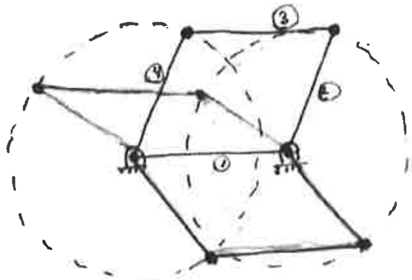
Lesson ~~15~~ 16

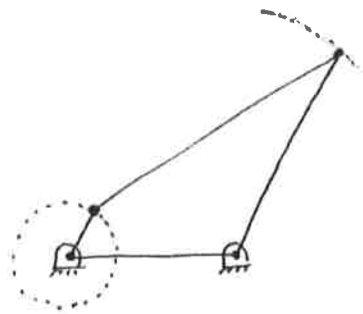
Longitudinal Control

Mechanisms

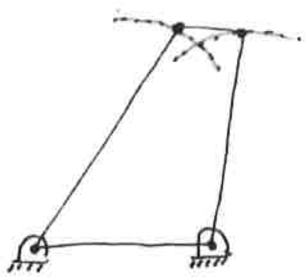
4 bar linkage



Drag Link

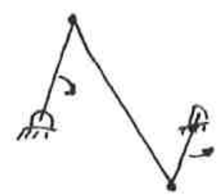


Crank Rocker



Double Rocker

The rotation direction is not always the same. for a drag link.



Anti - parallel

parallel

Gruebler's Equation (2D)

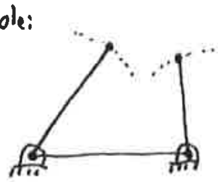
- Each link has 3 Degrees of freedom (DOF)
- Each pivot subtracts 2 DOF

2 translate
1 rotate

The total system DOF = $3(N-1) - 2P$

links (N), pivot (P)

Example:



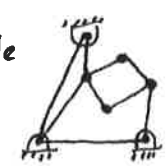
How many DOF?
3 links $\Rightarrow N = 3$
2 pivots $\Rightarrow P = 2$

$$DOF = 3(N-1) - 2P$$
$$= 3(3-1) - 2\cdot 2$$
$$6 - 4 = \underline{\underline{2}}$$

Example

3 Links
3 pivots $\Rightarrow 3(3-1) - 2\cdot 3 = \underline{\underline{0}}$
triangles are stable

Example

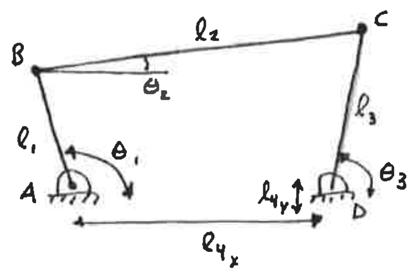


9 links
7 pivots $\Rightarrow 3(9-1) - 2\cdot 7 = 10$

How many DOF?

Overconstrained!

General 4 bar



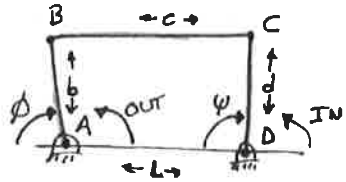
Assume system is connected

X direction : $l_1 \cos\theta_1 + l_2 \cos\theta_2 + l_3 \cos\theta_3 - l_{4_x} = 0$

Y direction : $l_1 \sin\theta_1 + l_2 \sin\theta_2 + l_3 \sin\theta_3 - l_{4_y} = 0$

These are constraints but they dont give us information on $\theta_1 = f(\theta_3)$

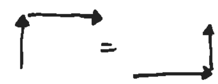
Freudenstein Equation (notice the angle convention!)



Consider the term AB as the vector from A to B

$AB = \uparrow$ $\qquad CD = \downarrow$ $\qquad DC = \uparrow$

From continuity, $AB + BC = AD + DC$



Solve for $BC = AD + DC - AB = -(DA + CD + AB)$

Freudenstein's insight was to take the dot product of BC with BC.

$$BC \cdot BC = -(DA + CD + AB) \cdot -(DA + CD + AB)$$

Find terms for location of B,C (assuming mechanism is aligned with x axis at A and D)

$$B = [-b\cos\phi,\ b\sin\phi] \qquad C = [-d\cos\psi,\ d\sin\psi]$$

Simplify $BC \cdot BC = c^2$!! Such that

$$c^2 = [l + b\cos\phi - d\cos\psi,\ -b\sin\phi + d\sin\psi] \cdot [\text{ditto}]$$

After some simplification

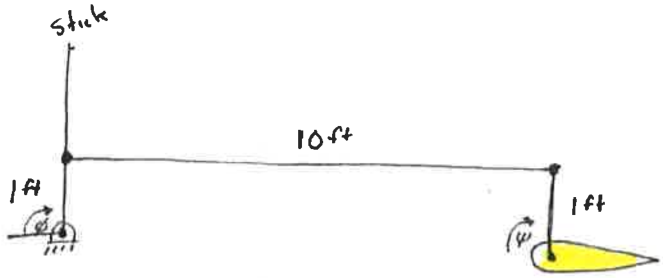
$$R_1 \cos\phi - R_2 \cos\psi + R_3 = \cos(\phi - \psi)$$

$$R_1 = L/d \qquad R_2 = L/b \qquad R_3 = \frac{L^2 + b^2 - c^2 + d^2}{2bd}$$

4 ~~3~~ unknowns

4 ~~3~~ equations $\rightarrow$ You need to specify ~~3~~ 4 positions.

Example



$L = 10ft$
$c = 10ft$
$b = 1ft$
$d = 1ft$

$R_1 = \frac{L}{d} = 10$

$R_2 = \frac{L}{b} = 10$

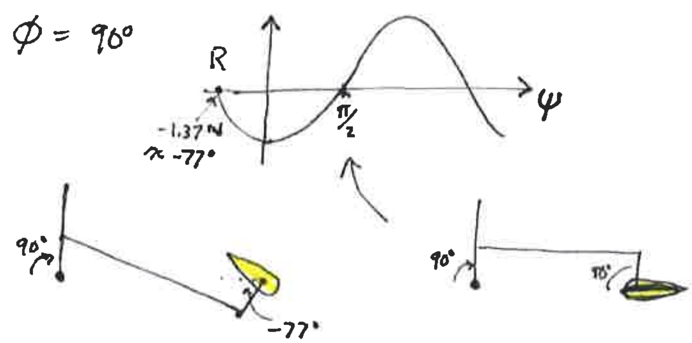
$R_3 = \frac{100 + 1 - 100 + 1}{2} = 1$

Freudenstein

$$10\cos\phi - 10\cos\psi + 1 = \cos(\phi - \psi)$$

$$\text{Residual} \equiv 10\cos\phi - 10\cos\psi + 1 - \cos(\phi-\psi) \longrightarrow 0$$

when $\phi = 90°$



What about the gearing ratio? $\frac{d\psi}{d\phi}$

Take $\frac{d}{d\phi}$ of Freudenstein while remembering that $\psi \doteq f(\phi)$

$$\frac{d}{d\phi}\left(R_1\cos\phi - R_2\cos\psi + R_3 - \cos(\phi-\psi)\right)$$

$$= -R_1\sin\phi \cancel{\frac{d\phi}{d\phi}}^{1} + R_2\sin\psi\frac{d\psi}{d\phi} + 0 + \sin(\phi-\psi)\underbrace{\frac{d}{d\phi}(\phi-\psi)}_{1-\frac{d\psi}{d\phi}}$$

Solve for $\frac{d\psi}{d\phi}$

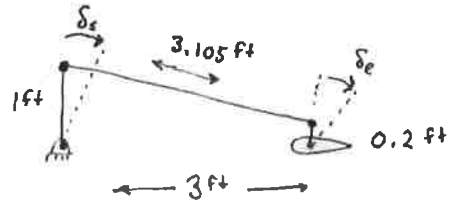
$$\frac{d\psi}{d\phi} = \frac{-\sin(\phi-\psi) + R_1\sin\phi}{R_2\sin\psi - \sin(\phi-\psi)}$$

For the above,

$\frac{d\psi}{d\theta}(\theta = 90, \psi = 90) = 1.0$ ✓

$\frac{d\psi}{d\theta}(\theta = 90, \psi = -77) \approx -0.98$

Example (shorter pushrod)



$L = 3$
$b = 1$
$c = 3.105$
$d = 0.2$

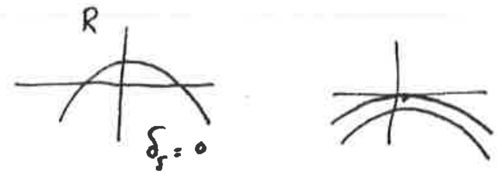
$R_1 = 15 \quad R_2 = 3 \quad R_3 = 0.9974$

At $\delta_s = 0$ We expect a gearing ratio of 5, since $\frac{b}{d} = 5$

What are the limits of stick travel?

$\delta_s \approx 15° \Rightarrow \delta_e = 108°$

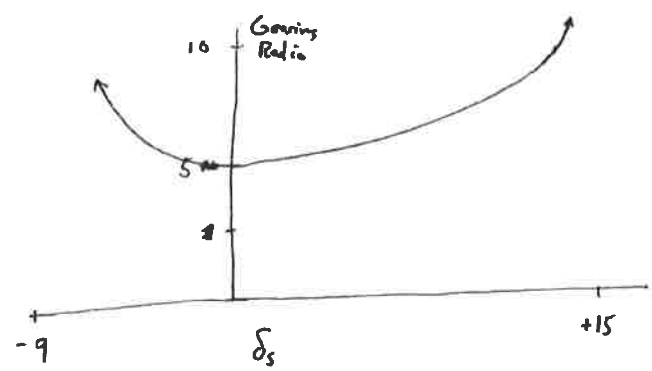
$\delta_s \approx -9° \Rightarrow \delta_e = -70°$



What is the gearing ratio at $\delta_s = 15°$? $G \approx 216$

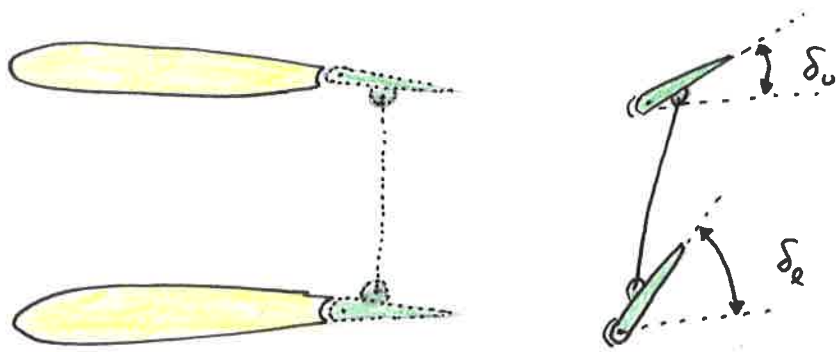
" at $\delta_s = -9°$ $G \approx 380$

$\Leftarrow$ This indicates that 1 lbf-ft at the surface requires 200-300 ft-lbf at the stick.... not happening...



Biplane Ailerons

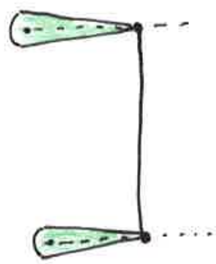
A common but flawed way to connect the ailerons on a biplane is:



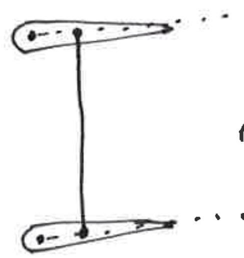
$\delta_u \neq \delta_\ell$

The upper and lower surfaces don't have the same angle (other than $\delta_u = \delta_\ell = 0$).

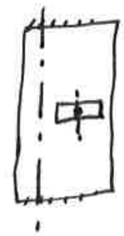
Fix 1



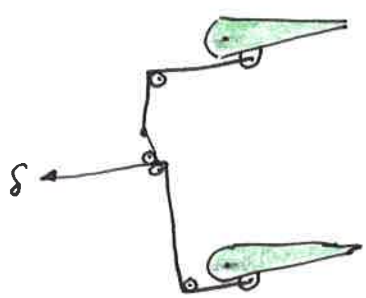
Fix 2



requires slot in surface



Fix 3



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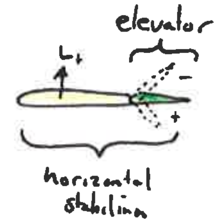
Elevator



previously, we trimmed our conceptual aircraft by adjusting i_t (the tail incidence angle)

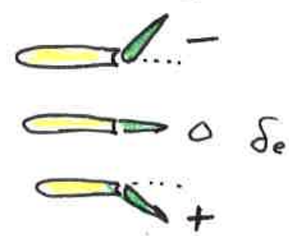
Now, we add a hinged elevator to the horizontal stab, which changes L and M.

$$\Delta C_L = C_{L_{\delta_e}}\delta_e = \frac{dC_L}{d\delta_e}\delta_e$$

and

$$\Delta C_m = C_{m_{\delta_e}}\delta_e = \overbrace{\frac{dC_m}{d\delta_e}}^{\text{elevator control power}}\delta_e$$

Sign convention



Thus $C_{m_{\delta_e}}$ is usually a negative #.

Applied to the aircraft pitching moment gives

$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_{\delta_e}}\underbrace{\delta_e}_{\text{Adjusting the elevator allows for trimmed flight}}$$

$C_m \to 0$

For the aircraft's total lift

$$\Delta C_L = \frac{dC_L}{d\delta_e}\delta_e = \underbrace{\eta\frac{S_t}{S_w}}_{\text{ref to wing q and area.}}\underbrace{\overbrace{\frac{dC_{L_t}}{d\delta_e}}^{\text{elevator lift effectiveness}}\delta_e}_{\text{Incremental lift coeff of tail}}$$

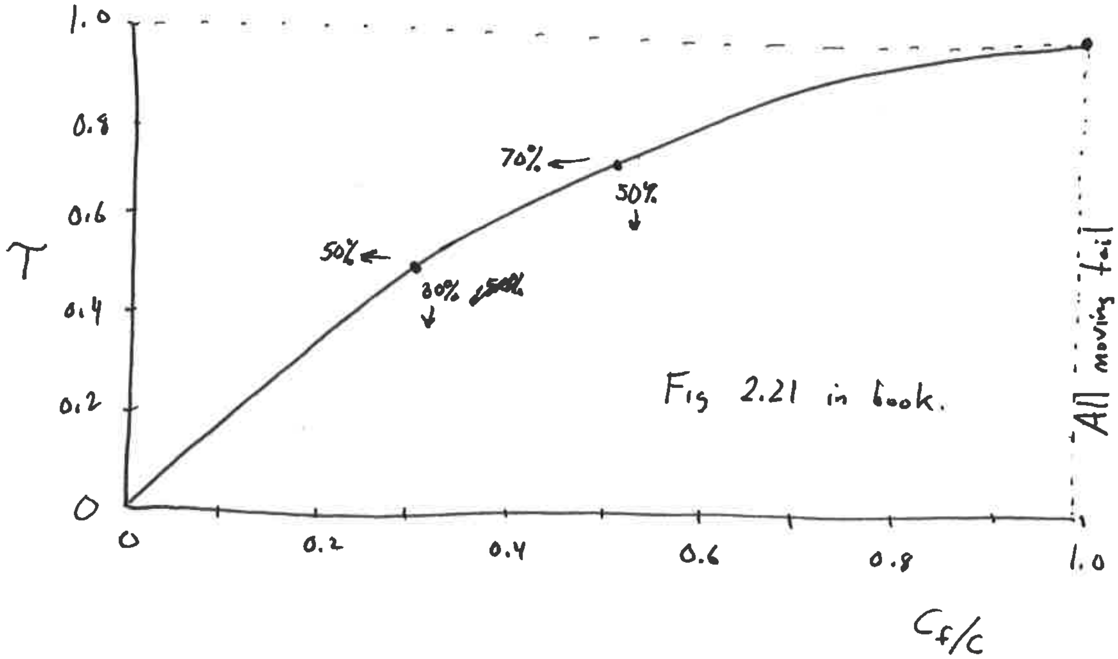
Elevator Effectiveness

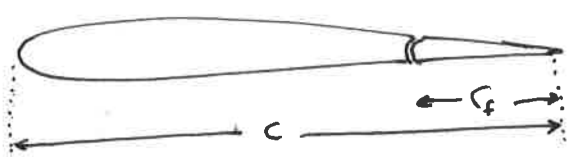
$$\frac{dC_{L_t}}{d\delta_e} = \frac{dC_{L_t}}{d\alpha_t}\cdot\left.\frac{d\alpha_t}{d\delta_e}\right|_{C_L\text{ const.}} = C_{L_{\alpha_t}}\cdot\underbrace{\left.\frac{d\alpha_t}{d\delta_e}\right|_{C_L\text{ constant}}}_{\text{Angle of attack effectiveness, Flap effectiveness parameter}} = C_{L_{\alpha_t}}\tau$$

For small angles, $\dfrac{d\alpha_t}{d\delta_e} \approx \dfrac{C_{L_\delta}}{C_{L_\alpha}}$

How effective is a flap at generating lift compared to angle of attack

Flap Effectiveness Parameter





Notice that τ is not a linear function of C_f/c.

Smaller flap chords (C_f/c) are comparatively more effective

A 30% flap chord has 50% of the effectiveness of a fully all moving tail

So $C_{L_{\delta_e}}$: <u>(Lift)</u>

$$C_{L_{\delta_e}} = \eta \frac{S_t}{S_w} \frac{dC_{L_t}}{d\delta_e} = \eta \frac{S_t}{S_w} C_{L_{\alpha_t}} \tau$$

<u>Moment:</u>

$$\Delta C_m \approx \frac{-\overset{\text{distance}}{l_t} \cdot \overset{\text{Force}}{L_t}}{\frac{1}{2}\rho V^2 S_w \bar{c}_w} = -V_H \eta \Delta C_{L_t} \qquad V_H = \frac{l_t S_t}{\bar{c} S_w}$$

$$= -V_H \eta \frac{dC_{L_t}}{d\delta_e} \delta_e$$

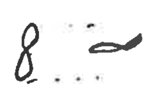
Combine with prev result for $C_{m_{\delta_e}}$

$$\underbrace{C_{m_{\delta_e}}}_{} = -V_H \eta \frac{dC_{L_t}}{d\delta_e} = -V_H \eta C_{L_{\alpha_t}} \tau$$

The change in pitching moment wrt flap deflection depends on
- the tail volume
- dynamic pressure ratio
- lift curve slope
- flap effectiveness

Q: How can you increase the ~~[illegible]~~ elevator control power?

A: $ECP \equiv C_{m_{\delta_e}}$

- Increase tail length l_t } V_H
- Increase tail area S_t } V_H
- Increase dynamic pressure 
- Increase tail AR $\rightarrow C_{L_{\alpha_t}} \uparrow$ 
- Increase flap effectiveness 

Elevator angle to trim

$$C_L = C_{L_\alpha}\alpha + C_{L_{\delta_e}}\delta_e$$

$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_{\delta_e}}\delta_e \Rightarrow 0$$

Solve for δ_e

$$\delta_{e_{trim}} = -\frac{\left(C_{m_0} + C_{m_\alpha}\alpha_{trim}\right)}{C_{m_{\delta_e}}}$$

Substitute back into C_L

$$C_{L_{trim}} = C_{L_\alpha}\alpha_{trim} + C_{L_{\delta_e}} \overbrace{\frac{\left(-C_{m_0} - C_{m_\alpha}\alpha_{trim}\right)}{C_{m_{\delta_e}}}}^{\delta_{e_{trim}}}$$

Rearrange to solve for α_{trim}

$$\frac{C_{L_{trim}} + \frac{C_{L_{\delta_e}} C_{m_0}}{C_{m_{\delta_e}}}}{C_{L_\alpha} - \frac{C_{L_{\delta_e}} C_{m_\alpha}}{C_{m_{\delta_e}}}} = \boxed{\alpha_{trim} = \frac{C_{L_{trim}} C_{m_{\delta_e}} + C_{L_{\delta_e}} C_{m_0}}{C_{L_\alpha} C_{m_{\delta_e}} - C_{L_{\delta_e}} C_{m_\alpha}}}$$

Similarly for $\delta_{e_{trim}}$

$$C_{L_{trim}} = C_{L_\alpha}\alpha_{trim} + C_{L_{\delta_e}}\delta_{e_{trim}}$$

solve for α_{trim} above

$$C_{L_{trim}} = -\frac{C_{L_\alpha}}{C_{m_\alpha}} C_{m_{\delta_e}} \delta_{e_{trim}} + \frac{C_{L_\alpha} C_{m_0}}{C_{m_\alpha}} + C_{L_{\delta_e}}\delta_{e_{trim}}$$

Solve for $\delta_{e_{trim}}$

$$\delta_{e_{trim}} = \frac{C_{L_{trim}} + \frac{C_{L_\alpha} C_{m_0}}{C_{m_\alpha}}}{C_{L_{\delta_e}} - \frac{C_{L_\alpha} C_{m_{\delta_e}}}{C_{m_\alpha}}} = +\frac{\left(C_{L_{trim}} C_{m_\alpha} + C_{L_\alpha} C_{m_0}\right)}{C_{L_{\delta_e}} C_{m_\alpha} - C_{L_\alpha} C_{m_{\delta_e}}}$$

Flight Measurement of the neutral point

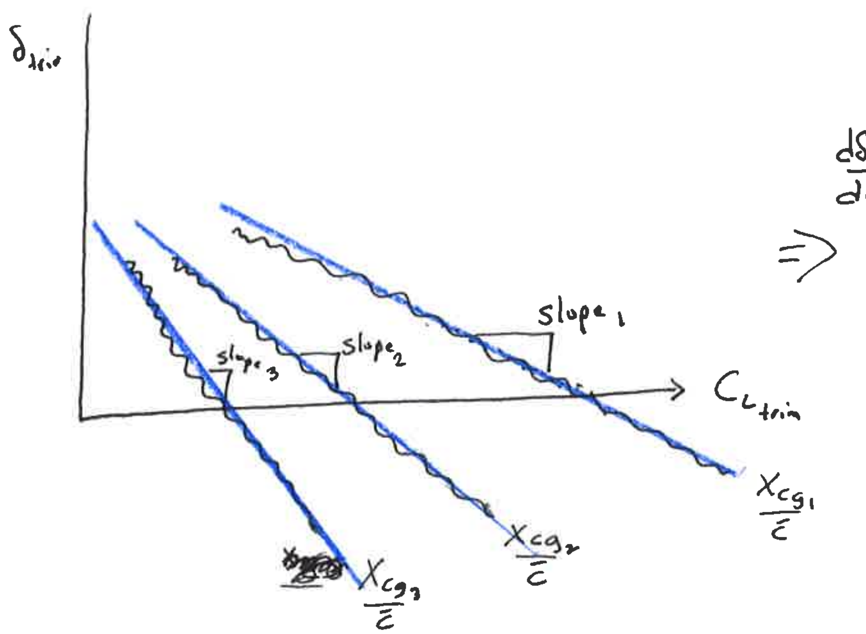
Find the slope of δ_{trim} wrt $C_{L_{trim}}$

$$\frac{d\delta_{trim}}{dC_{L_{trim}}} = \frac{d}{dC_{L_{trim}}}\left(\frac{C_{L_{trim}} C_{m_\alpha} + C_{L_\alpha} C_{m_0}}{C_{L_{\delta_e}} C_{m_\alpha} - C_{L_\alpha} C_{m_{\delta_e}}}\right)$$

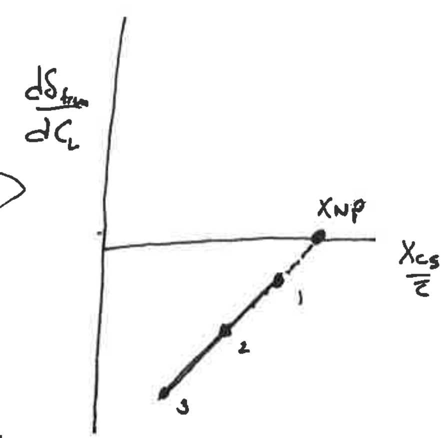
$$= \frac{C_{m_\alpha}}{C_{L_{\delta_e}} C_{m_\alpha} - C_{L_\alpha} C_{m_{\delta_e}}} = -\frac{C_{m_\alpha}}{-C_{L_\alpha} V_H \eta C_{L_{\alpha_t}} \tau - C_{L_{\delta_e}} C_{m_\alpha}}$$

$$= -\frac{C_{m_\alpha}}{-C_{L_\alpha} V_H \eta C_{L_{\alpha_t}} \tau - \eta \frac{\cancel{S_t}}{\cancel{S_w}} C_{L_{\alpha_t}} \tau C_{m_\alpha} \frac{V_H \bar{c} \cancel{S_w}}{l_t \cancel{S_t}}}$$

$$= \frac{C_{m_\alpha}}{\tau V_H \eta C_{L_{\alpha t}}\left(C_{L_\alpha} + C_{m_\alpha}\frac{\bar{c}}{l_t}\right)}$$



$\Rightarrow$



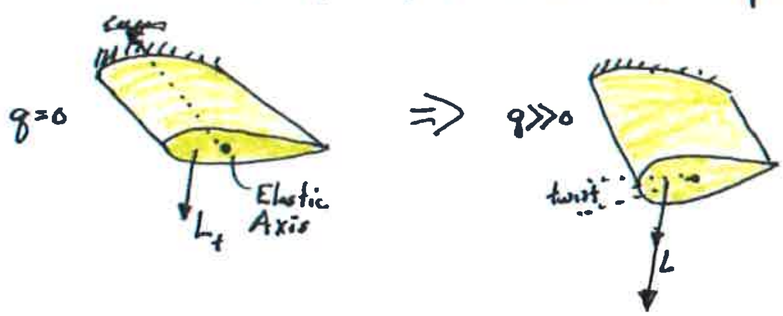
This can be done with multiple flights.

Other factors decreasing longitudinal stability

Aero elastics

The load on the stab varies with V^2 (since $q = \frac{1}{2}\rho V^2$).

There will be deflections due to aero loads, these may increase or decrease stability depending on the structural response.



exaggurated for effect.

For light aircraft, the static margin even in an incompressible flow may strongly depend on the flight velocity

Read: tiny.cc/AEM617TailStability

Harry Clements designing the C-180

- Suspected deflection in horz tail → reduced stab at/near V_{ne}
- pencil lead to detect deflection
- Not found!! why? production changed design!

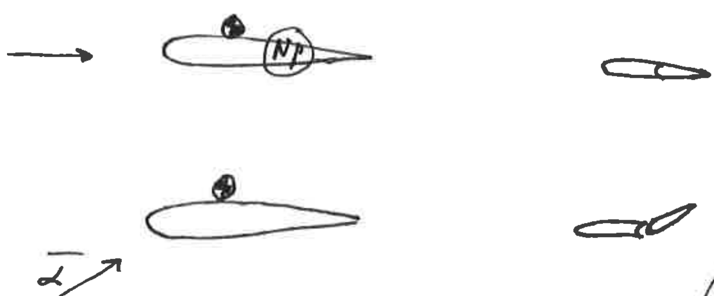
$$\left(1 - \frac{C_{L\delta_e}}{C_{L\alpha_t}}\,\frac{C_{h\alpha}}{C_{h\delta_e}}\right) = \left(1 - \frac{(+)}{(+)}\,\frac{(-)}{(-)}\right) = \left(1 - (+)\right) < 1$$

So the $\frac{x_{NP}}{\bar{c}}$

$$\frac{x_{NP}}{\bar{c}} = \frac{x_{ac}}{\bar{c}} + \underbrace{\frac{C_{L\alpha_t}}{C_{L\alpha_w}}\left(\overset{\text{less than 1}}{\quad}\right)\eta\, V_H\left(1 - \frac{d\epsilon}{d\alpha}\right)}_{\text{Smaller than for stick fixed.}} - \frac{C_{m\alpha_f}}{C_{L\alpha_w}}$$

A floating elevator aircraft has an X_{NP} nearer to X_{ac} than the equivalent fixed stick aircraft.

$$\boxed{\text{Stick free is less stable}}$$



1) Increasing α tends to move the elevator TEU.

2) Elevator deflection TEU tends to increase α

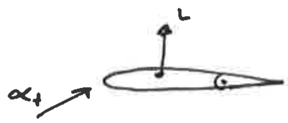
This is positive feedback.

Have you ever heard a pilot say

"The airplane flys well hands-off."

They (pilots) are saying the correct concept.

Lift tail $\bar{w}$ floating elevator



$$C_{L_t} = C_{L_{\alpha_t}} \alpha_t + C_{L_{\delta_e}} \delta_e$$

$$\delta_e = -\frac{C_{h_\alpha}}{C_{h_{\delta_e}}} \alpha_t$$

$$= \left(C_{L_{\alpha_t}} - C_{L_{\delta_e}} \frac{C_{h_\alpha}}{C_{h_{\delta_e}}} \right) \alpha_t = \underbrace{C_{L_{\alpha_t}} \left(1 - \frac{C_{L_{\delta_e}}}{C_{L_{\alpha_t}}} \frac{C_{h_\alpha}}{C_{h_{\delta_e}}} \right)}_{C'_{L_{\alpha_t}}} \alpha_t$$

free floating $C_{L_{\alpha_t}}$!!

Substitute into previous C_{m_0} and C_{m_α} terms

$$C_{m_0} = C_{m_{0_w}} + C_{m_{0_f}} + C'_{L_{\alpha_t}} \eta V_H (\epsilon_0 + i_w - i_t)$$

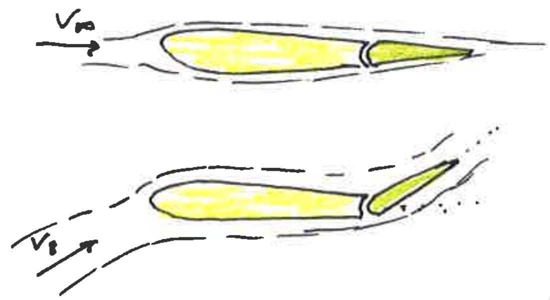
$$C_{m_\alpha} = C_{L_{\alpha_w}} \left(\frac{X_{cg}}{\bar{c}} - \frac{X_{ac}}{\bar{c}} \right) + C_{m_{\alpha_f}} - C'_{L_{\alpha_t}} \eta V_H \left(1 - \frac{d\epsilon}{d\alpha} \right)$$

Solve for $\frac{X_{NP}}{\bar{c}}$ from C_{m_α} equ.

$$0 = C_{L_{\alpha_w}} \left(\frac{X_{NP}}{\bar{c}} - \frac{X_{ac}}{\bar{c}} \right) + C_{m_{\alpha_f}} - C_{L_{\alpha_t}} \left(1 - \frac{C_{L_{\delta_e}}}{C_{L_{\alpha_t}}} \frac{C_{h_\alpha}}{C_{h_{\delta_e}}} \right) \eta V_H \left(1 - \frac{d\epsilon}{d\alpha} \right)$$

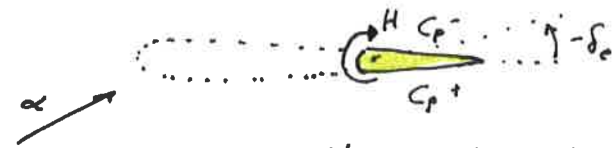
$$\frac{X_{NP}}{\bar{c}} = \frac{X_{ac}}{\bar{c}} + \frac{C_{L_{\alpha_t}}}{C_{L_{\alpha_w}}} \underbrace{\left(1 - \frac{C_{L_{\delta_e}}}{C_{L_{\alpha_t}}} \frac{C_{h_\alpha}}{C_{h_{\delta_e}}} \right)}_{\text{New term}} \eta V_H \left(1 - \frac{d\epsilon}{d\alpha} \right) - \frac{C_{m_{\alpha_f}}}{C_{L_{\alpha_w}}}$$

"Floating Elevator"



$$\delta_e = -\frac{C_{h_\alpha}}{C_{h_{\delta_e}}}\alpha$$

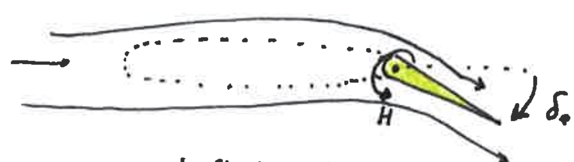
- C_{h_α} is the hinge moment derivative due to α



H is negative, the surface wants to move TEU with "+" α

$C_{h_\alpha} < 0$

- $C_{h_{\delta_e}}$ is the hinge moment derivative due to deflection δ_e



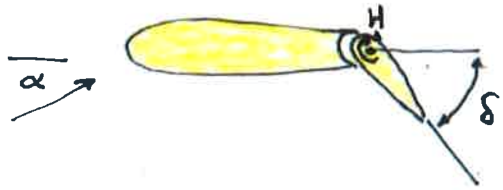
positive deflection tends to move surface back to zero deflection

$C_{h_{\delta_e}} < 0$

$$\delta_e = -\frac{(-)}{(-)}\alpha = (-)\alpha$$

This effects stability!

Hinge Moments (Necessary for the upcoming flight control system portion of the class)



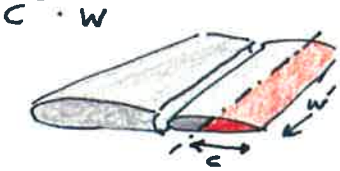
A moment is necessary to maintain the control surface at δ.

$$C_h = f(\alpha, \delta, Re, gap, etc) \quad \text{and possibly time}$$

$$H = C_h \cdot q \cdot S \cdot c \qquad = C_h \cdot q \cdot c^2 \cdot w$$

← chord aft of hinge

↖ area aft of hinge



The pilot is connected to the surface in some way

$$\delta = f(\underset{\delta_s}{\text{stick angle}})$$

Gearing Ra

$$F l_s \delta_e = H \delta_e \Rightarrow F = \left(\frac{\delta_e}{l_s \delta_s}\right) H_e$$

How much force can a pilot exert? How long? $H \propto V^2$; pilot is limited human!

Constraints? Stick position, structural stresses, . . .

Trim Tab

$$C_h = C_{h_0} + \underbrace{C_{h_\alpha}}_{\frac{dC_h}{d\alpha}} \alpha + \underbrace{C_{h_{\delta_e}}}_{\frac{dC_h}{d\delta_e}} \delta_e + \underbrace{C_{h_{\delta_t}}}_{\frac{dC_h}{d\delta_t}} \delta_t$$

For the pilot to have zero stick force, $C_h = 0$

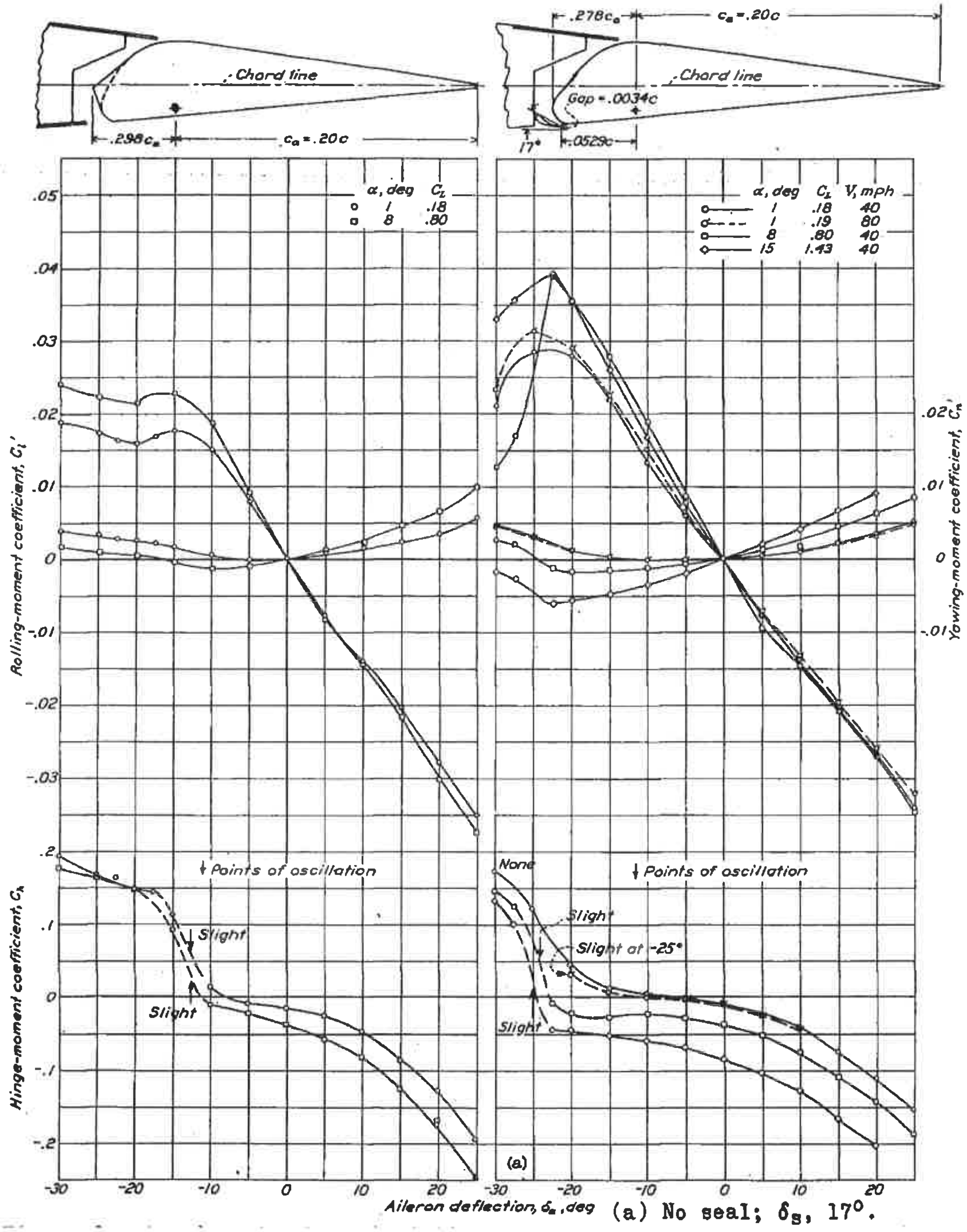
We (as pilots) can adjust δ_t to ensure $C_h = 0$ for a particular δ_e required at a particular α.

Stick free:

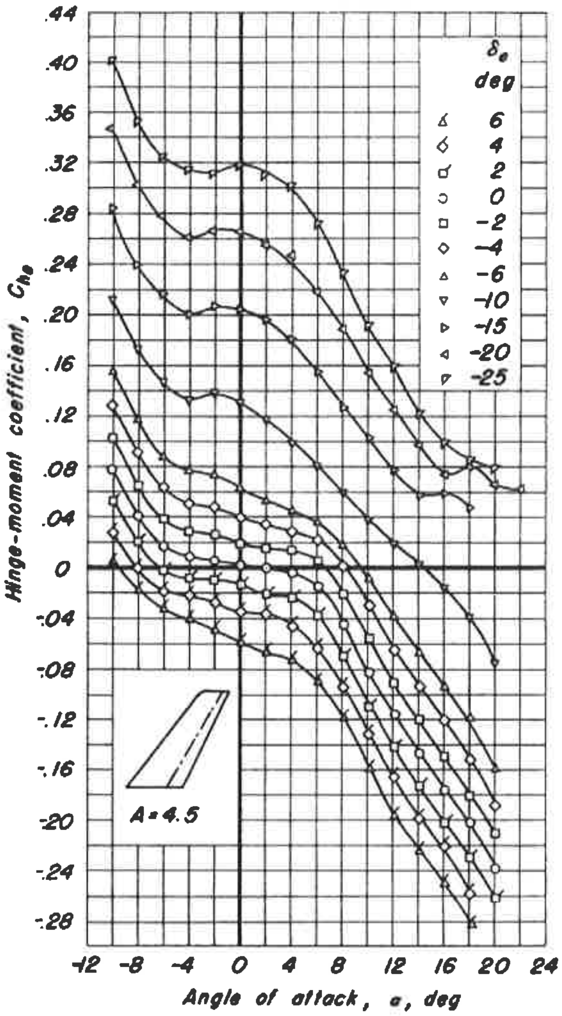
$$C_h = 0 = \cancel{\left(C_{h_0} + C_{h_{\delta_t}} \delta_t\right)}^{\text{trimmed } 0} + \underbrace{C_{h_\alpha}}_{\text{usually negative}} \alpha + \underbrace{C_{h_{\delta_e}}}_{\text{usually negative}} \delta_e \Rightarrow \delta_e = -\frac{C_{h_\alpha}}{C_{h_{\delta_e}}} \alpha$$

The elevator "floats".
TEU w/ α increas

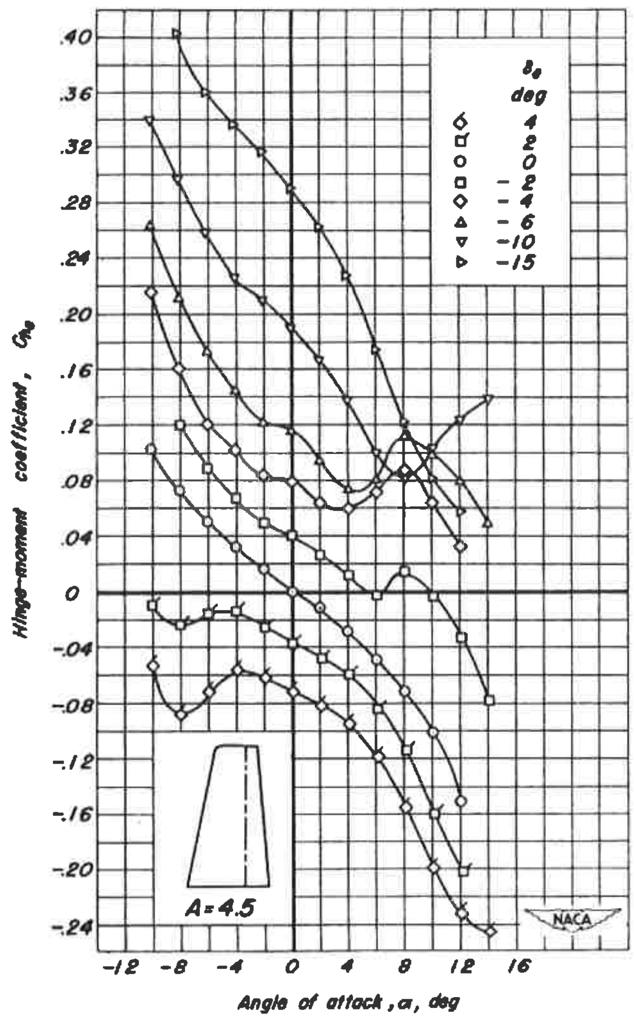
Frise



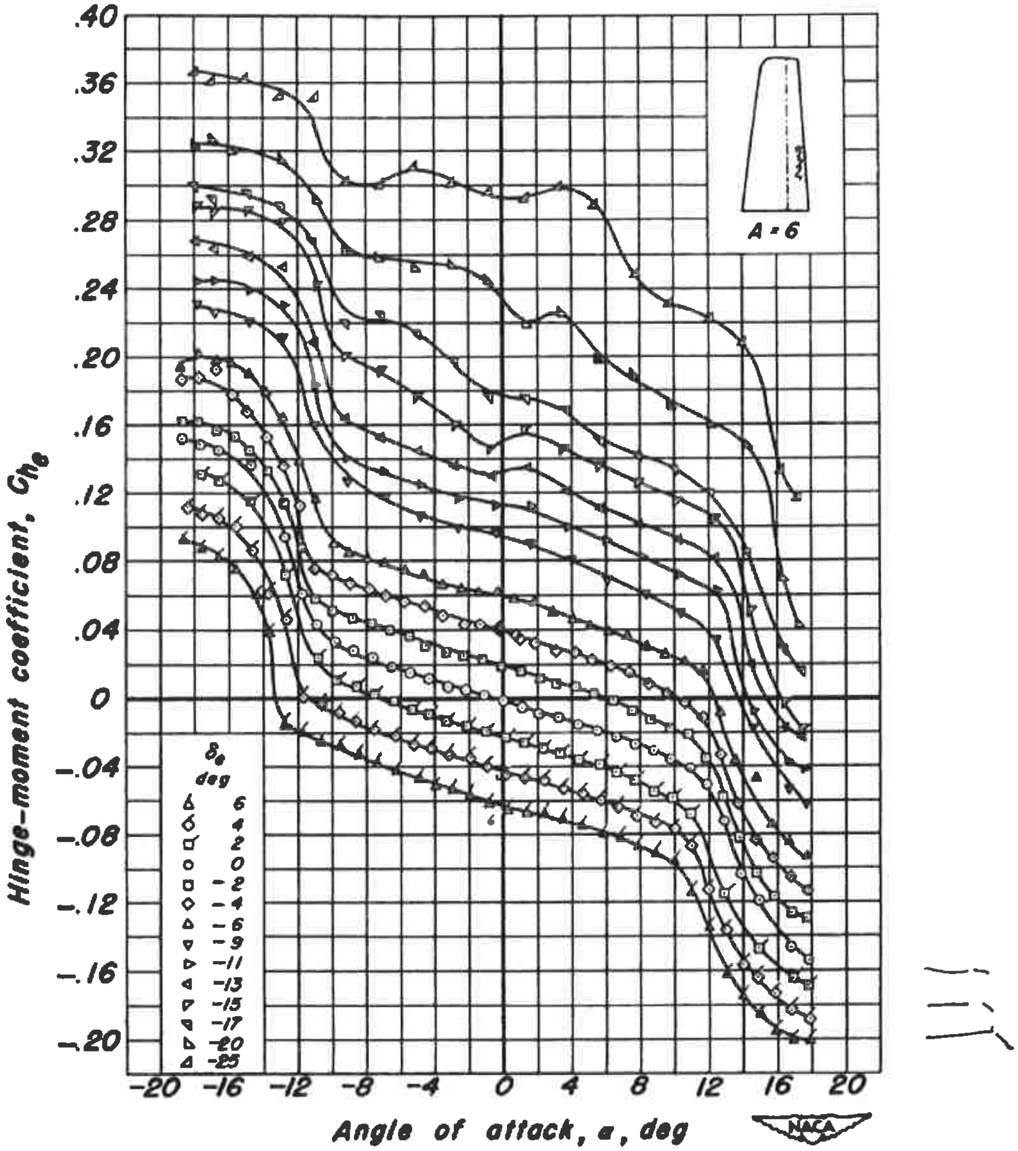
(a) No seal; δ_s, 17°.


Hinge-moment coefficient, C_{h_e}
Angle of attack, α, deg
δ_e
deg
6
4
2
0
−2
−4
−6
−10
−15
−20
−25
A = 4.5

(c) M, 0.85.


Hinge-moment coefficient, C_{h_e}
Angle of attack, α, deg
δ_e
deg
4
2
0
− 2
− 4
− 6
−10
−15
A = 4.5

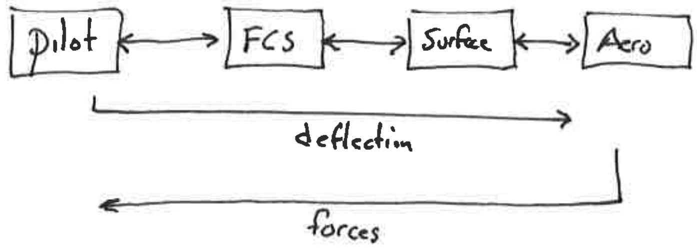
(e) M, 0.88.



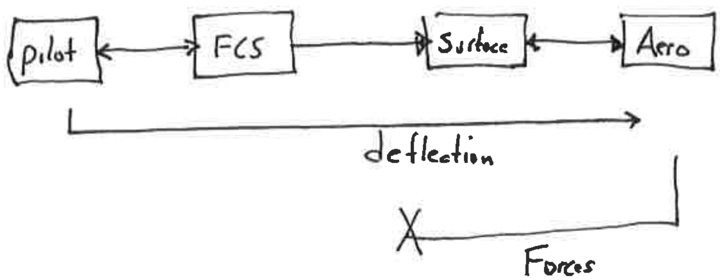
(b) Hinge-moment coefficient.

Reversible vs Irreversible Flight Control System.

Reversible

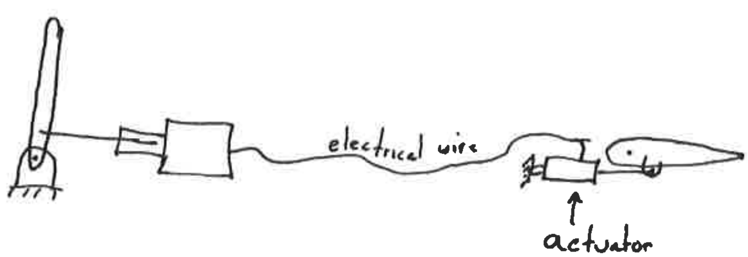


Irreversible



The pilot does not feel the aerodynamic forces!

Ex:



Fly by wire

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.

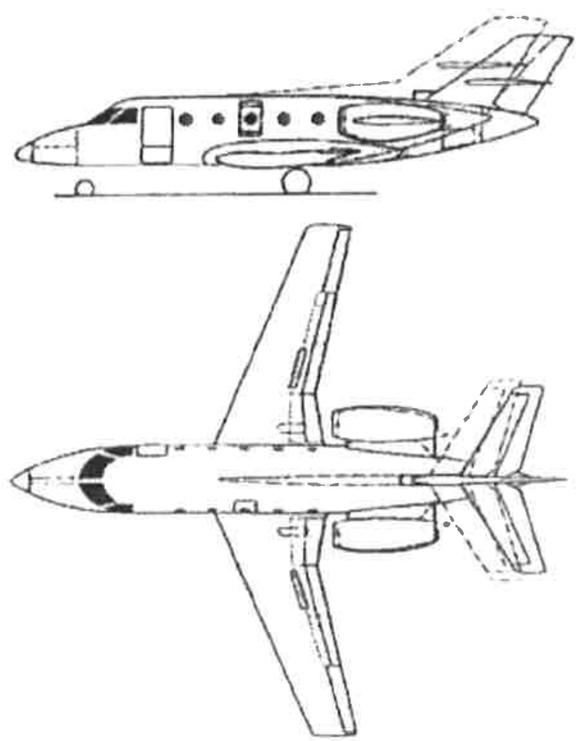


Figure 31.26 - Over-trimming cited in Corvette crash.
Source: Aviation Week and Space Technology, May 31 and October 18, 1971

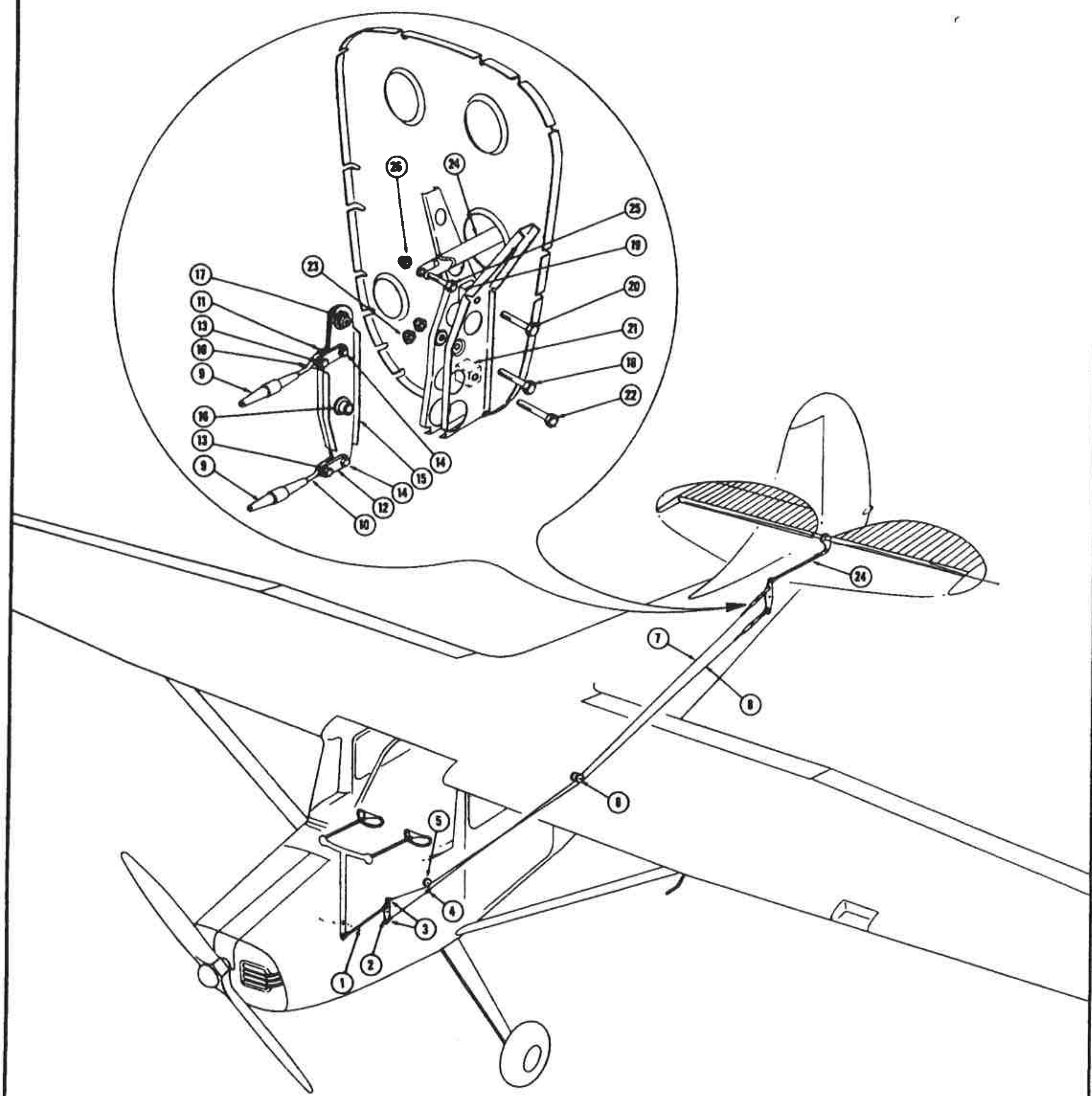
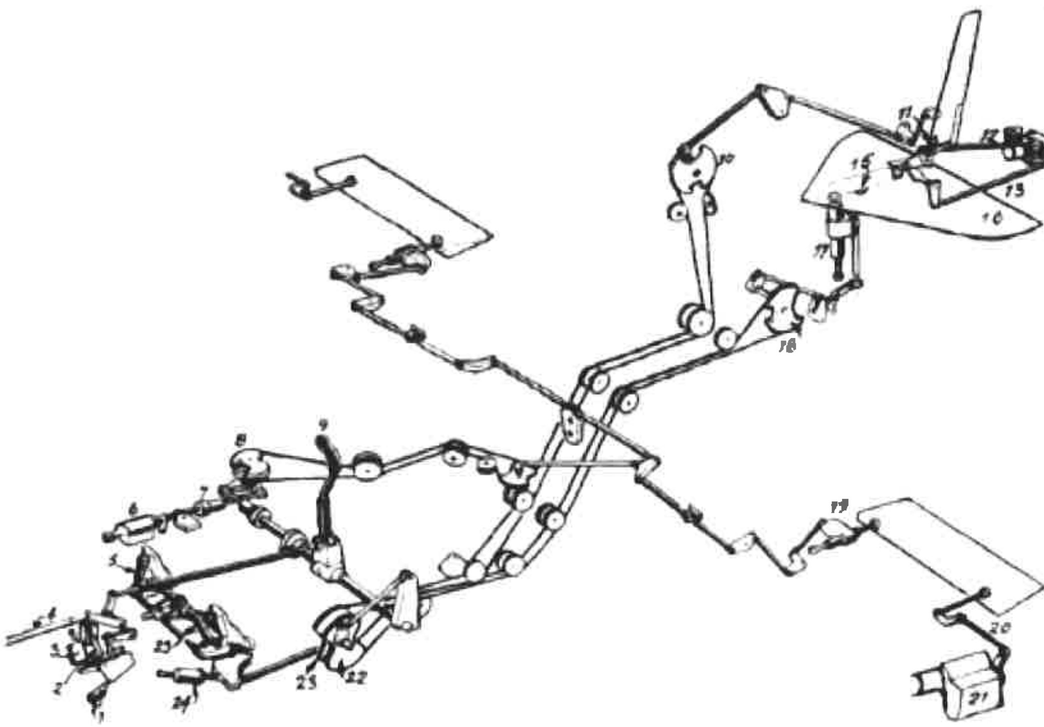
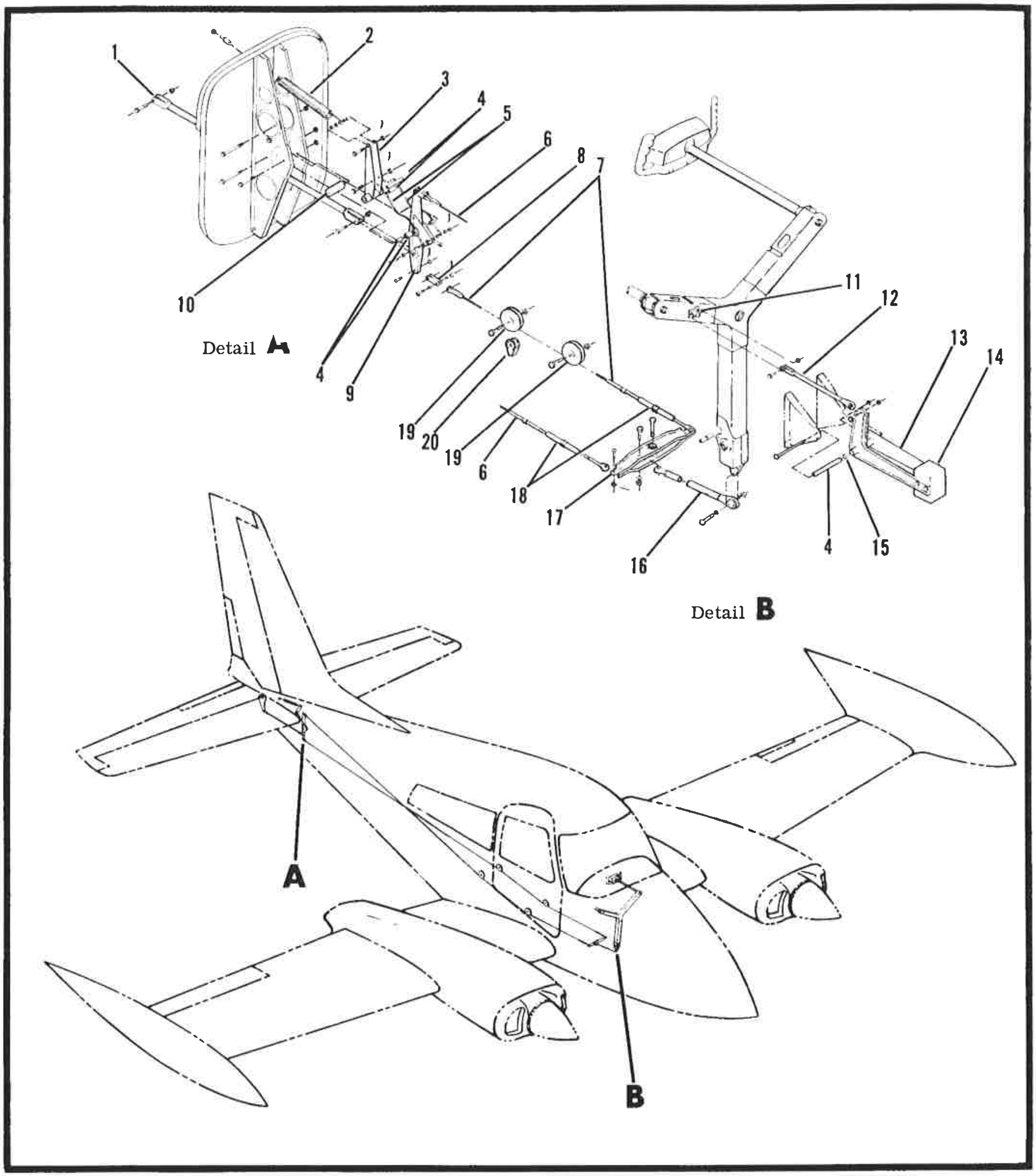


FIGURE 47 - ELEVATOR CONTROL SYSTEM



AV-8 Harrier Flight Control System. Source: [MWF67]



1. Elevator Push-pull Tube (Aft)
2. Elevator Down Spring
3. Down Spring Channel Assembly
4. Spacer
5. Down Spring Cable
6. Right Elevator Control Cable
7. Left Elevator Control Cable
8. Link
9. Elevator Bellcrank (Aft)
10. Bellcrank Stop
11. Bob-Weight Bracket
12. Push-pull tube
13. Bob-Weight Bellcrank
14. Bob-Weight
15. Bearing
16. Elevator Push-pull Tube (Forward)
17. Elevator Bellcrank (Forward)
18. Turnbuckle
19. Pulley
20. Cable Guard

Figure 6-2. Elevator Control System