1.0 Intro

This analysis came about from Alex Cruz posting details of his Saturno V3 model in

http://www.hippocketaeronautics.com/hpa_forum/index.php/topic,861.120.html early jul09.

He reports better performance with the Peck prop than the Igra/Ikara prop; 150s vs 135s.

Some gurus expressed surprise that a lowly Peck could outperform the Igra but no one seemed to be willing to do the work to confirm or disprove Alex's careful experiments.

Of course, the real answer is that the prop must match the model and the rubber motor.

It is likely that these matters have been covered before in issues 15 & 16 of Free Flight Quaterly, especially an article by Paul Rossiter, "P30 Propeller Analysis"

http://www.freeflightquarterly.com/ffqprevious.html

As a beach bum in Cooktown, Far North Queensland, I can't afford these august tomes so I beg yus gurus' indulgence for my pontificating. If anyone has more accurate info, especially planform and pitch distribution of Peck, Igra & Gizmo props, please email ricardo@justnet.com.au so I can improve this simulation.

I don't attempt to predict Alex's performance. This would require fitting some sort of equation to Pressnell's data and doing integration … difficult cos eye neber wen 2 skul en kunt reed en rite.

Rather I shew what is happening *in theory* at various parts of the flight profile and motor run.

2.0 P30

Weight	*0.05*
S area	*0.0745*
b span	*0.76*
k	*1.082*
Cdp	*0.01*
A Ratio	*7.75*

Fig 2.0

Saturno V3 is also described here.

http://www.hippocketaeronautics.com/hpa_forum/index.php/topic,2068.0.html

k is the correction for induced drag of the rectangular wing planform of Aspect Ratio 7.75
I assume parasitic drag coeff Cdp=0.01; perhaps is a bit optimistic for a slab sided fuselage.

I assume the Eppler designed Gottingen G804 [1] cos its the only thing I have wind tunnel data for at Re 20k - 25k. If I get some time, I'll run Xfoil[3] on Alex's foil but G804 is not too different. We need Re between 20k & 25k

						Aerofoil	G804	
P30			Tail			Re	25k	6.8
V m/s	L/D	Sink	Wash	CD	CDi		cd	cl
2.99	7.2341	0.4096	5.4	0.1659	0.0639	20075	0.092	1.2
3.12	**8.2907**	**0.3741**	**5.0**	**0.1327**	**0.0537**	**20967**	**0.069**	**1.1**
3.28	7.7602	0.4188	4.5	0.1289	0.0444	21991	0.075	1
3.45	7.2038	0.4749	4.1	0.1249	0.0359	23180	0.079	0.9
3.66	5.8228	0.6201	3.6	0.1374	0.0284	24586	0.099	0.8
4.23	5.8554	0.7122	2.7	0.1025	0.016	28390	0.077	0.6
5.18	5.2564	0.9683	1.8	0.0761	0.0071	34770	0.059	0.4

Fig 2.1

I assume trim at **cl=1.1** where we have best L/D and sink rate. Alex believes he is operating at about 0.95 – 1.0
Reynolds Number is **Re=20967** so the simulation will be optimistic cos the airfoil data is at 25000.

It is possible to check what the real cl is by measuring **glide speed**. If it is **3.12m/s**, the working cl is 1.1

If so *and* the **sink rate** is 0.3741m/s, this confirms our drag coefficient **cd=0.069**

Our thin undercambered sections at low Re often have such a narrow low drag bucket that best L/D and sink rate are effectively at the same trim or cl. This holds for everything I have wind tunnel data for at Re = 40k and below and also my pseudo attempts with Xfoil.[3]

3.0 Climbing prop driven fixed trim aircraft

If you apply more power while one of these is flying straight & level, it will start to climb. When it settles down to the climb, the airspeed will have dropped. This is cos part of the aircraft's weight is now supported by the prop so the wing doesn't need to generate as much lift.[1] A fixed trim aircraft can do this, only by reducing forward speed. At the extreme, when the climb is vertical and the prop is supporting the whole weight, the fixed trim wing must generate *no* lift; ie velocity = 0 and the aircraft is hovering without any gain in height.

It follows that there is a climb angle when a fixed trim aircraft climbs fastest and this happens at about 55°. Martin Simons deals with all this very clearly in "Model Aircraft Aerodynamics".[1]

Climb	**xGlide**	**Velocity**	Weight	Drag	**Thrust**
0	1.0000	*3.124*	0.000	0.05	0.046
5	0.9981	3.118	0.043	0.05	0.088
10	0.9924	3.101	0.085	0.04	0.130
15	0.9828	3.071	0.127	0.04	0.171
25	0.9520	2.974	0.207	0.04	0.248
35	0.9051	2.828	0.281	0.04	0.318
45	0.8409	2.627	0.346	0.03	0.379
55	0.7573	2.366	0.401	0.03	0.428

Fig 3.0 shews[2] propeller needs to provide a **thrust of 0.046N at 3.124m/s** for straight & level to **0.428N at 2.366m/s** for a climb at 55°.

For our tiny planes, props are more efficient at higher flight speeds cos there is more air going through the prop disc. More efficiency means less torque or rpm for the same thrust so the aircraft can maintain a climb attitude for a longer part of the motor run. High climb angles are inefficient cos not only is the flight speed less, but the greater thrust required leads to greater prop loading.

3.1 Same height, same model, different props & motors

A climb at less than 55° climb angle can match the height achieved by one at a steeper angle than 55° though they would need very different props & motors.

3.2 Same height and climb, different models & speed

Energy in rubber is converted to height energy, minus the energy lost along the way, drag x distance.

If two models of the same weight reach the same height with the same climb profile (ie the same distance travelled) but one gets there twice as fast as the other, the faster one will have used up much more energy cos greater drag.

The two models will have to be very different to do this. eg the slower prop will need more blade area and the model needs to be more efficient to climb on less power.

In each case, the slower model has a distinct advantage provided it is efficient enough to climb all the way to the end of its motor run.

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[1] Light aircraft pilots will confirm this.

[2] *Olde Englishe* used to make me appear as authoritative as Hepcat; ex-deHavilland Propellers and a true guru.

4.0 P30 props

There are only 2.5 props in use for P30; the Peck and the IGRA/Ikara. The half is the Gizmo Geezer which is a better quality and more consistent Peck.

http://www.gizmogeezer.com/props.htm

I only have the following information on the props via Hepcat. Both **9.4" diameter**. Pitch angle at **0.75 radius**

Pitch at 0.75 radius	Hepcat	Paul Rossiter	Gizmo 1.25 P/D
Peck	24°	(31+27)/2 = 29°	27.9° ?
Igra	**21°**	**21.5°**	

There are unsubstantiated rumours that the Peck has less pitch but the only measured info supports the above two gurus. Gizmo increase the pitch of the Peck as they make it more consistent.

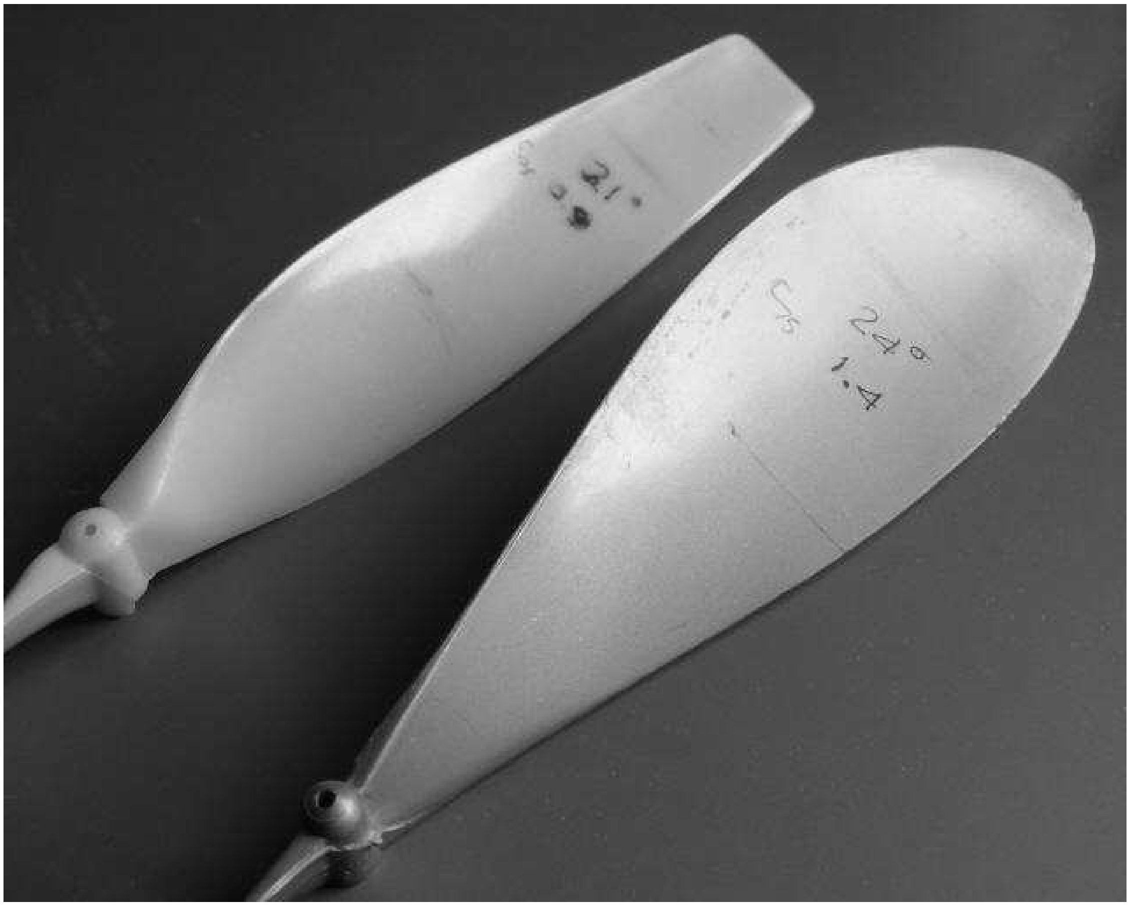

Fig 4.0 From this pic provided by Hepcat, I think the Igra has a **maximum chord** of **34mm** at about **0.43 radius** and is likely a MIL design.

I don't have any more info on the Peck so I'll stick with what I *think* is the Igra for this analysis.

A MIL prop designed for **0.1709N** thrust at **3.071m/s** and **21revs/s (rps)** will have the above parameters. This is for a climb at 15°. It's efficiency, **η=0.6793** and the torque at that operating point is **0.6gm m**

Climb	**Velocity**	**Thrust**	η	rps	gm m
0	3.124	0.046	0.5838	15.7	0.25
5	3.118	0.088	0.6901	17.7	0.37
10	3.101	0.130	0.6967	19.4	0.48
15	**3.071**	**0.171**	0.6793	21	0.60
25	2.974	0.248	0.6125	23.8	0.82
35	2.828	0.318	0.4033	29	1.25
45	2.627	0.379	0.1963	36.8	2.24
55	2.366	0.428		stalled	

Fig 4.1 shews the efficiency and torque required for this prop at other climb angles. **What does this tell us?**

- If the motor torque is less than 0.25gm m, thrust will be insufficient to sustain level flight and the plane will be sinking albeit slower than if just gliding.
- If the torque is greater than about 1.4gm m, the efficiency of the prop will have nearly halved. The plane will climb with high torque & rev/s but not as efficiently as at lower climb angles. Note the huge increases in torque and rps for a 53% increase in thrust when going from 25° to 45° climb. Large parts of the prop are stalled. In fact the prop reaches clmax for a climb of 35° . Thrust at higher climb angles is simply by brute force.

4.1 MIL prop design & analysis programme

makes the following assumptions.

- The blade section is Gottingen 417a, a thin plate curved section. Hepcat's photo shews the Peck is undercambered but I dunno about the Igra.
- Because the Reynolds Numbers in the prop are so small and vary so much, I've had to implement an approximation to the drag with Re to extrapolate the values I need. I've only data at 42000. I assume it's inversely proportional to rt(Re) which ties in with Hoerner[2] Re ranges from 6k7 – 16k at the design point to 6k1 – 12k4 for straight & level and 6k3 – 21k at 35° climb.
- I fudge cl & cd above the stall (as do most MIL prop programmes).

The prop assumed differs from the Igra as follows

	Assumed Prop	IGRA
• Blade tip	rounded	square but I haven't got one to measure.
• Max chord	32mm at 0.33	34mm at 0.43 radius
• Angle at 0.75	21.7°	21 – 21.5°
• Nominal D x P	9.4 x 9.3"	
• Blade foil	G417a	?

5.0 Rubber

Martyn Pressnell did these measurements for Aeromodeller mar03

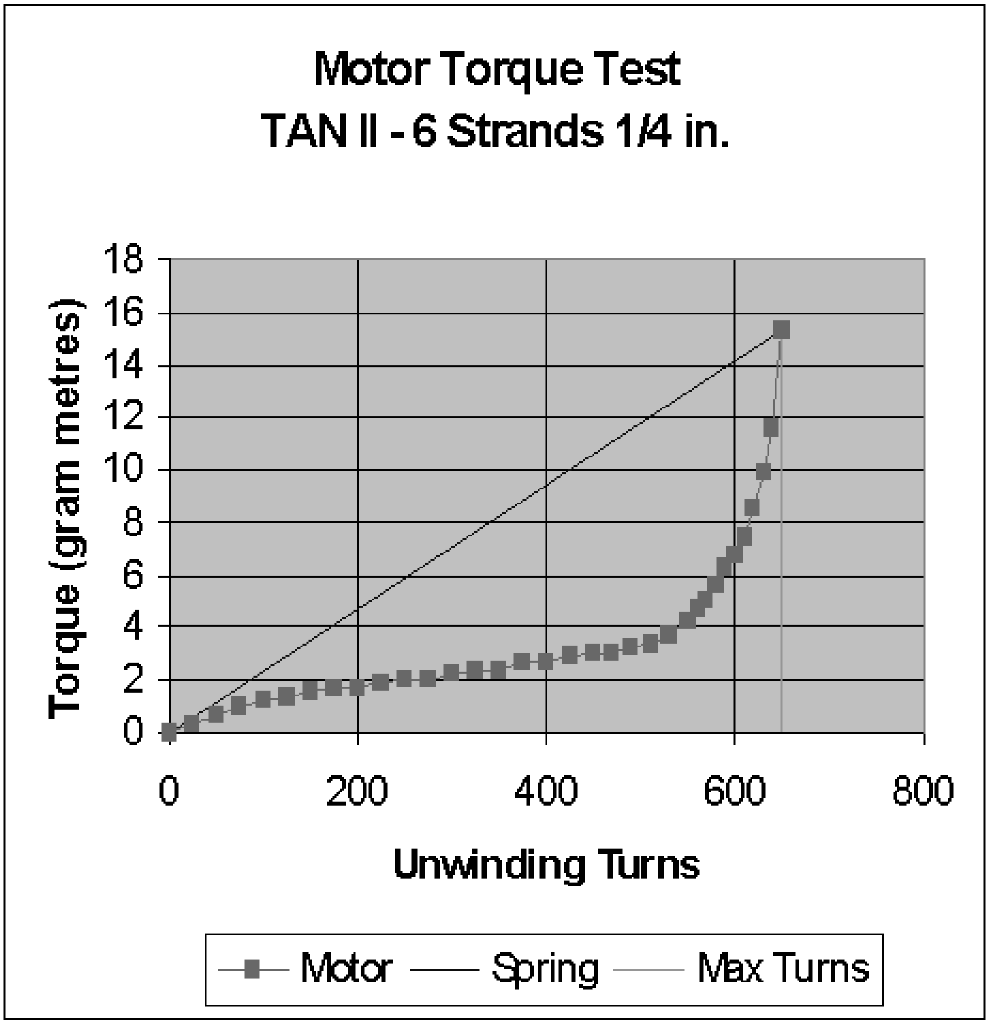

Fig 5.0

and reprints the article on his website http://www.martyn.pressnell.btinternet.co.uk/maxturn.htm

It illustrates the benefit of using a torque meter to wind rubber rather than counting turns. What we see is

- a fairly quick rise to 1gm m at about 60 turns
- a long even section where the torque gradually increases from 1 to 4gm m. This is the major part of the energy stored in the rubber as it takes us up to about 540 turns. It is delivered over a **4x torque** range and is the longest part of the motor run. The rubber is "**linear**" in this region and is very unlikely to break strands.
- Above the 4gm m **knee**, the rubber starts to harden and the torque rises very quickly. In flight, this is the initial burst of power.
- "Maximum" turns can be taken to be any point after the knee. Pressnell's 15.3gm m at 650 turns is for one wind to this without broken strands and at least one more without total failure. He expects broken strands if you take it to this limit on a second wind and perhaps total failure on subsequent winds.

Different motors, or even the same motor after running in or a full wind competition flight will exhibit the same general torque profile but the turns and torque will be different.

If you are counting turns, this will not get you to a consistent amount of energy storage in your motor.

If instead, you decide on **how far beyond the torque "knee"** you are prepared to go, this will lead to a consistent amount of energy storage as well as a consistent distance from broken strands or total failure.

One might decide to always **wind to twice the knee torque**; ie 8gm m on Pressnell's example. Using a torque meter while winding tells you when the knee has been reached cos the torque starts rising quickly.

There is a lot of energy stored in the "initial burst" but it is very difficult to use. Even a conservative "twice the knee torque" policy means the motor will deliver power over a torque range of 8x. Operating above the knee risks broken strands.

5.1 Matching rubber & prop

What we want to do is to match the good, long "**linear**" part of the power delivery to the flight regime where the model & prop are operating efficiently.

We also want the model to climb all the way to the end of the power run. ie we want torque to be greater than the 0.25gm m for level flight shewn in Fig 4.1 If we do this, a slower climb can attain the same heights as an impressive rocket-like but inefficient climb.

Pressnell tells us that torque is proportional to the X-section^1.5 so we try four different motors.

Presnell curves	20gm mediocre Tan II								X-section	
gm m	1	2	3	4	6	8	10	12	0.0625	6*1/4*1/24
turns	60	200	450	540	580	620	630	640		
	Linear									
gm m	0.35	0.71	1.06	1.41	2.12	2.83	3.54	4.24	0.0313	6*1/8*1/24
gm m	0.25	0.51	0.76	1.01	1.52	2.02	2.53	3.04	0.025	6*1/8*1/30
gm m	0.23	0.46	0.69	0.92	1.38	1.84	2.30	2.76	0.0234	6*3/32*1/24
gm m	0.19	0.38	0.58	0.77	1.15	1.54	1.92	2.31	0.0208	4*1/8*1/24

Fig 5.1 shews us that 6 strands of 1/8 x 1/24 is pretty good. It still be climbing at more than 5° at the end of the motor run. However, when the motor enters its **"linear"** section at a torque of 1.41gm m, the efficiency is low and the initial burst would have been even more inefficient.

4 strands of 1/8 x 1/24 however, has a torque of 0.19gm m at the end of the **"linear"** section so the model will be descending at the end of the run. The Peck prop, with greater pitch and more area will start descending even earlier.

Don DeLoach likes 6 strands of 3/32 x 1/24 and this gives good results with the simulated Igra. It climbs all the way to the end. With 0.92gm m at the start of the "linear" section, it maximises the efficient part of the run and minimizes the time and revs spent in an inefficient part of the flight profile by the initial burst.

I should point out one caveat. Pressnell's test is on mediocre Tan II which he says may be 3% thicker than usual. Read his article for details.

He also says Tan II supplied after 2002 is 1/30" rather than 1/24".

I shew 6 strands of 1/8 x 1/30 to be nearly the same as the DeLoach motor.

6.0 Alternative Strategies

6.1 How do we explain near vertical climb performance of F1B ?

- Variable trim allows climb at steep angles and high speed. This gets around the 55° best climb angle of a fixed trim model. A model can climb vertically if no lift is generated by the forward speed. ie cl=0. Variable trim allows this. Having said that, it would probably be better to trim for fast climb (if you are so inclined) at 55°. as aircraft are always more efficient than helicopters.

- Variable pitch allows a prop to be efficient over a wider torque, thrust & model speed range. For the prop and model in Fig 4.1, if the blade angle is reduced by 8° when climbing at 55° efficiency will rise from 0.138 to 0.456
- Large diameter props are needed for efficiency under these conditions.
- Alas, none of these options is available to P30.

6.2 .. and vintage Unlimited Rubber & Wakefield?

Many rubber models are trimmed for a fast spiral climb. In a spiral climb, the excess lift generated by the high speed is used to turn the model. The high speed also allows the prop to be more efficient.

But the high speed also generates high drag so this is not as efficient as the strategy in sections 4 & 5.

Even if there are no restrictions on rubber, a longer motor run is more efficient. This is well illustrated by the last of the unlimited rubber pre 1954 Wakefields with geared motors or Oh-So-Long fuselages.

Again variable pitch helps to deal with the initial burst. It is possible to have a variable pitch folder with simple bent wire technology that wouldn't be out of place on a pre 1954 Wakefield.

7.0 Conclusion

The Igra P30 prop is most efficient when matched to a fairly long motor run.

If the motor is sized so that the **"linear"** section of the motor run, both avoids operating in a flight regime where the prop is stalled and inefficient, and also allows the model to climb to the end of the run, the height gained might match that of faster climbing models.

The Igra prop in a P30 model has just sufficient flexibility to allow this with the 4x torque delivery of the **"linear"** section of the motor run.

8.0 References

[1] Martin Simons – Model Aircraft Aerodynamics 2nd ed.
[2] Hoerner – Fluid Dynamic Drag
[3] Xfoil – Mark Drela http://groups.yahoo.com/group/xfoil http://raphael.mit.edu/xfoil
[4] Drag Bucket – the range of lift coefficients where an airfoil has low drag
http://www.charlesriverrc.org/articles/asfwpp/lelke_airfoilperf.htm

9.0 History

22jul	incorporate Hepcat's comments
12jul	correct P30 weight to 50gm
11jul09	to Hepcat