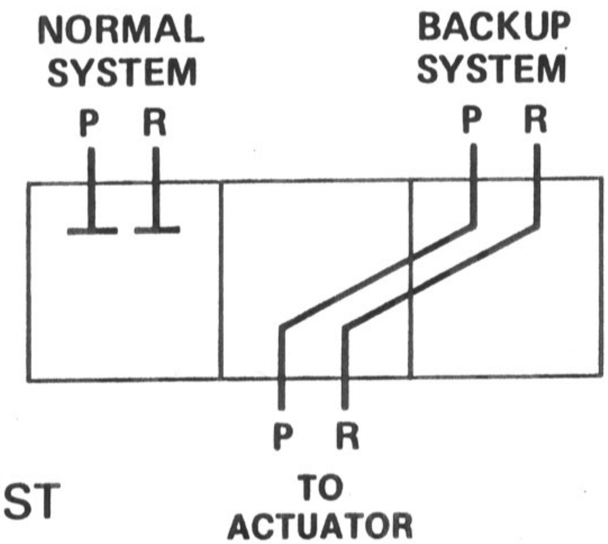


SWITCHING VALVE

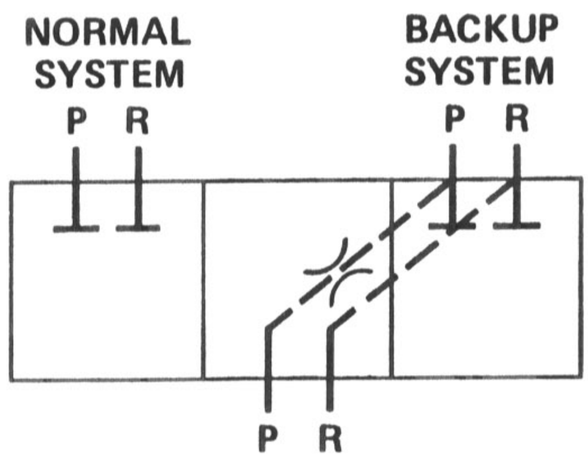
NORMAL



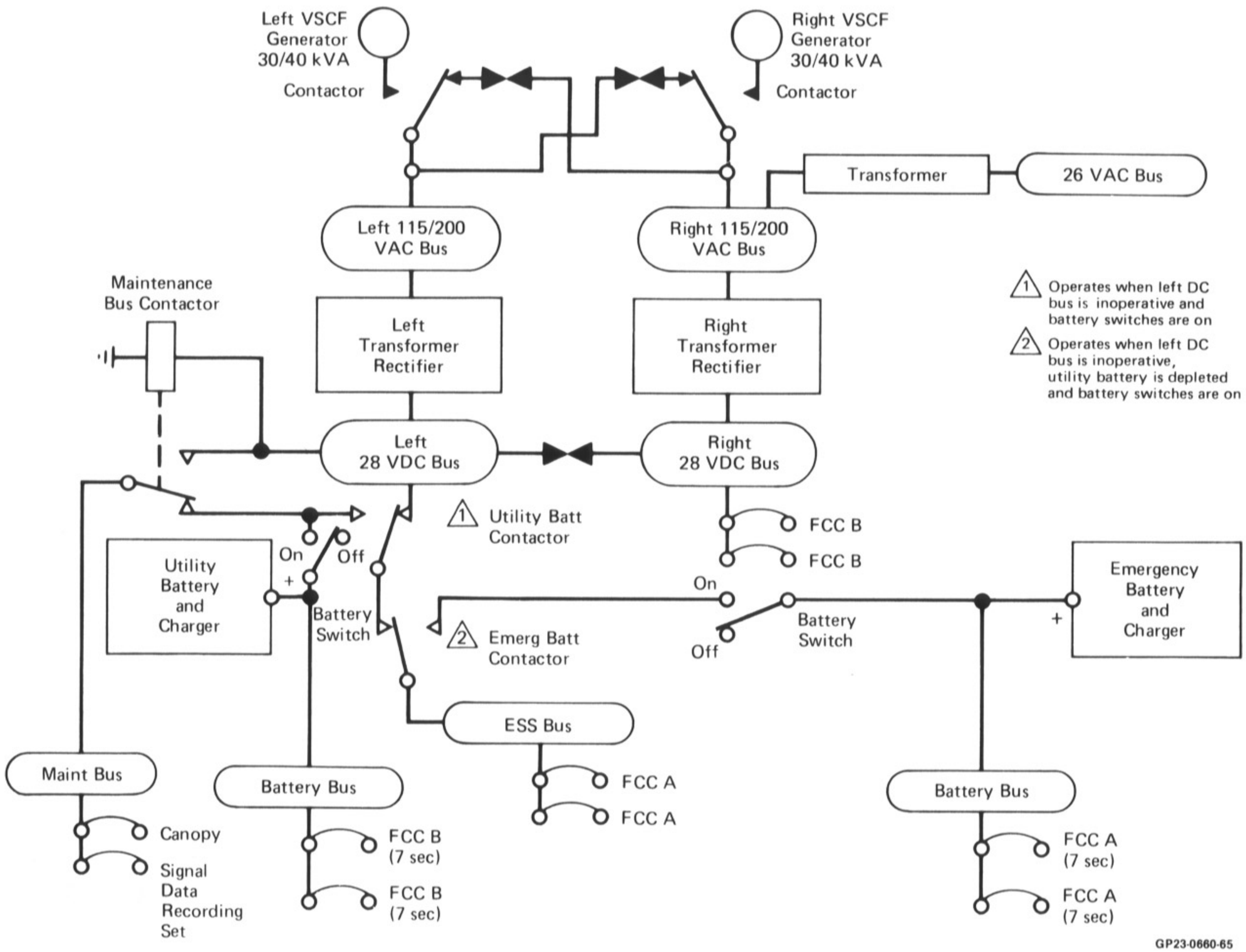
BACKUP



BLOCK AND TEST



F/A-18A Electrical Power System Simplified Schematic



Discussion of F/A-18 Flight Controls

Benefits of Digital Flight Control System Mechanization

- Flight Control System and Avionics System Integration
  - Autopilot and Data Link Modes
  - Built-In-Test
  - Specialized Controls and Displays
  - Flight Test Instrumentation - Flexible and Efficient

- Digital FCS Mechanization - Cost Effective Solutions to Development Problems
  - Multi-Purpose Control Surface Usage
  - Multiple Sensor Inputs
  - Optimal Scheduling of Control Surface

What Were The Lessons Learned ?

F/A-18A Lessons Learned
Design Database

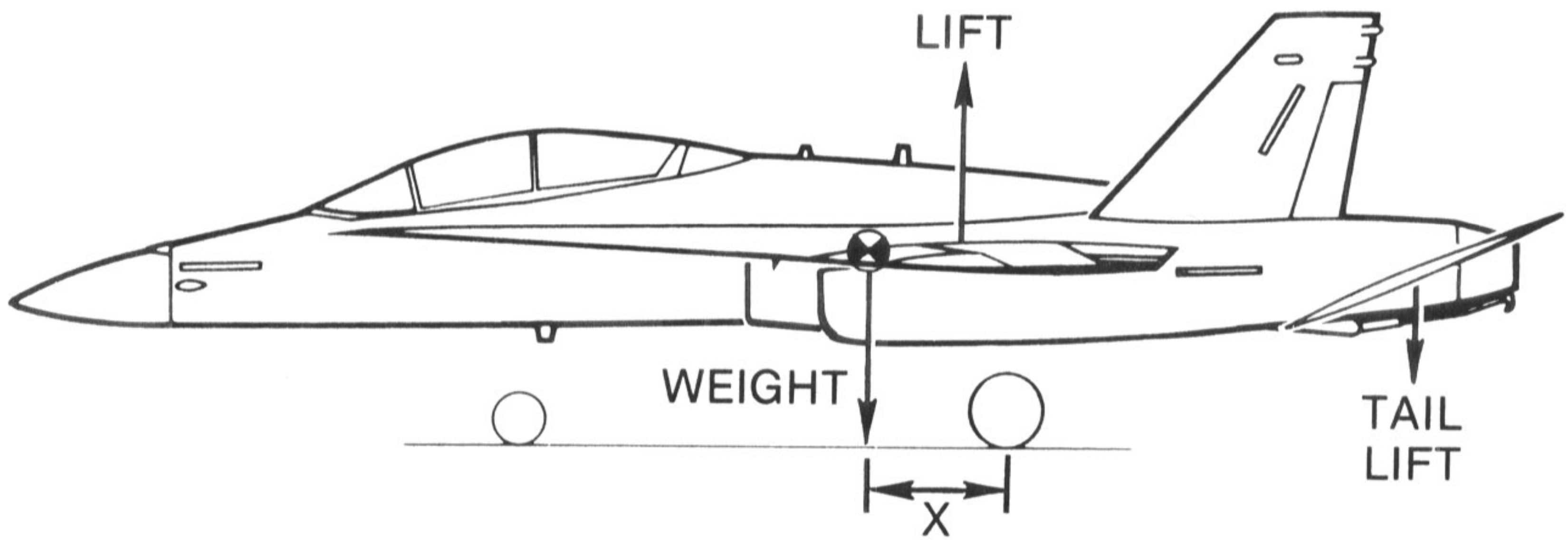
- Limited Aerodynamics, Loads and Dynamics Database
  - Small Scale, Low Fidelity Wind Tunnel Models
  - Modified YF-17 Database
  - No Loads Pressure Instrumentation on Model
- Problem Areas Encountered During Flight Testing
  - LEF Loads
  - Wing Flexibility
  - Aileron Flex - Rigid Ratio
  - Effect of Tip Missiles
  - Approach AOA

- Database - Risk Was Known But Not Quantified
- Risk Management Not Widely Used During This Time

CHANGES DURING FLIGHT TEST DEVELOPMENT

PROBLEM	POTENTIAL CONVENTIONAL SOLUTIONS	F/A-18A FLIGHT CONTROL SYSTEM SOLUTION
NOSE WHEEL LIFTOFF CHARACTERISTICS	— RELOCATE LANDING GEAR — INCREASE STABILATOR AREA	— RUDDER TOE-IN SCHEDULING — SCHEDULED LEADING EDGE FLAP DEFLECTION
ROLL PERFORMANCE	— INCREASE WING STIFFNESS — ADD SPOILERS — INCREASE DIFFERENTIAL STABILATOR HINGE MOMENT AND BENDING MOMENT CAPABILITY	— OPTIMIZE DIFFERENTIAL STABILATOR AND AILERON SCHEDULES — DIFFERENTIAL TRAILING EDGE FLAPS — DIFFERENTIAL LEADING EDGE FLAPS
ROLL COUPLING	— OPERATIONAL LIMITATIONS — MINOR ROLLING SURFACE-TO-RUDDER INTERCONNECT MODIFICATIONS	— OPTIMIZE ROLLING SURFACE-TO-RUDDER INTERCONNECT — INERTIAL COUPLING COMPENSATION FEEDBACKS
STRUCTURAL LOADS	— INCREASE STRUCTURAL WEIGHT	— OPTIMIZE CONTROL SURFACE SCHEDULES — ROLL RATE LIMITER
POWER APPROACH DIRECTIONAL MODE CHARACTERISTICS	— INCREASE VERTICAL STABILATOR AREA	— ESTIMATED SIDESLIP RATE FEEDBACK — RUDDER PEDAL-TO-ROLLING SURFACE INTERCONNECT

NOSEWHEEL LIFTOFF



AT NWLO AERODYNAMIC MOMENTS = WEIGHT MOMENT = 36,000 * X

RUDDER SCHEDULE IMPROVES LONGITUDINAL STABILITY