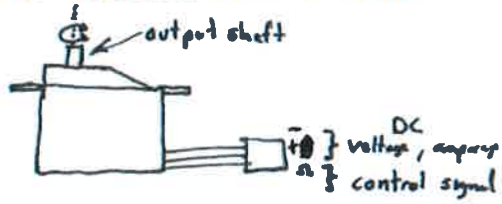
Servos

RC FCS

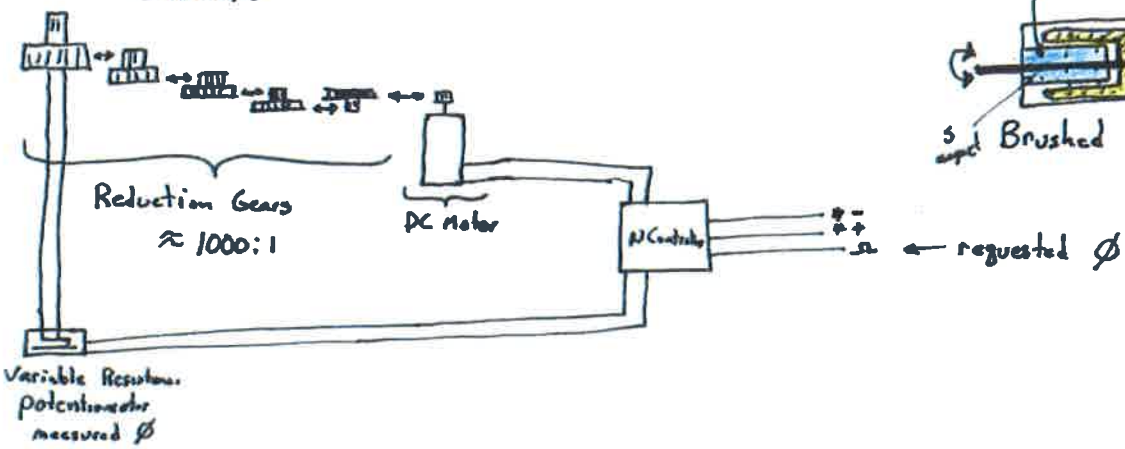
μC

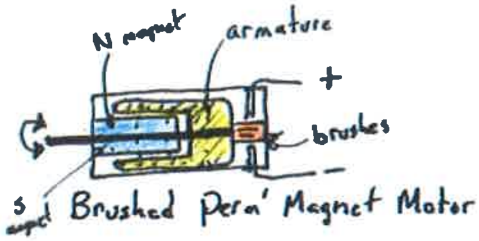
Notes posted at: tiny.cc / ServoLecture

Analysis of the electromechanical servo.

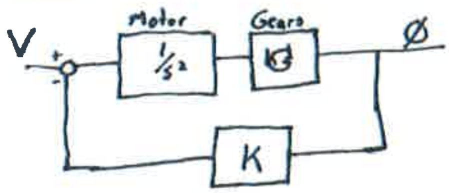


Schematic





System Model



Simplifications:

- Gears have inertia
- Gears have play + friction
- Potentiometer is noisy (sometimes terrible on small servo

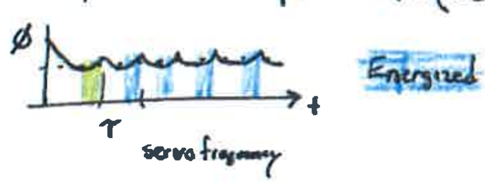
Limitations

- Holding torque: An actual application requires holding a position ∅ with an applied torque.

  The brushed motor can only provide torque when ~~the~~ current is applied.

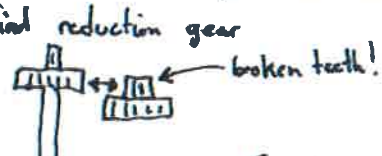
  And the motor torque is <u>more</u> than necessary to maintain position ∅. (i.e overshoot)

  This is the source of servo buzz.



- Gear strength

  The reduction drive requires high torque with a limited (very limited!) number of engaged teeth. High quality servos use metal gears or reinforced composites for the final reduction gear

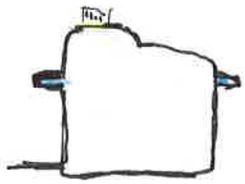


<u>A true weak link</u>

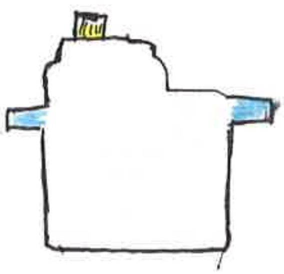
From experience, don't buy nylon geared servos.

Common Servo Sizes

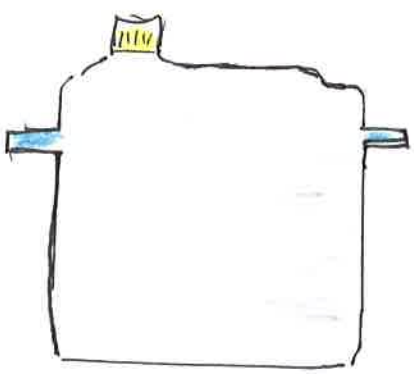
see: servocity.com



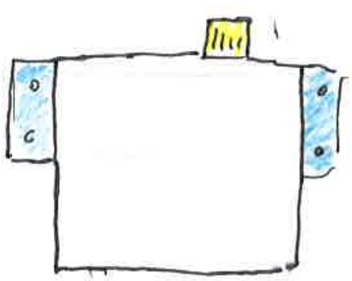
4.7g "Nano" HS 35HD 11 oz-in
~5.0g



≈10g Mini HS 65MG 25 oz-in @ 4.8v
31 oz-in at 6.0v



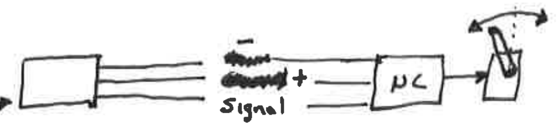
≈40g Standard Futaba S3003 44 oz-in at 4.8v
57 oz-in at 6.0v



Flat for thin aileron servos mounted in the wing.

Servo Signals

Pulse Width Modulation →



"The width of a pulse specifies the servo angle"

The pulses have a 50 Hz PRF. (pulse repetition frequency)

Since the period is the inverse of frequency,

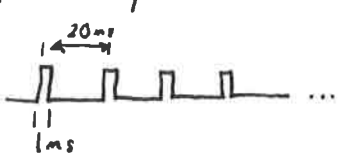
$$T = \frac{1}{PRF} = \frac{1}{50\,\text{Hz}} = 0.02\,s = 20\,ms$$

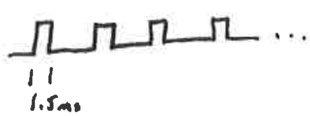
A new pulse starts every 20ms

The servo angle is specified by the pulse width

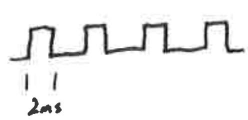
where a 1 ms pulse is the minimum angle and a 2 ms pulse is the maximum angle

Ex: We have a 90° travel servo. Show the angle specified by each pulse train.

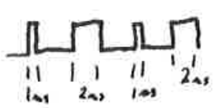
- 

  1ms ⇒ 0°
  
- 

  1.5ms ⇒ 45°
  

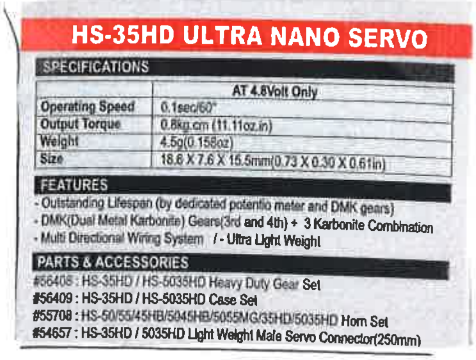
- 

  2.0ms ⇒ 90°
  

- 

  Servo response is not 50Hz
- 
  Non compliant, response depends on servo controller ?

Servo Torque and Speed



HS-35HD ULTRA NANO SERVO

SPECIFICATIONS

	AT 4.8Volt Only
Operating Speed	0.1sec/60°
Output Torque	0.8kg.cm (11.11oz.in)
Weight	4.5g(0.158oz)
Size	18.6 X 7.6 X 15.5mm(0.73 X 0.30 X 0.61in)

FEATURES

- Outstanding Lifespan (by dedicated potentio meter and DMK gears)
- DMK(Dual Metal Karbonite) Gears(3rd and 4th) + 3 Karbonite Combination
- Multi Directional Wiring System / - Ultra Light Weight

PARTS & ACCESSORIES

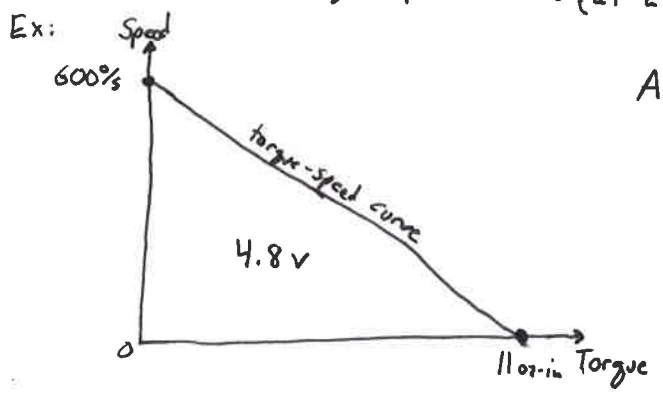
#56408 : HS-35HD / HS-5035HD Heavy Duty Gear Set
#56409 : HS-35HD / HS-5035HD Case Set
#55708 : HS-50/55/45HB/5045HB/5055MG/35HD/5035HD Horn Set
#54657 : HS-35HD / 5035HD Light Weight Male Servo Connector(250mm)

Servos are effectively rated by torque and speed.

- Output "stall" torque (e.g. 11 oz-in)
- Maximum rotating speed (e.g 60°/0.1 s)

Because the servo is a motor, you won't get the maximum torque and the maximum speed at the same time. Rather, there is a torque-speed curve (at a particular voltage)

Ex:



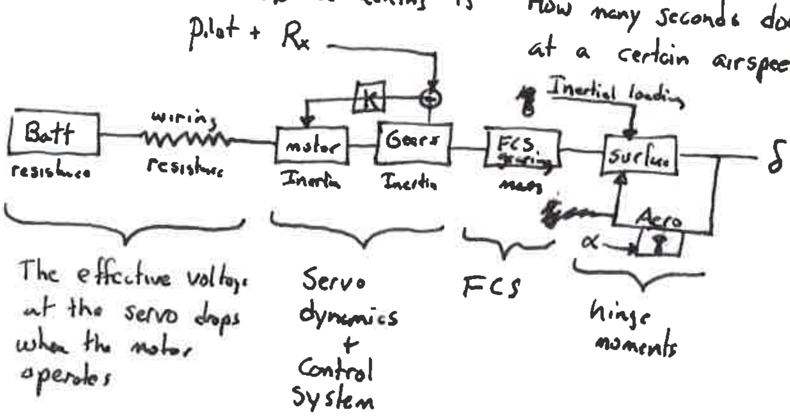
Assume a straight line model:

$$S(T) = 600°/s - \frac{600°/s}{11\ \text{oz-in}} \cdot T$$

If you need 400°/s, the maximum applied torque is:

$$400°/s = 600°/s - \frac{600°/s}{11\ \text{oz-in}} \cdot T \Rightarrow \boxed{T = 3.6\ \text{oz-in}}$$

The question that we should be asking is "How many seconds does it take to get to full deflection at a certain airspeed?" ← Hard Question



Q: Is this a reversible FCS? 368 topic
A: No.

"Domnasch" paper
"Root" paper

Lower bound: Motor only with simple aero loads

still an ODE

$$\dot{\theta} = f(T) = \dot{\theta}_{max} - \frac{\dot{\theta}_{max}}{T_{max}} T \leftarrow T = f(G, H) \leftarrow H = q S c C_h \leftarrow C_h \approx \frac{dC_h}{d\delta}\delta \leftarrow \delta = f(\theta)$$

Easy to solve once you select the models.

Upper bound:

Determine the maximum torque at δ, assume torque constant over travel

Engineering Managers bound.

If you are operating in a region where the servo travel time is requiring you to determine a high quality hinge moment and motor model, you are operating too close to the edge.

Get a bigger servo! and Check your hinge moments (with analysis!)

Servo Gears or Use quality equipment

How I learned to stop worrying and

There are essentially 3 types of servo gears:

Nylon / plastic:

Quiet, light, cheap, teeth fail easily — low torque applications

Reinforced plastic ("Karbonite" from Hitec)

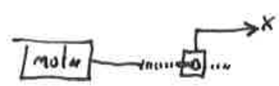
Quiet, medium price, tough — medium torque

Metal:

Noisier, $$, wears out — High torque

More Torque?

Landing gear ... use a jackscrew



Slow!

Brands to consider

- Futaba
- Hitec
- Spectrum
- ⋮

Avoid
- no-name
- e-max
- anything with poor typography

Fake Servos exist.

Amazon!

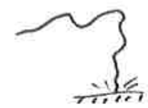
You can pay the same for a crummy servo.
(e.g. SPA story)

Deadband / hysteresis

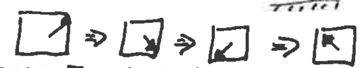
Unusable for aircraft

poor frequency response

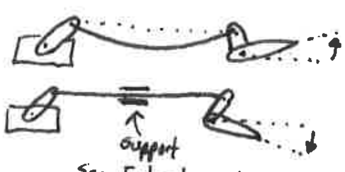
Flight Control System (FCS) mistakes leading to flight path deviations



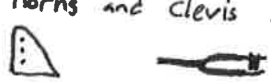
- Reversed Controls ⇒ preflight, "box" controls



- Weak or dead battery ⇒ preflight check + timer
  size the battery for current draw
- Broken antenna or poor reception ⇒ range check, dipole orientation
- Interfering controls (e.g. rudder w̄ up elevator) ⇒ "box" controls + preflight
- Stripped Gears after hard landing ⇒ inspect and test each component after hard landings
- High g hinge moments (esp. elevator on tilt) ⇒ proper sizing of servo
  (in a dive, less up elevator allows g to increase even more)
- Control surface flutter (saturates servo .... loss control) ⇒ stress/deflection of surfaces especially torsion.
- Frequency Interference (esp. older 72 MHz radios) ⇒ test on ground + preflight
- Wrong mode (e.g. mismatch between brain + aircraft) ⇒ human factors + checklist
- Foreign Object interference with T_x, R_x, or FCS ⇒ Clean FCS area, clean pilot, remove extra junk + test
  (e.g. neck strap jamming rudder) true case
  (e.g. linkage at g loading w̄ vibration w̄ other control) Fake!
- poor quality servos or wrong type of servos ⇒ buy quality and do the analysis
- Bending linkages ⇒ proper support, pull-pull system, horn mounting with back plate

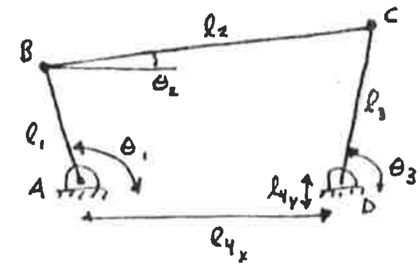


- Wrong or poorly tuned feedback control gains ⇒ gnd demo, check for sign error, analysis
- loose or broken horns and clevis or missing screws ⇒ preflight + airworthiness check (3rd party ?)



- PIO (pilot induced oscillations), control power issues ⇒ Analysis w̄ #s, $\eta = \frac{g}{g_\infty}$
- Aft CG, not enough dihedral, S+C issues ⇒ Analysis w̄ #s, Design reviews, listen to others
  (e.g. Falcon, S.Pete) See within seconds!

General 4 bar



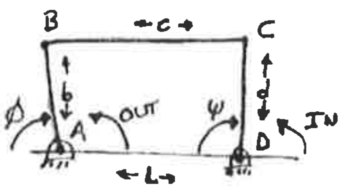
Assume system is connected

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

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

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

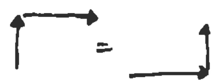
Freudenstein Equation (notice the angle convention!)



Consider the term AB as the vector from A to B

AB = ↑ CD = ↓ DC = ↑

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

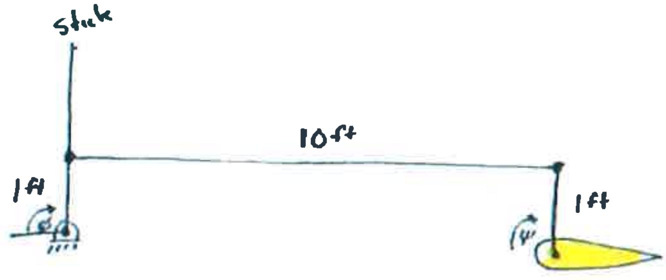
$$R_1 \cos\phi - R_2 \cos\psi + R_3 = \cos(\phi - \psi)$$

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

4 ~~3~~ unknowns

4 ~~3~~ equations → You need to specify ~~3~~ 4 positions.

Example



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

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

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

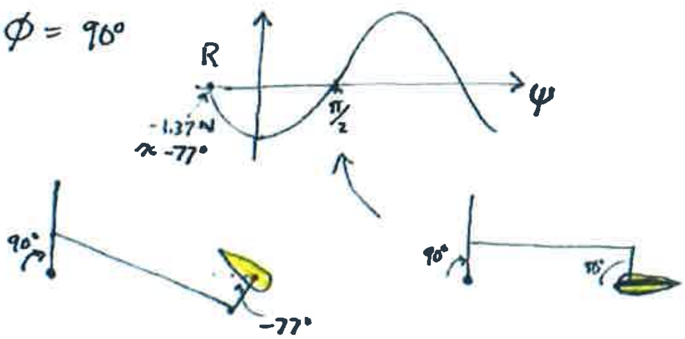
$R_3 = \frac{100 + 1 - 100 + 1}{2} = 1$

Freudenstein

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

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

when $\phi = 90°$



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

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

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

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

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

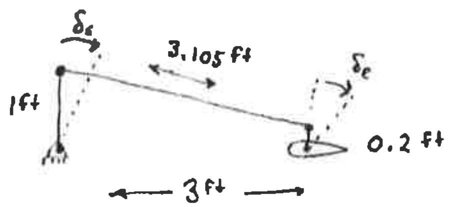
$$\frac{d\psi}{d\phi} = \frac{-\sin(\phi-\psi) + R_1\sin\phi}{R_2\sin\psi - \sin(\phi-\psi)}$$

For the above,

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

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

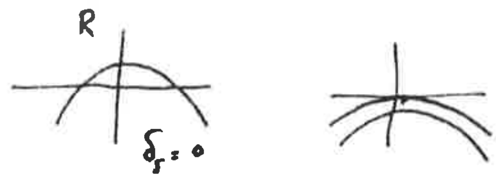
Example (shorter pushrod)



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

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

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 $\delta_s = 15°$? $\quad G \approx 216$

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

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