Aircraft Design

SN-1

(fixed pitch prop)

<u>Objective:</u> RC aircraft with commercial components and <100 Wh <55 lb MGTOW with <u>maximized range</u>

Electric aircraft level flight range eqn:
(Raymer 790)

$$R = 3.6 \frac{L}{D} \frac{E_{sb} \eta_{b2s} \eta_p}{g} \frac{m_b}{m}$$

batt. specific energy Wh/kg
eff from battery to motor shaft
propeller eff.
battery mass (kg)
total mass

maximize $\frac{L}{D}$ ← aero config
maximize η_{b2s}, η_p ← propulsion config
maximize $\frac{m_b}{m}$ (generally have less structural weight)

Immediately appealing to do hand launch to eliminate landing gear weight / drag
↑ or other launch pts

canard / flying wing better for L/D (but stability complications)

target range: [redacted] $E_{sb} \cdot m_b = E$ (Wh) = 100 Wh
(best case)

$\eta_{b2s} \approx 93\%$ (no gearbox) using APC props
$\eta_p \approx 85\%$ (best from ~~APC data~~)
$\frac{L}{D} = 20$ (by far best case)
$m = 5$ lb (ambitiously low) $= 2.27$ kg

$$R = 3.6 \cdot 20 \cdot \frac{100\,Wh \cdot .93 \cdot .85}{9.81\,\frac{m}{s^2}} \cdot \frac{1}{2.27\,kg}$$

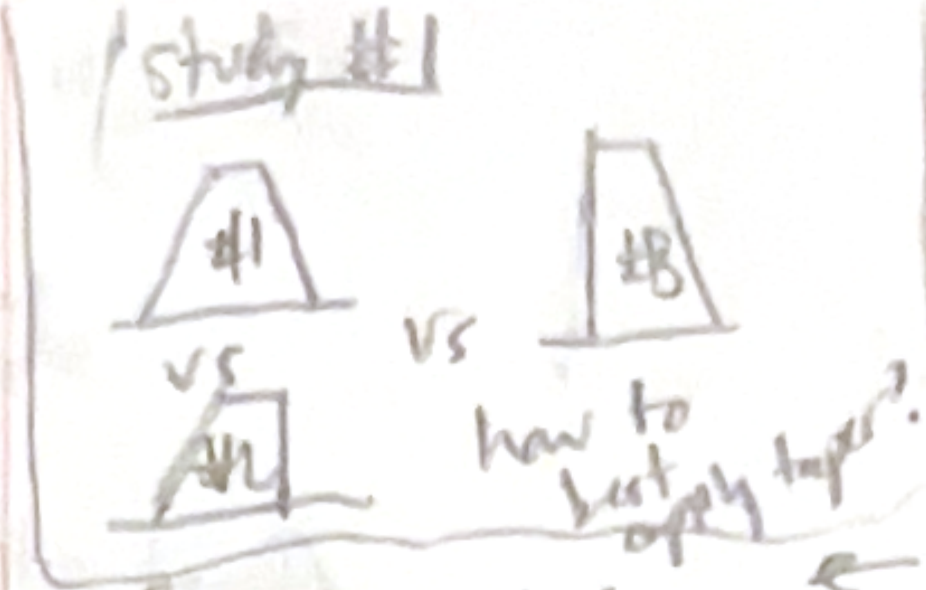
$= 256$ km (wayy too high)

try $\frac{L}{D} = 15$

$R = 192$ km (better)

(Sens analysis code in SN_1 EW shows m, $\frac{L}{D}$ to be the most important vars by far

SN-1



$\lambda \simeq 0.4$
no sweep
use #3 to push weight forward for CG
(doesn't it also push x_{ac} forward tho?)

SN-1FW
(flying wing version)

or

endplate but that complicates mechanism

Sketch #1:

how to apply directional stability?

add little winglets with control rudder on

or use split ailerons

note: sweep improves lateral stability

airfoil reqs: high $\frac{L}{D}$, low/near zero C_m

assume Re $\simeq$ 500k – 5 mill

$V \sim 80-200$ fps $\cong 25 \rightarrow 60 \frac{m}{s}$

with $1.2 \frac{kg}{m^3}$ atm. density

accept –5% s.m. (gyro flight system) & relaxed static stability

corrections will add drag, check off vs conventional

Raymer pg 744 → discussion of my program

initial planform sizing w/ raymer methods:

first of all: maximize AR

coupling between $\frac{L}{D}$, AR, plane weight

use $\frac{T}{W}$ vs $\frac{W}{S}$ plots for cruise, climb, turn reqs ← here!

$\frac{T}{W} = \frac{\eta_p}{V} \frac{P}{W}$ assume $\eta_p = 0.8$

$V \in (25, 60) \frac{m}{s}$

$\frac{W}{S} = q\sqrt{\pi AR e C_{D_0}}$ for max prop range

sustained turn: $\frac{W}{S} = \frac{T/W \pm \sqrt{(T/W)^2 - (4n^2 C_{D_0}/\pi AR e)}}{2n^2 / q\pi AR e}$

regardless of w/s: $\frac{T}{W} \geq 2n\sqrt{\frac{C_{D_0}}{\pi AR e}}$

Note: learn abt Boeing's Latin Squares

Cruise: $\frac{T}{W} = \frac{1}{(L/D)_{cruise}} = q\, C_{D_{min}} \frac{1}{w/s} + K \frac{1}{q} \frac{W}{S}$

SN-1FW

raymer 144

Sustained turn:
$$\frac{T}{W} = \frac{q C_{D_0}}{W/S} + \frac{W}{S}\frac{(n)^2}{q \pi AR e}$$

$$\left(\text{and: } \frac{T}{W} \geq 2n\sqrt{\frac{C_{D_0}}{\pi AR e}}\right)$$

$$k = \frac{1}{\pi AR e}$$

Cruise:
$$\frac{T}{W} = q C_{D_0}\frac{1}{W/S} + k\frac{1}{q}\frac{W}{S}$$

Rate of Climb:
$$\frac{T}{W} = \frac{\overset{\text{set as req}}{V_v}}{V} + \frac{q}{W/S}C_{D_0} + k\frac{1}{q}\frac{W}{S}$$

* incorporate into rest design for produce

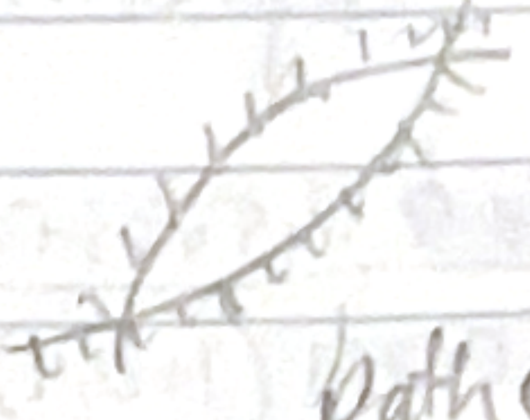
not relevant for

~~Takeoff~~ :

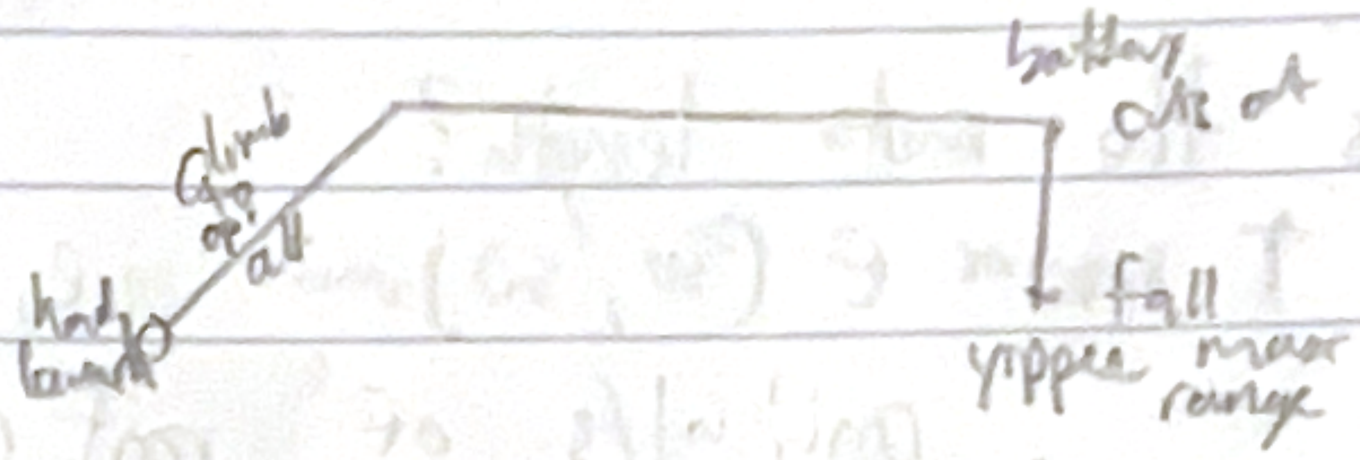
need reqs for n and V_v

V_v unfortunately might be coupled to range b/c it can set time to altitude of max range

putting these into SN-1FW for initial analysis

Sidetrack: how to plot  to best indicate design spaces? patheffect w/ ticked stroke!! (matplotlib)

Mission profile:



unit analysis: $\frac{W}{S} \to \frac{kg}{m^2}$ in raymer $\frac{W}{S}$ in $\frac{lbf}{ft^2}$ (???)

$q = \frac{kg}{m^3}\cdot\frac{m^2}{s^2} = \frac{kg}{m\cdot s^2} = N\cdot m$

$\frac{\frac{kg}{m\cdot s^2}}{\frac{kg}{m^2}} = \frac{m}{s^2} = \frac{N}{kg}$ ✓ W = mass not W weight! oops!

not possible to hand launch

initial analysis showed V-2 levels of wing loading, need to make reqs based on hand launch (HL)

studies: - hand launch or not? Rubber band/truck launch?

- FW vs conventional vs canard

req stall speed ≤ 9 m/s based on human throwing a 10 lb object (bag limit, see plot)

AR = 8

CLmax ≈ 1.1 (guess for now)

e = 0.8

CD0 = 0.02

$$\left\}\ 3.72\frac{W}{kg},\ 54.8\frac{kg}{m^2}\right.$$

for $\boxed{25\frac{m}{s}\text{ cruise speed}}$ ← huge assumption on req power

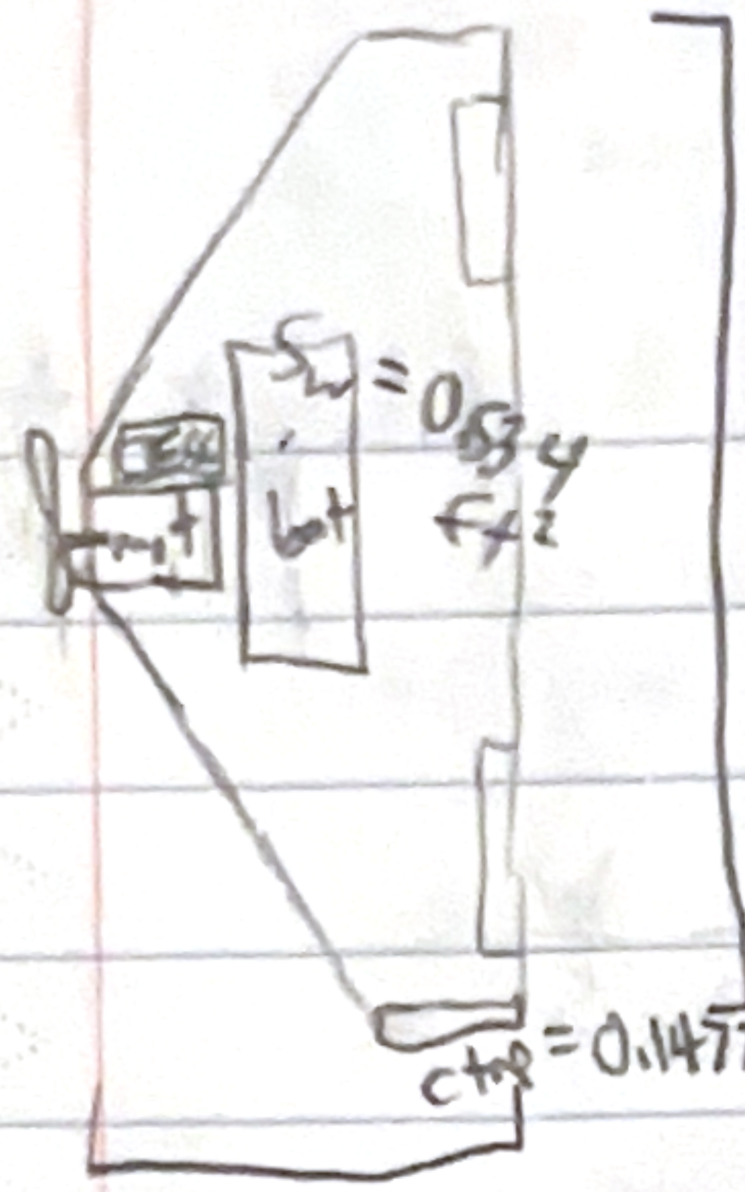
$54.8\ \frac{kg}{m^2}$ wing loading, est 6 lb weight = 2.72 kg

$\hookrightarrow S_w = 0.04964\ m^2$
$= 0.53\ ft^2$

bullshit estimation from DBF

SN-1
FWHL

$\lambda = 0.4$



With $AR = 8$, $b = \sqrt{AR \cdot S_w}$
$= \sqrt{8 \cdot 0.5343\ ft^2} = 2.067 ft$

2.067 ft

$C_{root} = 0.3693 ft$

$\left(3.765\ \frac{W}{kg}\right)$ $54.7965\ \frac{kg}{m^2}$

$\hookrightarrow$ with 2.72 kg,
$W_{req} = 10.24\ W$

(<100Wh)

$P = IV$, lower V means higher capacity

V_{nom} for 1 lipo

$E = 3.6 \cdot C \leq 100 Wh$

$C_{root} = \frac{2 \cdot S}{b(1+\lambda)}$

$C \leq \frac{100 Wh}{3.6V} = 27.78\ Ah = 27777\ mAh$ ← for 1S

vs $C \leq \frac{100\ Wh}{6 \cdot 3.6V} = 4630\ mAh$ ← for 6S

$C_{tip} = \lambda \cdot C_{root}$
(raymer 76)

mostly impactful for η_{b2s}, so worry abt it later

$C_{root} = \frac{2 \cdot \cancel{0.5343} \; 0.5343\ ft^2}{2.067 ft\ (1+0.4)} = 0.3693\ ft$

$C_{tip} = 0.1477\ ft$

uh oh, what's the motor length?

random T-motor ∈ (30, 50) mm i.e. 0.09843 ft, 0.164 ft

only ~1/3 of root chord so we should be ok

I might be able to lower power req further by relaxing speed reqs!

tmrw do airfoil selection, Cm analysis, and revise weights