Actuator Re-design Example

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Actuator Redesign

- **Goal:** Simulated re-creation of real-life actuator redesign problem
- **Achievements:**
  - Developed Rosetta design model of servovalve, cylinder and actuator
  - Developed power constraint and functional models
  - Hand translated Rosetta models into MATLAB system representations
  - Used interactions to represent constraint and functional model interaction
  - Used MATLAB model to demonstrate early detection of constraint violation
- **Status:**
  - Actuator problem analyzed and Rosetta models written
  - Generated interaction result between power and functional models
  - Analytically predicted power constraint violation based on MATLAB models
Prior Airplane Design Experience with Altering an Existing Design

Solution Option #1: Put stiffness in structure

Option Not Fully Explored

Solution Option #2: Put stiffness in actuator
(increase diameter of piston and actuator)

Impact:
- Mold line change
- Increased drag
- Reduced LO
- Structural redesign

Impact:
- Increased hydraulic fluid flow
  (to maintain surface deflection rates for flying qualities)

Required bigger hydraulic pump and accumulators

Added weight

Required boring out largest available pump

Reached power extraction limit from engine

(Appeared Late 94)
(Full Impact in Late 95)

Reached power extraction limit from engine and power transmission limit of AMAD gearbox in upper left-hand corner of flight envelope (high and slow)

Reached structural redesign

Need: (Summer 92)
- Require flutter stiffness while minimizing weight

Impact: (Early 94)
- Mold line change
- Increased drag
- Reduced LO
- Structural redesign

Required boring out largest pump which would fit in allowable physical envelope as constrained by OML and internal structure

Required bigger hydraulic pump and accumulators

Impact: (~93)
- Increased hydraulic fluid flow
  (to maintain surface deflection rates for flying qualities)

Required bigger hydraulic pump and accumulators

Problem: (Appeared Late 94)
(Late 93)
(Full Impact in Late 95)

The accumulators were added for several reasons including this.

Need: (Summer 92)
- Require flutter stiffness while minimizing weight

Option Not Fully Explored

Since it was not the minimum-weight design solution

Required boring out largest pump which would fit in allowable physical envelope as constrained by OML and internal structure

probably not

Required bigger hydraulic pump and accumulators

(Appeared Late 94)
(Late 93)
(Full Impact in Late 95)

Reached power extraction limit from engine

Reached power extraction limit from engine and power transmission limit of AMAD gearbox in upper left-hand corner of flight envelope (high and slow)

Problems:
- Required boring out largest pump which would fit in allowable envelope as constrained by OML and internal structure
- Required bigger hydraulic pump and accumulators
  (Appeared Late 94)
  (Full Impact in Late 95)

Solution Option #1:
Put stiffness in structure

Solution Option #2:
Put stiffness in actuator
(increase diameter of piston and actuator)

Impact:
- Mold line change
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- Structural redesign

Impact:
- Increased hydraulic fluid flow
  (to maintain surface deflection rates for flying qualities)
Using Systems Design Tools – Actuator
## Design Assumptions / Limitations

- Specifics of the operating modes are not available
- Only the servovalve and cylinder piston are modeled

### Power Assumptions
- Maximum engine power approx $2.4 \times 10^7$ ft-lbs/s
- 0.5% or less of engine power available to power hydraulic system
- About 12.5% of hydraulic power used in an actuator
- Maximum power available to actuator is about 15,000-20,000 ft-lbs/sec

### Efficiency Assumptions
- Engine--90%
- Hydraulic pump--60%
- Servovalve--90%
- Hydraulic cylinder--99%

### Modeling
- Modeling done in conjunction with KU Aerospace department faculty
Functional Servovalve Equations

\[
\frac{Q}{Q_{\text{max}}} = \frac{U}{U_{\text{max}}} \sqrt{1 - \frac{P}{P_s}} \text{sgn}\left(\frac{U}{U_{\text{max}}}\right),
\]

where

\[
\frac{Q}{Q_{\text{max}}} = \% \text{ max flow rate achieved}
\]

\[
\frac{U}{U_{\text{max}}} = \% \text{ max valve opening achieved}
\]

\[P = \text{differential pressure}\]

\[P_s = \text{source pressure}\]
Functional Servovalve Equations (cont)

\[
\text{power} = P_s Q_s - P_2 Q_2 + P_1 Q_1
\]

\[
\left| \frac{Q}{Q_{\text{max}}} \right| \leq 1
\]

\[
\left| \frac{U}{U_{\text{max}}} \right| \leq 1
\]

\[
\left| \frac{P}{P_s} \right| \leq 1
\]

constraints
begin continuous

//Nonlinear steady state valve equation.
F1: \( \frac{Q}{Q_{\text{max}}} = \frac{U}{U_{\text{max}}} \times (1 - \frac{P}{P_{\text{S}}}) \times \text{sgn}(\frac{U}{U_{\text{max}}})^{0.5}; \)

//Flow, spool disp, diff pressure cannot exceed
//max
C1: \( \text{abs}(Q) \leq \text{abs}(Q_{\text{max}}); \)
C2: \( \text{abs}(U) \leq \text{abs}(U_{\text{max}}); \)
C3: \( \text{abs}(P) \leq \text{abs}(P_{\text{S}}); \)

end servovalve_fcn;
The Redesign Problem

- Additional force required to overcome flutter in high speed operating mode
  - Differential pressure relatively low due to high speed operation
- Power obtained by increasing piston area in the cylinder
  - Assumed starting point of 2.5in\(^2\)
  - Increased to 2.75in\(^2\)
- Actuator power budget assumed to be 15,000-20,000 ft-lbs/sec
- Functional model indicates no problems and additional force is obtained
Results of MATLAB Model Run
Interaction With the Power Model

- The actuator has an associated power limitation of 15,000-20,000 ft-lbs/sec
  - The power constraint model is expressed is separated from