Aircraft Efficiency

<u>Why build a homebuilt aircraft?</u>

A) economy (so we can afford to fly)
B) increased performance
C) both
D) there may be more we can do

<u>General Aviation Aircraft. Just look at A/C on the ramp</u>

A) Flying cacti
  1) Bumps
    nav lights
    gas caps - act as spoilers
    things in high pressure areas - i.e. bottom of wing
      hinges (more about this later)
      Tie down rings
  2) Protrusions
    outside on airframe - antennas
    inside the cowl
    components with cylindrical cross section = increased drag coefficient.
      ~ 5X's the drag coeff. of a turbulent airfoil
      ~ 50X's the drag coeff. of a laminar airfoil
    what can you do?
      1) eliminate - put them inside the wing tips
        (Whip antenna @ 300 mph takes 3+ hp)
      2) fairings - reduce drag up to 90%
      3) sweep angle - 60 degrees reduces drag up to 85%

B) How much faster will you go? What is the biggest improvement?
  1) The same change will produce different results on different planes. The change depends on:
      a) The percentage of the total A/C drag.
        (Putting retractable gear on a tumbleweed wouldn't decrease it's total drag much.)
      b) speed of the plane to begin with.
        i.e fairing a rotary beacon

100 Kts	=	.1 Kt
150	=	.6
200	=	2.0
250	=	5.5

Different shapes with   Relative drag

same cross sectional area at the same velocity		in lbs
	Flat plate	1.0
	Cylinder	.95
	Half sphere forward	.35
	Half sphere backward	1.5
	Rounded cylinder	.25
	Streamlined body	.04
	Streamlined body with pressure recovery	.035
	Wire	.9

<u>Where to start?</u>

A) walk around your plane and make a list of things to improve
B) remove the cowl and take a close look.

<u>Cooling Drag</u>

A) NACA (National Advisory Committee for Aeronautics)
30 to 46% of total aircraft drag. ~ 5% is possible in a well designed system.
B) Formula 1 ~ 0%
C) Excrescence drag - drag from gaps, holes, seams and exits
D) Poor baffling can produce > 50% of the excessive cooling drag.
All garlock seals leak.

Propeller - Inlet - Cowl relationship

1) propeller thrust distribution for inlet location.
2) boundary layer thickness at back edge of spinner and shank of the propeller.
3) differential pressure across inlet.
4) reverse flow on standard inlets.
5) prop extension to decrease flat plate area.

Inlet (stagnation inlet)

1) shape - round = smallest surface area/volume

easiest to provide best seal to plenum.

2) size - calculated from mass flow required for BTU from engine chart.

Mass flow = area X velocity X plenum efficiency

Oversized inlets ➔ velocity resulting in ➔ pressure thus ➔ cowl drag around the inlets.

3) round lip edge to decrease inlet stall and reduce inlet drag

Plenum design

1) uses Bernoulli's Law:
   volume = ➔ velocity = ➔ pressure
2) Greater ✦p across the cylinders carries off more BTU.
3) diffuser can diverge 5☜/side ± (air flow remains attached due to ➔ Velocity and ➔ pressure)
4) A = area of inlet (calculated by mass flow requirement)
   A = area at the rear of the effect diffuser
   A = area over the cylinder and head, A area = A area
5) slowing the free stream velocity 10 - 40% ➔ Cooling drag losses.
6) there should be no sharp bends or edges to minimize flow separation.

Outlet - starts under the cylinders

1) area as small as possible to re-accelerate the air to free stream condition to ➔ drag.
2) Convergence zone leads to exit fuselage/firewall airfoil rounded gentle curved sides should be ~ 35 deg.
3) shape - NACA studies
   - straight sided rectangular shallow angle converging ramp
   - ramp as parallel to free stream flow as possible at end
   - width to depth ratio of ramp
     a) 7 to 1 for cooling systems
     b) 1 to 1 for exhausts (augmenter)

4) inlet to outlet ratio: what's recommended, what works & why.
   a) stock Van's: RV4 ratio ~ 39sq" X 60sq" = 150%
      RV6 ratio ~ 44sq" X 56sq" = 127%

Designed for full throttle climbs at 90-100 mph
Results = increased drag at higher speeds

b) what works better:

Inlet 34sq" (decreased To 30sq" no change)
Outlet 26sq" (excludes exhaust area)
Ratio 76%, could be smaller w/same ratio, CHT's 350☜ max.

c) Exhaust augmentation increases outlet velocity at higher power settings, reducing lower plenum/cowl pressure which increases ✦p across cylinders. This aids in cooling at lower climb speeds.

<u>Aerodynamics 101</u>

Not much to know

1) drag is bad
2) efficiency is good
3) more hp is better

Formulas:

hp X prop efficiency = thrust hp

1) thrust hp $= \dfrac{\text{Flat plate area (sqft) X speed (mph)}}{146225}$

Flat plate area $= \dfrac{\text{Thrust hp X 146225}}{\text{Speed}}$

Speed $= \dfrac{\text{Thrust hp X 146225}}{\text{Flat plate area}}$

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2) Propellor efficiency ask the manufacturer

Hartzell: stock 76-66-6 ☝ 78% ±
blended airfoil ☝ 80.5% ±

3) horsepower:

(gals leaned to max pwr, 100☜-120☜ rop)

HP $= \dfrac{\text{fuel flow X 5.9lbs/gal}}{\text{bsfc}}$

Brake specific fuel consumption (bsfc)

360 stock motor 8.5:1 comp	.50
360 10.5:1 comp, flowed, w/everything	.44
200 10.5:1 comp, w/everything	.40

4) horsepower increases for 360 due to :
   a) rpm; 100 rpm = ~ 1.8 - 2.0 hp/cylinder
   b) manifold pressure; 1" =~ 2.1 - 2.2 hp/cylinder

5) calculating drag (in lbs)
   Dynamic Pressure X drag coeff X area of object = actual drag
   a) dynamic press in lb/sqft:
   = pv

   = air density .00238
   (sea level std day)
   V = true airspeed in ft/sec
   (1 mph = 1.467 ft/sec)

   b) drag coeff: is a number of the force of the wind as compared to what you would expect. i.e a flat plate = 1.3 due to edge & wake turbulence.

$$\frac{\text{dynamic press X sqft of the object X drag coeff X tas in fps}}{\text{550 ft-lbs-sec /hp X prop eff}}$$

Produces HP required/object

Example: unfaired aileron hinge brackets @ 220 Kts
   In high pressure side wing, using drag coeff of 1.35 (probably low) requires ~ 2.4 Hp for all brackets.

   Faired w/streamlined bodies using .045 drag coeff requires less than .1 hp, ® faired = 2.3 hp increase = 1+ mph
   Canoe fairing

RV-4 Performance Increase with each Modification

1992 approx 220 mph stock IO360
1) cold induction plenum

2) "Y" stack exhaust

Hp	195
Prop efficiency	.78
Speed	220
Flat plate area	2.0

1993 Sun 100 race 230 mph

3) electronic ignition
4) lower firewall clean-up and fairing
5) increased rpm to optimum helical tip speed (2925 rpm)
6) dynamic balance (.004 ips or better)

Note: ~ 2 hp / cylinder / 100 rpm
results in +16 hp
hp increased 8 mph
drag reduction increased 2 mph

Hp	211
Prop efficiency	.78
speed	230
flat plate area	1.95

1994 Sun 100 race 235 mph

7) Racing tail wheel (no steering)
8) gap seal
9) lamb tire
10) 2 piece wheel pants

(4 single exhaust - no effect)

Note: 5.0% ➡ Flat plate area
Increased ~ 5 mph ☝ to 10 hp
Drag reduction increased 5 mph

HP	211
prop efficiency	.78
speed	235
Flat plate area	1.85

1995 Kilo Lima Trials 248 mph

11) B&C alternator
12) Engine (compression 10:1 & flow cylinders)
Prop (~ 80.5%, thinned & changed twist) ~80.5% per Hartzell
Fuel injection servo modifications
13) Plenum
14) Cowling inlet rings
15) 4 into 1 exhaust (HPC coated)
16) Augmentor outlet (jet effect)
(Should be shorter exhaust collector)
17) Cooling tunnel fuselage modifaction
18) Improved firewall fairings
(Added convergence fairings - ♐ ♑ 35 is best)
19) new gear leg fairings (laminar airfoil w/pressure recovery)

Hp increased 7 mph		HP	225
Drag reduction increased 6 mph		prop efficiency	80.5
		Speed	248
		Flat plate area	1.74

1997 March 254 mph (preparation for Café Triaviathon)

20) Inlet ring and cowling modification
  to increase servo intake ram air

21) aileron cuff position (re-rigged)

22) aileron hinge bracket canoe fairings

23) Eng mod (increased compression, ceramic tops ~ 11:1 and friction coated skirts. Friction coated oil gears and advanced cam gear timing)

24) wing tips (higher aspect ratio, lower drag)

hp increased 3.5 mph	Hp	235
drag reduction increased 2.5 mph	prop efficiency	80.5
	Speed	254
	Flat plate area	1.68

1997 Sept 27 Triaviathon Record

250.7 mph TAS @ 6000' max. speed
44.7 mph min. speed
3308.2 fpm average rate of climb

New Score 2380 (breaking old record by 81%)

Note: it was very calm & cold, flat plate area now 1.45 - 1.5
⑧ top speed at sun 100 race should be approx 264 mph

Only the triaviathon record was calculated to standard day. All other race data was race day conditions (poorer than standard day) resulting in sub-optimum performance.

2000 Sun 100 race 261 mph (standing start)

25) Thermal barriers under the cowl. (No idea if it did anything)

26) New canopy and fastback modification

27) painted the plane

Note: I thought I should have been faster	hp	235
	prop efficiency	80.5
	Speed	261
Hp increased 1 mph	Flat plate area	1.5
drag reduction increased 6 mph		

Current best speed under perfect conditions 265+ mph
Conclusions:

Over the years,

The increase in hp 195 hp to 235 hp (40 hp total)
Increased Prop efficiency 78% to 80.5%

So:

$$\frac{\underline{235 \text{ X } 80.5 \text{ X } 146225}}{2} = 239.5 \text{ mph}$$

Means: (220 mph to 264 mph = 44 mph overall gain)

19.5 mph increase since 1992 was due to the hp & prop

24.5 mph was due to drag reduction which represents a **27% reduction in Total Airframe Drag**

(20% faster = 42% reduction in drag if constant pwr.
⑧ remaining 15% reduction= a 23% increase in hp & 2.5% in prop eff.)

If you add each gain from hp from each race it = 19.5 mph

Drag reduction is better, lower cost, lower maintenance and you get free speed or increased mileage.

Fuel savings from:

1) drag reduction
2) electronic ignition: 1 - 10% from sea level to 12,000'
3) high compression: >>>

Mileage gain ☜ 2X's hp

Torque increase	%
8:1 to 9:1	2
9:1 to 10:1	1.7
10:1 to 11:1	1.5
11:1 to 12:1	1.3
12:1 to 13:1	1.1

Mods produced

1) increased speed
2) increased economy

My speed increased 44 mph or 20% faster than stock. However, economy cruise at 14,000' @ 190 mph ground speed requires 4.5 gph resulting in ~ 42 mpg, or ~ 900 mile range w/reserve.

Flying with other RV's w/o any of the mods uses ~ 22% less fuel per stop especially when were high and lean.

If lower than 65% power you can run Lean Of Peak.

1850 hrs X 8 gals/hr =~ 14,800 gals burned
X $3.75 /gal
$ 55,500
X 20%
$ 11,100 savings

27% of increased performance from drag reduction

27% ÷ 42% (if constant pwr) = 64% X $11,100 = $ 7,100 from drag reduction alone

Approx 135 gals free/yr for 14 years