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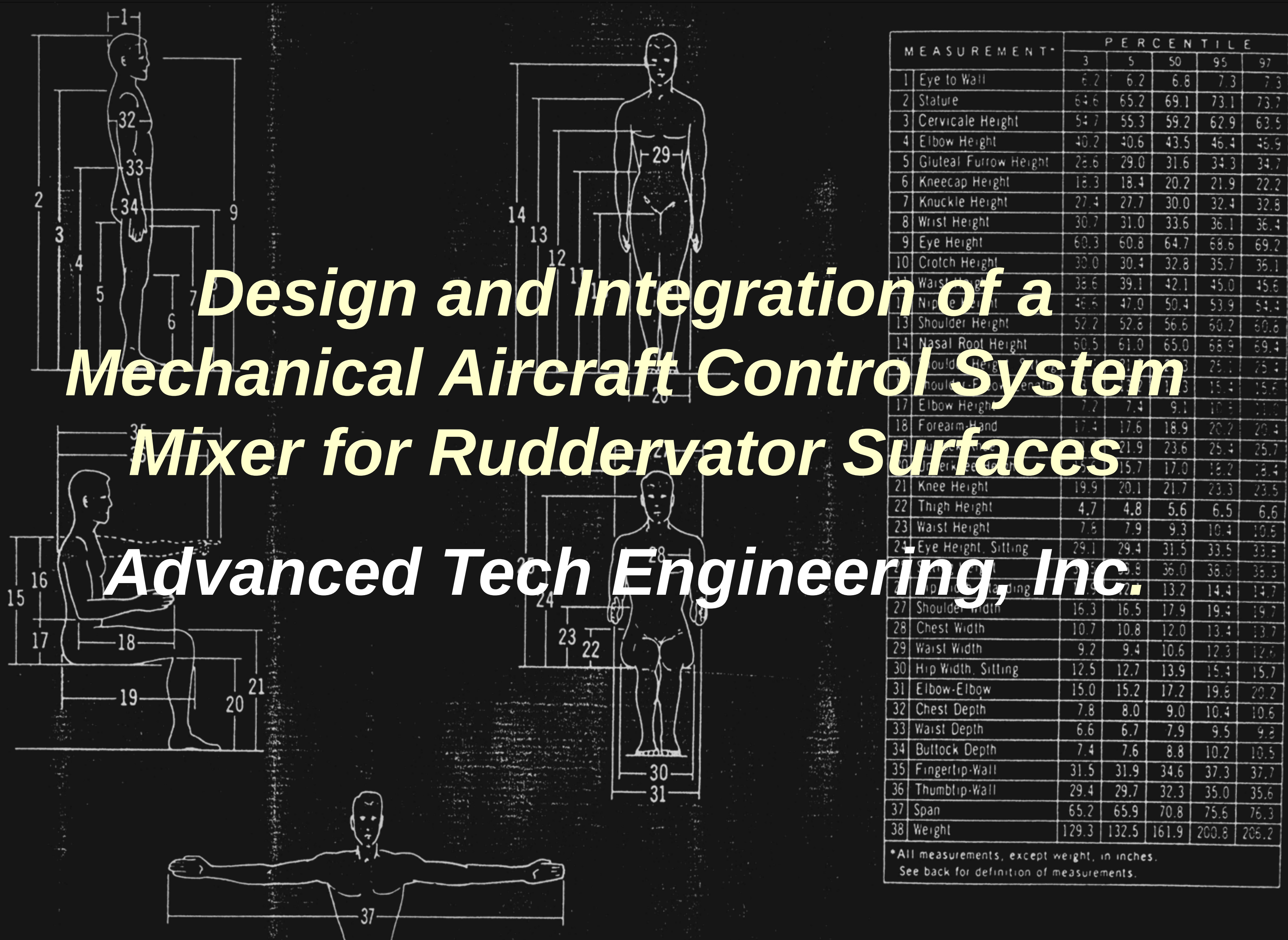

Design and Integration of a Mechanical Aircraft Control System Mixer for Ruddervator Surfaces

Advanced Tech Engineering, Inc.

DOCUMENT DATE: 10/25/2012

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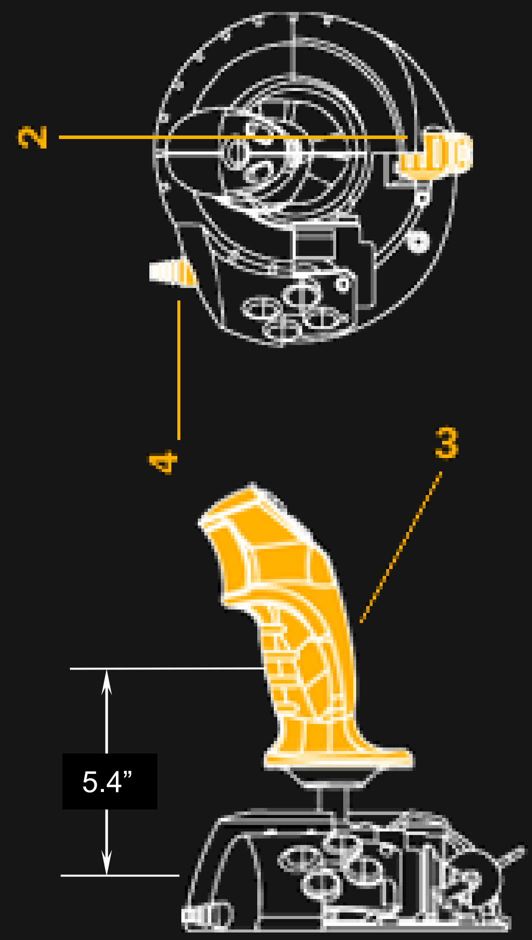
Requirements

Design a control mechanism mixer that mechanically controls ailerons, and (v-tailed) ruddervators using a single handed yoke. Its movement should mimic the Microsoft Sidewinder Joystick. The mixer can be designed to connect to cables or pushrods, but I am not interested in the runs to the control surfaces, just the mixer. Size and cost are important design factors.

I'd like for you to clearly depict the design solution using hand sketches and hand drawings. I would also like you to supply me with how many hours it took to complete the concept.



MS Sidewinder Joystick

Assumptions

Aircraft:
- Center-Stick Tandem Seating Aircraft

Simplicity:
- No use of gears and complex linkages
- Keep the system low cost and low mass (i.e. size for stiffness, then strength)

System:
- All Control Surfaces have Control Horns with Moment Arms ~ 0.6"
- Direct Mechanical Linkage and Mechanical Gain (increase or decrease through lever design) only through bell cranks and levers

Calculations:
- Use Small angle Approximations (for angles < 3 deg) in force-moment calculations
- Maximum Control Surface Deflection are to be ±30 deg for all Control Surfaces
- Control Surface Deflection Rates to be at least 60 deg/sec
- Control Surface Unit Weight = 3 lb/ft2 (may be high, but will use this for now)
- Wingspan = 36 ft
- Wing Chord = 6 ft
- Aileron Length = 50% of b/2 = 9 ft (Outboard Half of Semi-span)
- Aileron Chord = 20% of Wing Chord = 21.6 in

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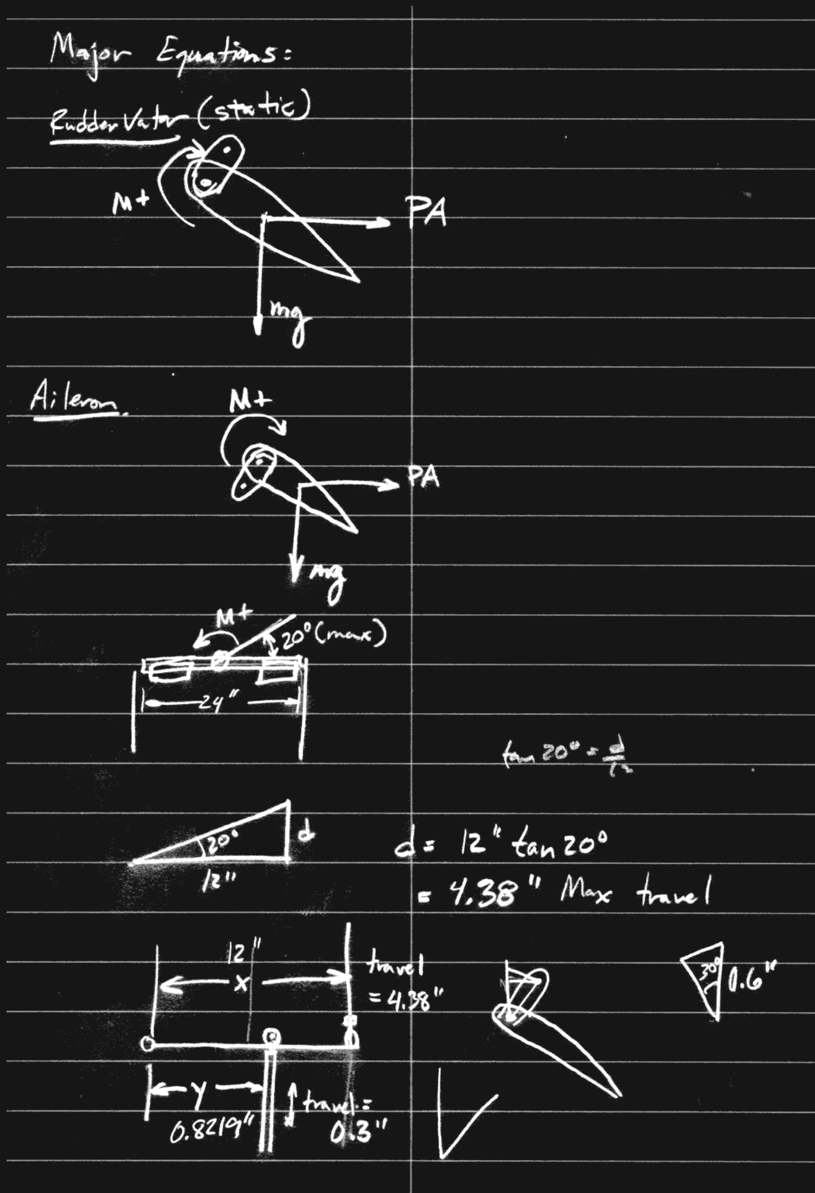
Assumptions (cont.)

- Stall Speed = 50 KTAS at SLS where Q = 8.5 psf
- Tail has Similar Aspect Ratio, but 1/3 Projected Horizontal Area with a 45 deg Dihedral

Loads:

- Zero Total Forces and Moments on Stick and Rudder Pedals in Neutral Position through the Flight Envelope
- Balance the use of Tension Only Members (i.e. cables) vs. Push Rods to optimize tradeoff between Slop/Tolerance and Overall System Mass
- Check Flight Envelope Highest Dynamic Pressure of 135 psf (200 KTAS at SL) vs. 6 g's Load Factor at Stall Speed Q and use the maximum Control Surface Moments of the two.
- Maximum Stick Input Forces (5th Percentile Male at 1G Load Factor from Human Engineering Bulletin 56-5H) below the 100 KTAS Assumed Maneuver Speed
    - Aft Force = 42 lb (Pos X direction)
    - Fwd Force = 30 lb (Neg X direction)
    - Right Side Force = 15 lb (Pos Y direction)
    - Left Side Force = 8 lb (Neg Y direction)
    - Left Rudder Pedal Push Force = 334 lb (Neg X direction)
    - Right Rudder Pedal Push Force = 246 lb (Neg X direction)

Answer – Methods



The method used in sizing Mixing Moment Arm Structure is explained below:

The Maximum Travel of the Stick at $\pm$ 30 degrees is fixed as equivalent to the corresponding Control Surface Maximum Deflections of $\pm$ 30 degrees (see Assumptions). Also, the maximum Ruddervator Deflection Angle and the Maximum Rudder Pedal Deflection of $\pm$ 20 degrees (see Assumptions and Illustration on left) correspond.

The Rudder Pedal input is transferred aft to the Mixer to a point that is at the same waterline as the pivot axis. Thus, the Stick Pitch Deflection remains unaffected.

Likewise, any Stick Pitch input that is transferred aft to the mixer does not transfer any rotation forward to the Rudder Pedals, leaving the two ruddervator affecters independent of each other.

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Answer - Design Details

The Mixer Assembly sits aft of the co-pilot in a tandem configuration aircraft. Push Rods run forward from the Ruddervators and aft from the Stick (Roll Input). Tension cables run from just outboard of the Rudder Pedals aft to where they address the Mixer as shown in the given illustration. The Roll Control function is not part of this mixing system and is intended to be the standard push rod and bell horn layout running outboard to the wing.

Due to no requirement to understand loads, the maximum Control Surface Moments are not described in this project. However, this could be done using first-order analysis such as a flat plate with drag calculated as the Dynamic Pressure applied to the Exposed Control Surface centroid. Another calculation could be the maximum Load Factor condition pulling on the full control surface mass at the surface centroid coupled with the minimum drag vector (as stated earlier), to maximize the total Control Surface Moment. Depending on what the Maximum Load Factor is, the Maximum Moment can be understood.

These maximum loads would be used to size the structural members that compose the Mixer Assembly, the Tension Cables running forward to the Rudder Pedals and it's respective fasteners, the Push Rods running from the Control Stick, and it's fasteners, to the Mixer and directly to the Ailerons through bell horns. (I can go into more depth on these calculations if you'd like later).

The development of Stick Force Feel can accomplished by understanding the desired stick forces (% of Max Load on a 5^{th} Percentile Human) for given Flight Envelope conditions and using levers such as bell cranks to dial the stick force up and down accordingly.

A pitch trim mechanism can be created by applying a variable spring force (non-aero trim) on the Control Stick in the Pitch Axis.

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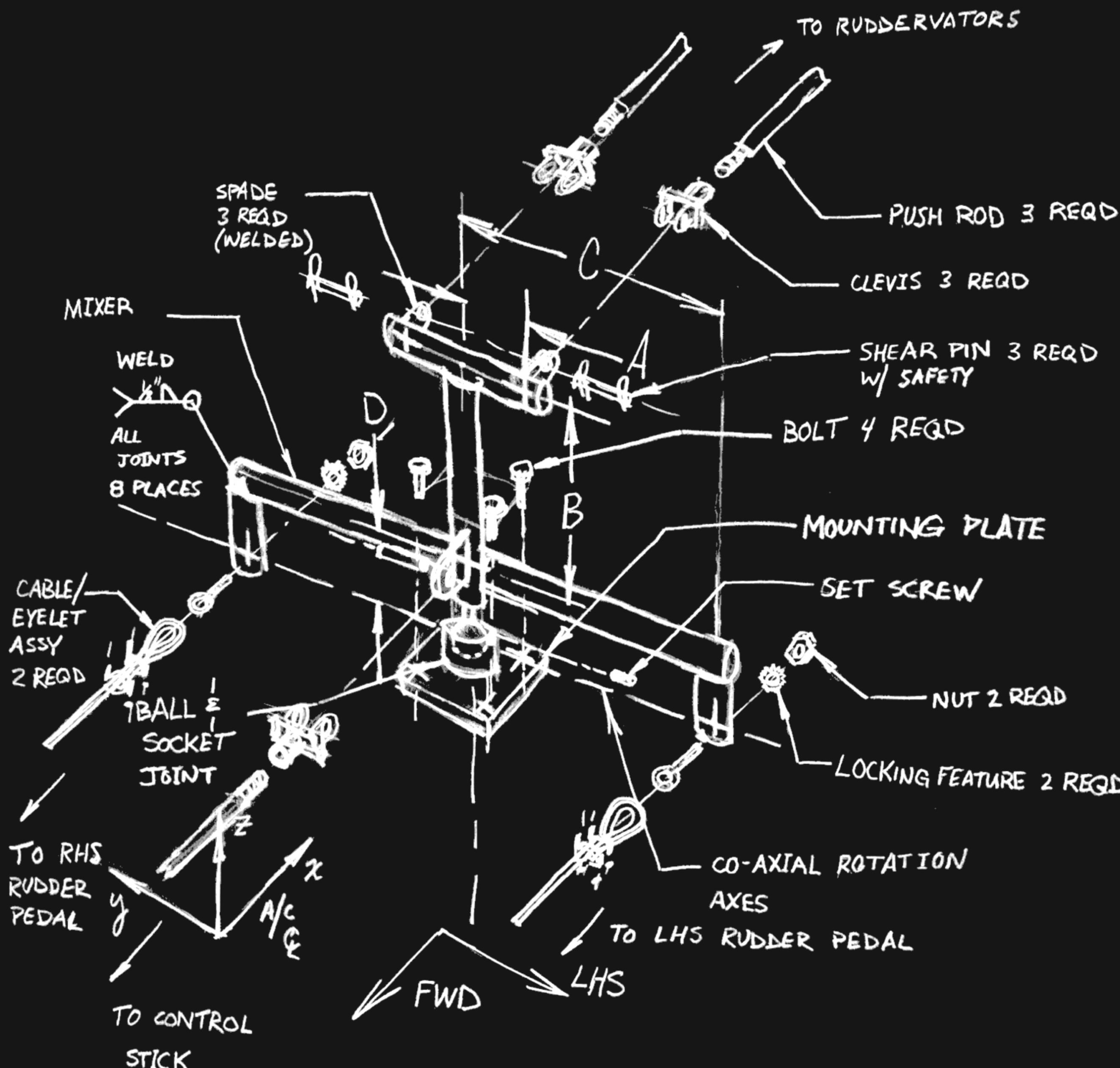
Answer – Isometric View

As drawn
Dimensions are:
A = 2.0 inches
B = 6.0 inches
C = 2.0 inches
D = 3.8 inches



Answer - Parts List

Below is a notional (incomplete) parts list for this system.

MIXER						
QTY	**DASH NO.**	**CAGE CODE**	**PART NO.**	**NOMENCLATURE**	**MATERIAL**	**NOTES**
1	-103			PLATE, MOUNTING	CRES	1.0" COUNTERBORE, 1/2" DIA 4 HOLE PATTERN
1	-101			MIXER STRUCTURE	ALUMINUM	1" DIA ALUMUNUM TUBE X 6' LENGTH
2		070U6	AN42B-27	BOLT, EYE	CRES	3/16" DIA, UNF, 2.5" GRIP LENGTH
4		AS	18-2-G	SLEEVE, COMPRESSION		
2		070U6		CABLE		3/32" DIA, 120.0" LENGTH
3		070U6	AN665-34R	CLEVIS, MALE THREAD	CRES	1/4" DIA HOLE
2		070U6	AN100-X	THIMBLE, CABLE		
3		070U6		INSERT	CRES	3/8" ID, 1/2" OD, 1.0" LENGTH
1		070U6		JOINT, BALL		1.0" SPHERICAL HEAD
4		070U6		NUT, JAM	CRES	3/16" DIA, UNF, 1/4" THICK
9		070U6		NUT, JAM	CRES	3/8" DIA, UNF, 1/4" THICK
8		070U6		NUT, LOCKING	CRES	1/8" DIA
6			AN381-153	PIN, COTTER	CRES 18-8	
0			AN395-47	PIN, CLEVIS	CAD PLATED	1/4" DIA, 1.5" LENGTH
3		070U6		ROD END	CRES	3/8" DIA
3		070U6		ROD, PUSH	CRES	3/8" DIA
8		070U6		SCREW	CRES	1/8" DIA
4		070U6	AN960	WASHER, FLAT	CRES	3/16" DIA, 0.031" THICK
9		070U6	AN960	WASHER, FLAT	CRES	3/8" DIA, 0.031" THICK
4		070U6		WASHER, LOCKING	CRES	3/16" DIA, 0.031" THICK
9		070U6		WASHER, LOCKING	CRES	3/8" DIA, 0.031" THICK

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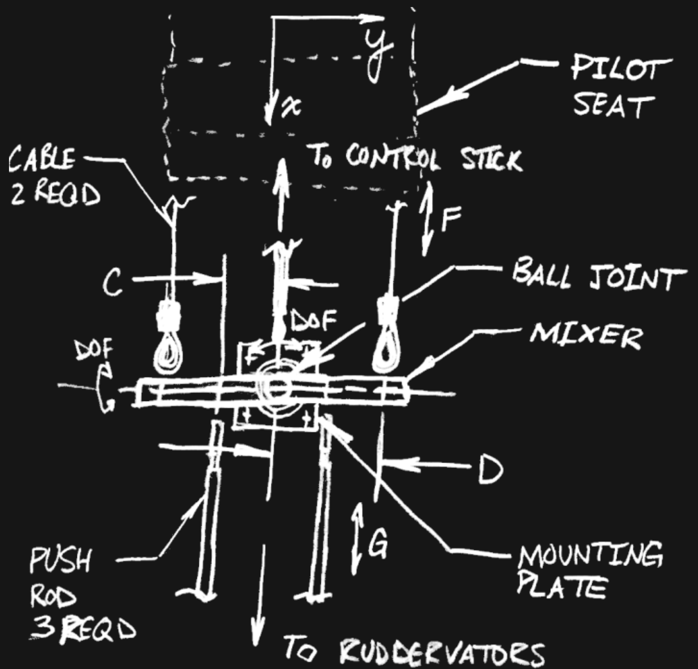
Answer - Sketches



View Looking Inboard

Displacement of the Push Rods and Tension Cables can be calculated by the maximum deflection of either the Rotated Control Surfaces or the Rotated Control Stick, to whichever it is connected.

Per the above illustration, Distances E, F & G have been found in the analysis given in the next slide.

As drawn Dimensions are:

A = 3.8 inches
B = 6.0 inches
C = 2.0 inches
D = 2.0 inches

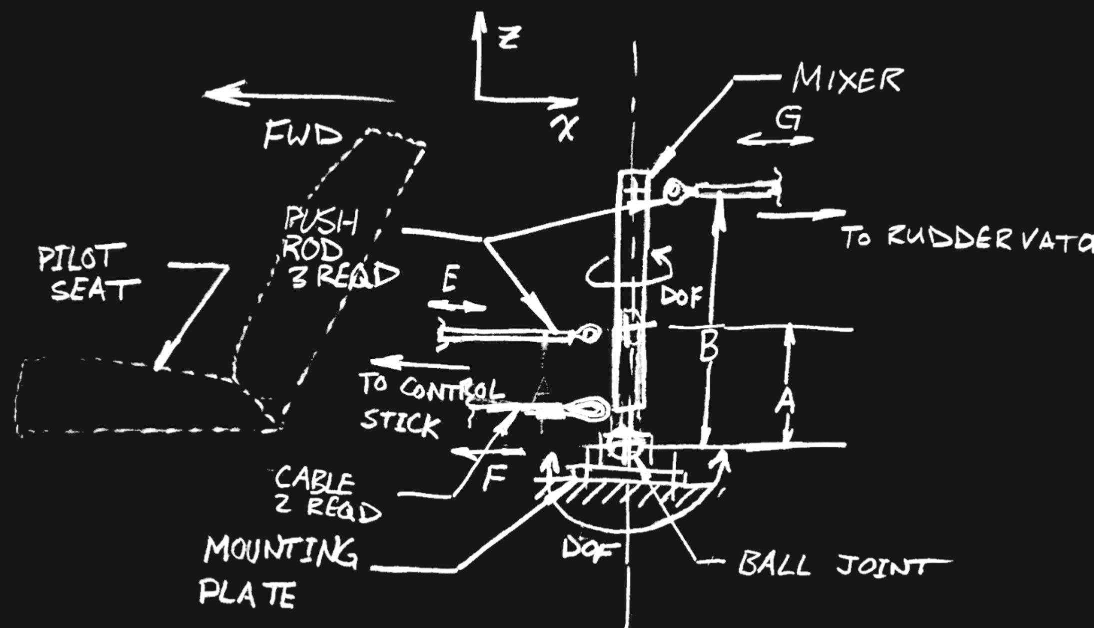
Half Travel:

E = 0.38 inches
F = 0.30 inches
G = 0.30 inches

* Note: These dimensions do not correspond to those noted on the previous slide.

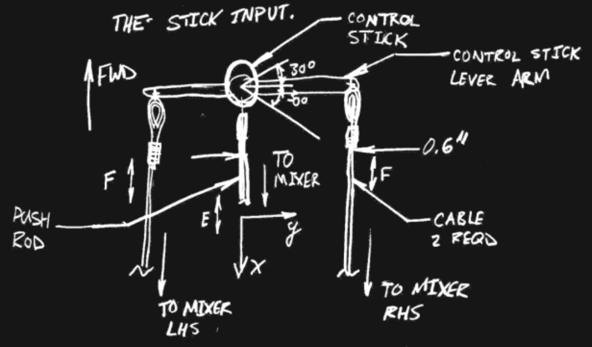
View Looking Down

The two given illustrations characterize the Degrees of Freedom that are allowed by the Ball Joint at the bottom of the Mixer Assembly.



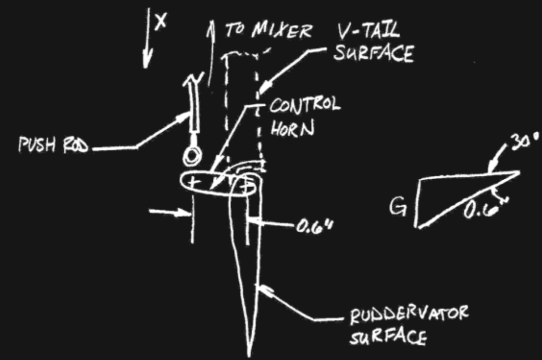
Answer - Calculations

SINCE OUR MAX RUDDERVATOR DEFLECTION = 30deg = MAX STICK YAW INPUT, WE CAN ASSUME A LEVER ARM OF 0.6" BELOW THE STICK INPUT.



VIEW LKG DOWN

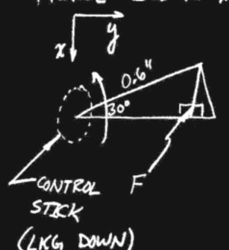
TRAVEL DUE TO DEFLECTED RUDDERVATOR (30°)



$G = 0.6'' \sin 30° = 0.3''$

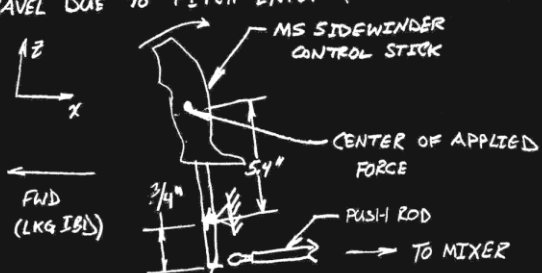
(LKG NORMAL TO HINGELINE OF RHS RUDDERVATOR)

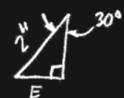
TRAVEL DUE TO YAW INPUT (FROM CONTROL STICK)



$F = 0.6'' \sin 30° = 0.3''$

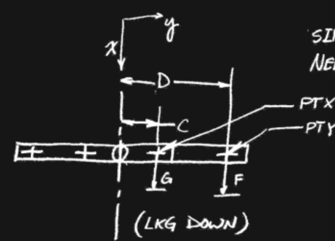
TRAVEL DUE TO PITCH INPUT (FROM CONTROL STICK)





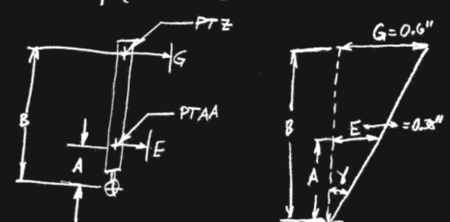
$E = \frac{3}{4}'' \sin 30° = \frac{3}{8}''$

LOCATION OF ATTACH POINTS ON MIXER



SINCE THE ATTACH POINTS X & Y NEED TO TRAVEL FORE & AFT BY DISTANCE G & F RESPECTIVELY, THE VALUES OF C & D ARE EQUAL.

$F = G = 0.3''$ ∴ PICK $D = 2.0'' = C$ SINCE WE ARE WORKING WITH 1/2" TO 1" φ TUBING



DUE TO A LINEAR RELATIONSHIP... $\gamma_1 = \gamma_2$ → $\tan\gamma_1 = \frac{E}{A}$, $\tan\gamma_2 = \frac{G}{B}$ ∴

(A) $\frac{E}{A} = \frac{G}{B}$ → Pick $B = 6''$ TO KEEP GEOMETRY SMALL

→ $A = 3.8''$ FROM EQN (A)

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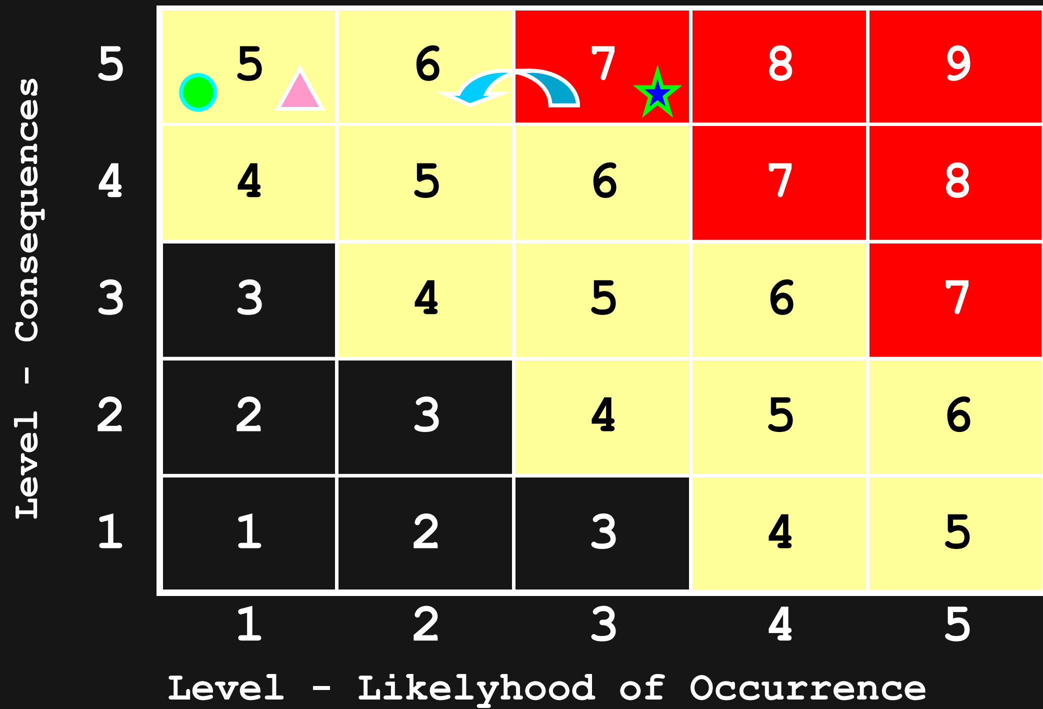
Answer - Trade Study

Importance	Merit	Sub-Merit	Type	Target	Rating	Risk	Score
100	**Function**	Inputs per the MS Sidewinder Joystick Geometry	1	Optimize	5	No Risk	100
90	**Safety**	No Control System Binding	1	Optimize	3	Risk	54
		Pilot Load Input to Operate in Worst Case	1	Optimize	3	Risk	
80	**Performance**	Low Mass	2	Minimize	3	No Risk	48
		Natural Pilot Feel	2	Optimize	3	No Risk	
		Operates in Adverse Scenarios	1	Optimize	3	Risk	
		Supplies Adequate Control Power	1	Optimize	3	Risk	
70	**Value**	Long Life Cycle	2	Maximize	5	No Risk	70
		Development Cost	2	Minimize	5	No Risk	
		Production and Deployment Cost	2	Minimize	5	No Risk	
		Sustainment and Disposal Cost	2	Minimize	5	No Risk	
60	**Integration**	Simple and Understandable	2	Optimize	5	No Risk	60
		Low Part Count	2	Minimize	5	No Risk	
		Non-Evasive Layout	2	Optimize	5	No Risk	
50	**"Ilities"**	Minimized Part Count	2	Minimize	5	No Risk	50
		Multiple Function Components	2	Maximize	5	No Risk	
TOTAL							**382**
						System Capability Rating	**84.9%**

Anything that is not a "5" with a Threshold Type is identified as a Risk.
All Ratings Start as a "3" until they are proven to increase/decrease.
For the Type Category, Threshold = 1, Range = 2.

Above is Qualitative to Quantitative Trade Study Analysis that personifies our Measures of Merit for the given Mixer System. Due to the weighted scoring, this very Trade Study can be pitted against alternative solutions for the Mixer Problem and produce a quantifiable and visual result. Also, the Trade Study alone delivers a Capability Rating that in essence measures our solution against an absolute answer by normalizing our results.

Answer - Risk Mitigation



Low Risk = 1 - 3
Medium Risk = 4 - 6
High Risk = 7 - 10

<u>Risk</u>

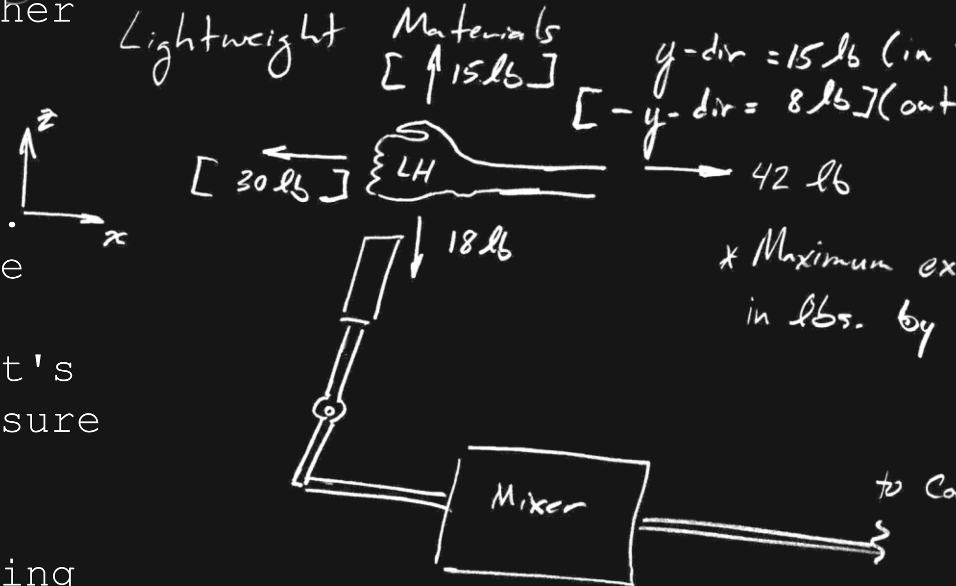
- ☆ Control System Binding
- ● Adequate Pilot Load Input to Operate
- △ Supplies Adequate Control Power

From the Trade Study Analysis in the previous slide, we can conclude that there are several Risks that will absolutely need to be addressed prior to engaging in production of any Airborne Prototypes.

These Risks are demonstrated in this chart at their perceived Levels. We have a propensity to eliminate any and all risk in buildable hardware. However, as illustrated by the blue arrow, we can only translate our Total Risk Level left due to our inability to change our assumed Consequences, for this case.

Sensitivities

- Design will be sensitive to Operating Load Factor (g's)
- We want to design into the system a direct relation between Stick Forces and Dynamic Pressure (KEAS) for Safety (i.e. don't rip wings off at high Q, smoother flight, non-aerobatic maneuvers)
- Maximize chord lengths on control surfaces to decrease sensitivity at higher dynamic pressure (for Safety).
- Be aware of Stick Movement Envelope (±30 deg roll (stick), ±30 pitch (stick), ±20 deg yaw (pedals)) and it's relation to forces from Dynamic Pressure and Load Factor
- Be careful to prevent binding of Control System in any way (i.e. sliding elements, if any, from "racking", stick and rudder pedal forces to not counter each other within the linkages and maintain straight hingelines (minimize curvature of bent hingeline) at high Load Factors.



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Alternatives

- I have an alternate, less robust concept of sliding sleeves and stops conceptually designed.
- May consider use of only push rods to minimize slop if necessary.
- May develop more ideas for changes in this layout to accommodate:
    - Side-by-side seating with a centerstick
    - Side-by-side seating with a sidestick
    - Tandem seating with a sidestick