The Muddiman Flying Machine Electrified

1. Introduction and Description of the Flying Machine

Our flying buddy Ernie Padgette has talked often about the “Don Muddiman Flying Machine”. For those that are recent to the hobby, have forgotten or perhaps never heard, the “Muddiman Flying Machine” was designed a few years ago (late in the last century – gosh I have gotten old!) by Don Muddiman as a high speed, high thrust acrobatic RC plane. At that time Don was part of the “Cloud Dancers” RC aerobatic demonstration team and flew the Flying Machine as part of the show. My guess is that aside from the demonstration wow factor of a highly maneuverable and fast plane, that Don designed a comparatively fast and high wing loading plane so that it could be flown regardless of the wind/weather that occurred at the show sites. It also resulted in a comparatively small wingspan plane so that it packs and travels well. Figure 1 is a picture of Don Muddiman’s Flying Machine. Don is clear about the superior performance of the Flying Machine as compared to its look-alike “competitor” the “HOTS” that was kitted by Midwest following the introduction of the “Flying Machine”. For more information, history, and plans see Don’s website at: http://www.eagle-i.us/fm/

Figure 1. Don Muddiman’s Flying Machine

The Flying Machine had/has an enthusiastic following among the knowledgeable and almost made it to ARF production. Today short kits for the “.40” and “.60” size are available from Laser-Works, and I ordered two, “.40” size kits for this project. As I wrote above, Ernie has talked often about the Flying Machine and repeatedly suggested (if you know Ernie you understand) that I needed to build one. Finally, Ernie offered me a deal I could not refuse, he would fund the build of two “.40” size Flying Machines if he got one from the litter. Also, he wanted to play into my experience base of electric building/flying so electrification was to be part of the plan. Reluctantly I agreed, with the major hesitation being building such a high wing loading plane and also concerns about how many watts could be loaded into a 44-inch wingspan airframe and whether we would both be unhappy with the possible proverbial flying brick that takes-off, flies, lands and crashes at one rather high air speed.

2. Description of Electrification Problem

Here is the Flying Machine’s baseline design point from Don Muddiman’s website.

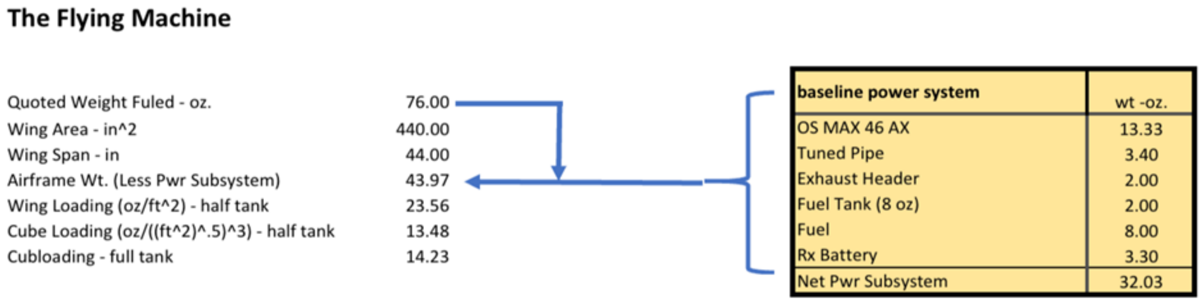
Wing Span:	44”
Fuselage Length:	40.25”
Wing Area:	440 Sq.-In.
Wing Loading(68Oz.):	22 oz./sq.-ft.
Engine:	O.S.Max 46AX
Propeller:	Master AirScrew 9.5 x. 6 in (static:17,500 rpm)
Fuel:	8 oz.
Servos:	DS811
Weight:	4.25 lbs

The electrification challenge was to reproduce the performance that the Flying Machine was credited with and still provide a reasonable flight time. I targeted 9 minutes for a “typical” sport flight. The first question was how to insure the unlimited vertical performance of the Flying Machine and its high-speed. Note that the propeller clearance is pretty much used up with a 9.5-inch diameter propeller and with the fairly small size of the plane, extending the landing gear for a larger propeller and lower RPM electric motor was not a real option. We can put some larger wheels on to help, but we are also looking for speed and hence lowest drag. So, we are pretty much locked in to aiming for an electrical set-up and airframe that will reproduce the Flying Machine’s 17,500 rpm with a 9.5x6 inch propeller. And doing so while limiting weight to 64 ounces and packaging the needed watts in the existing airframe dimensions.

3. Feasibility

As a first step I wanted to understand the boundaries of what I had to work with. To have any hope of success we need to not add significant weight to the Flying Machine and also have a realistic hope that the battery we end up with will provide a reasonable flying time. Figure 2 is an accounting of the Flying Machine’s characteristics and an estimate from published equipment weights of the baseline power system. You will see that I have included a full fuel tank and the Rx battery in this weight tally. In our electric system we will eventually use the electronic speed controller’s (ESC) battery eliminator so we will use the RX battery weight to add to the total equipment we will replace. This totals 32 ounces as shown on the right in Figure 2. Per the above from Don Muddiman’s web site, we use his total ready to-fly weight of 4 pounds, 4 ounces with 8 ounces of fuel to give a take-off weight of 76 ounces. When the baseline power system weight is subtracted from the fueled ready-to-fly weight we have about

44 ounces to work with for our airframe. This would include everything except the motor, ESC, battery, and motor wiring. From a feasibility standpoint we can use the 32 ounces of the baseline system and determine that perhaps a 16 ounce battery, 3 ounce ESC, 10 ounce motor, and 3 ounces of wiring will replace the baseline power system. Why did I think this indicated enough feasibility to continue? The answer is I have several planes in the 5-7 pound range that use ".32" to ".80" size motors. For these the batteries are in the 14-20 ounce range, the motors in the 7 to 12 ounce range and the ESC's on the order of 3 ounces. So…. this looks at least like a possible success at this level of detail, and reason enough to continue and proceed with ordering the short kits.



The Flying Machine

Quoted Weight Fuled - oz.	76.00
Wing Area - in^2	440.00
Wing Span - in	44.00
Airframe Wt. (Less Pwr Subsystem)	43.97
Wing Loading (oz/ft^2) - half tank	23.56
Cube Loading (oz/((ft^2)^.5)^3) - half tank	13.48
Cubloading - full tank	14.23

baseline power system	wt -oz.
OS MAX 46 AX	13.33
Tuned Pipe	3.40
Exhaust Header	2.00
Fuel Tank (8 oz)	2.00
Fuel	8.00
Rx Battery	3.30
Net Pwr Subsystem	32.03

Figure 2. Baseline Weights and Airframe Characteristics

You will note I am targeting to have no worse than an equivalent weight of the Flying Machine when fully fueled. You could argue that I should target an all-up weight with a half tank since the average flight properties of the Flying Machine will be experienced with an average fuel load. My thought process is that at this point I am only addressing feasibility, that is: does any of this make sense and is there any reason to abandon the project? So, using the heaviest condition of the glow version allows me the most weight to work with. As I go through motor and battery selection and then building, I will always be looking to reduce weight. The wild card of course will be the airframe weight that results from the build. The wing loading and cube loading numbers for the glow powered Flying Machine suggest that the Flying Machine could be a real handful; perhaps something like a scale EDF jet model. On the other hand there are videos of Don Muddiman's design actually flying……….

4. Power System

Sizing the motor and battery was the critical part of assembling an electric Flying Machine. As identified above there were several constraints to the results we were hoping for with this project. The list looks like this:

a. Static thrust to weight greater than 1.25 to enable the Flying Machine's vertical performance. We picked 1.25 somewhat arbitrarily since we are unsure of the static thrust of the original glow set-up and wanted some margin since we won't be sure of the final weights until much later in the build process. Using some manufacture tables for electric motors I found that 17,000 rpm and a 10"x5 inch propeller might produce a static thrust on the order of 151 oz. Yikes! That would give us a thrust to weight of the glow version of something like 1.9. So 1.25 is conservative with the hope that I can find an electric set up that results in 17,500 rpm with a similar propeller.

b. Propeller diameter 10 inches or less. The original was 9.5 inches so this seems like a good upper limit. If we have to go to 10 inches we can always increase the baseline wheel diameter by .5 inch if the ground clearance becomes a problem.
c. Flight time target of 9 minutes. Again, a somewhat arbitrary number as the flight time will depend on flying style. If the electric Flying Machine has the capabilities we hope for, then it will be likely flown aggressively. Typical electric performance modeling tools will use 70-85% of maximum throttle to predict a "mixed" maneuver sport flight time.
d. No change to the cowl profile, or motor location. The Flying Machine has a unique design that by appearance and physical layout should remain the same to have a Flying Machine that is true to Don Muddiman's original vision. Affected here of course is the motor diameter allowable and the size of the ESC.
e. All-up flying weight less than 76 ounces.
f. Cooling that allows a lot of watts to be put in the .46 size airframe. At 150 watts/pound we are expecting at least 700 watts. Remember that the 150 watts/pound is a metric for "aerobatic" models, and we want in addition unlimited vertical performance.

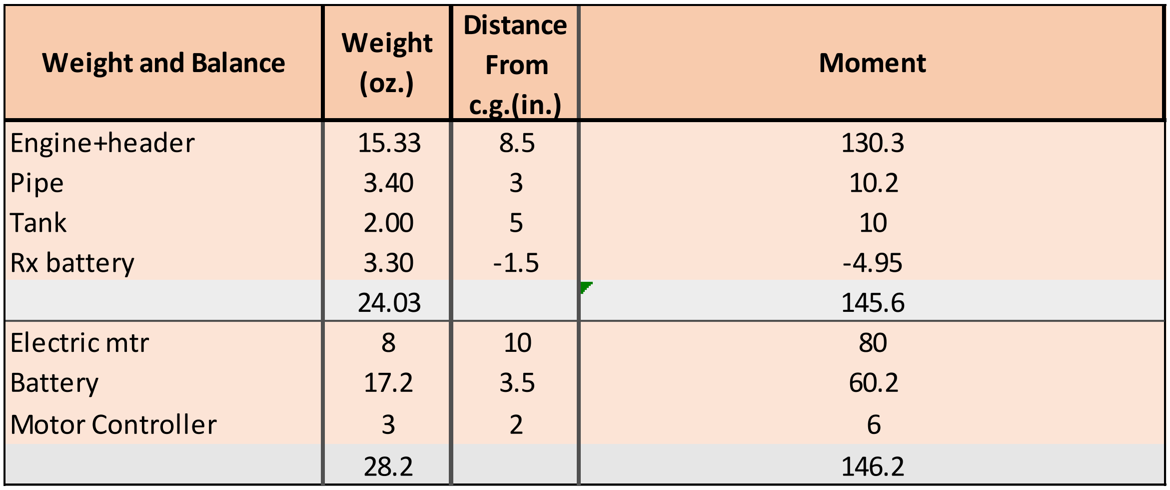
I began motor investigations by looking at my "typical" motor, namely the RIMFIRE line that I have used with good results. The ".32", ".46", and ".55" RIMFIRE motors could not produce the static thrust needed with a 9-10 inch propeller and required either large currents or very heavy batteries. What I then looked for was a motor less than 9 ounces, that would produce high RPMs (high thrust with a small propeller) and provide runtimes from 7-9 minutes with a 6s battery with less than 4000 mah capacity in order for the weight to be in bounds. I looked first at the Scorpion Motors which have a reputation for high performance (and cost). As I looked at these during the winter (2019-2020) the supply of these motors which are made in Hong Kong began to dry up. I then included some Cobra Motors which are also in wide use. The Cobra motors seemed to lead me towards 5s batteries which for some reason are not available in a wide range of sizes. In the process of web searching, I came across a new brand, "BadAss" RC motors. These had some motors in the 7-9 ounce range that would accept 6s batteries and also had some comparatively high Kv (rpm/volt) values. Figure 3, shows a subset of the motors I looked at using the "MotoCalc" PC program, the on-line "eCalc" tool, and where available manufacture data. Both the Cobra and BadAss motor manufactures have on-line tables that show test data for current load, RPM and thrust with various propeller sizes. These are very helpful and often preclude the need to do more analysis. I have ranked these somewhat subjectively by how I interpreted the combination of the two analysis tools and published data. In the end, I settled on the BadAss 3520(790 KV), as this motor seemed to offer good performance with several options for propeller and battery cell count and capacity. As option "1a" this yields more than 200 watts/pound, a static thrust-to-weight of 1.5, flight times on the order of 7 minutes and speeds of 80 mph and 35 mph vertical. More Yikes!

5. Battery Sizing

From figure 3 we are hoping a 6 cell 3300 mah battery with the Badass 3520-790 motor will provide adequate flight time. We also made a foam board mockup of the front end of the Flying Machine and determined that at most a 6 cell 4000mah battery would fit and be serviceable from a hatch between the wing and cowl. However, we still need to focus on the smallest battery possible to minimize weight, allow airflow inside the fuselage and provide volume for the motor controller (ESC). What is uncertain at this point is where the battery will have to sit to support the required center of gravity location. This location can in turn affect both the location of the ESC and the ease (or not) of battery change out. Table 4 looks at the moments about the center of gravity from both the glow design and the electric version we are contemplating. Weights are in ounces and distances in inches. The +3.5 inch location of the center of the Lipo battery when mapped to the fuselage mockup indicates again we have a feasible plan. However, note that since we don't have the actual airframe we are going to use the battery placement is still very tentative and will remain so until we can balance a nearly completed airframe. All we can know at this point is that the battery center when located 3.5 inches (+ or – 1 inch) from the required center of gravity "should" allow us to balance correctly. Since the plans and the fuselage mockup allow this position latitude, we again see that our plan is feasible. Worst case would require alternate battery sizes which again encourages the motor we have selected since it seemingly offers flexibility in battery and propeller sizing. You might note that in Table 4 that I've used an empty tank configuration vs. the tanks full assumption that I used previously. Here I want to be assured I can fly with the center of gravity aft, for the lightest condition where previously I wanted to allow all the weight I could for motor and battery sizing.

Pick ?	Motor	Prop	Cells	mah	Cube Loading	Watts/lbs	F/w	Flt. Time (@75% Thr)	Mtr temp	Speed	Vert. Speed	Tool (eCalc usless specified)	Comment
	Cobra 3520/ 820	10x6	5	3300	13.20	142	1.25	9.3	115	70	17		5s batteries have limited size selections
		10x6	6	3300	13.80	216	1.60	7.7	138	80	35	6s Not recommened by manufacture	
		9x6	6	3300	13.80	163	1.32	9.2	122	80	24	6s Not recommened by manufacture	
1	**BadAss 3520 /790**	10x6	5	3300	13.30	140	1.23	9	126	69	16		use either 4/5/6 s depending on performance and prop plenty of top end performance
						170	1.19					Manufacture	
1a		10x6	6	3300	13.90	215	1.59	7.7	151	80	35		10 min at f/w=.8/ 57 mph
						147	1.13	15+		60		MotoCalc	Flt time questionable
						270	1.53					Manufacture	
1b		9x6	6	3300	13.90	161	1.28	9	142	80	22		
						164	1.05	15+		71		MotoCalc	Flt time questionable
	Cobra 3515/950	9x6	5	3300	13.10	145	1.23	10.8	124	76	18		
						140	**0.91**	14		68	**na**	MotoCalc	
						182	1.34					Manufacture	
	BadAss 2826/690	10x6	6	3300	13.60	149	1.27	10.6	131	71	18		
						147	1.08	15+		62		MotoCalc	Flt time questionable
						172	1.25					Manufcature	
2	**BadAss 2826 / 1030**	10x6	4	3300	12.40	144	1.24	8.5	118	67	16		Should work but not much battery choice. Might need larger battery for agressive flying - but would also lower performance
				4000	13.00	140	1.21	9.2	122	70	15		
						149	1.12	15+		61		MotoCalc	Flt time questionable
						181	1.33					Manufacture	
	BadAss 2820 / 1350	9x5	4	4000	12.8	168	1.22	9	138	74	17		
						155	**1.04**	15+		60		MotoCalc	Flt time ? / Mtr and Batt temp warning
						258	1.43					Manufacture	Full power duration caution
3	**BadAss 3515 /1130**	10x6	4	4000	13.1	174	1.38	7.8	133	75	25		
						165	1.2	15+		65		MotoCalc	Flt time? / Batt temp warning
						218	1.41					Manufacture	Full power duration caution

Figure 3. Motor Comparisons



Weight and Balance	Weight (oz.)	Distance From c.g.(in.)	Moment
Engine+header	15.33	8.5	130.3
Pipe	3.40	3	10.2
Tank	2.00	5	10
Rx battery	3.30	-1.5	-4.95
	24.03		145.6
Electric mtr	8	10	80
Battery	17.2	3.5	60.2
Motor Controller	3	2	6
	28.2		146.2

Figure 4. Battery Location and Center of Gravity

6. Performance Modeling

Some comments on the performance modeling tools that were used in Figure 3 are in order. I used three methods, the online eCalc tool, MotoCalc for the PC, and the manufactures test data from the Badass websites. Each provides slightly different data. MotoCalc seems to be the most conservative in terms of net performance prediction and uses the most details about the specific airframe, however it seems to overestimate flight times. The on-line tool, eCalc (it is subscription based) seems to yield optimistic predictions but unlike MotoCalc gives some detailed predictions of motor temperatures. Both tools suffer from limited propeller data which complicates interpreting their results. The manufactures website indicates their data is measured and uses specific and relevant propellers. However, the ESC and battery used are not indicated and no information about flight times at other than test current levels are included. So here I looked to the manufacture for static thrust predictions, eCalc for motor temperatures and MotoCalc for a contrast of more conservative estimates. Finally, I also turned to the "RealFlight" flight simulator and used a model similar to my target and then edited all its properties to see if it seems to behave in a manner that the analysis tools are leading me to expect. For the Flying Machine I found a RealFlight "Stick" model and turned it in to a Flying Machine "equivalent". It of course still looked like a "stick" but the edited version matched the properties of the Flying Machine and the electric power system contemplated here.

7. Servo Sizing

One concern with the Flying Machine is making sure that the servos can deal with the speeds we are expecting if we come close to matching the Flying Machine's heritage performance. With the desire to limit weight and the smaller size of the flying machine it is very tempting to use mini or micro servos. So, the motivation here is to explore the hinge moments the Flying Machine might produce. First to see if “smaller” servos might work out. Secondly and more importantly, since we are planning to fly fast, I wanted to be sure that “standard” servos will be ok since their use on a plane this size would be a typical expectation. Figures 5-6 show these estimated hinge moments for the control surfaces using two methods. The first is from a formula developed by Chuck Gadd and displayed on the “MN Scale and Gadd Scale R/C” web site. The second is taken from an NACA war time report where hinge moments were measured in wind tunnels. For the latter I selected a case of a thin symmetric airfoil and a similar shaped simple control surface. I then adjusted the hinge moment data from this case based on the effective aspect ratio of the control surface. In the figures below “%Chord” corresponds to the control surface chord as a percentage of the total surface (wing, horizontal tail, and vertical tail). The performance estimation the RealFlight simulation results suggested that 100 MPH would be a reasonable upper limit for the Flying Machine’s top speed., including a full power dive.

Surface	Elevator	**Span**	15.75	**Av. Chord**	2	**%Chord**	36.36	**Servo Arm**	0.43	**Control Arm**	0.8
		Velocity (mph)									
		40		**60**		**80**		**90**		**100**	
Servo	**Surface**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**
10	5.36	0.70	1.04	1.57	2.35	2.79	4.18	3.53	5.28	4.35	6.52
20	10.59	1.33	2.00	2.98	4.49	5.30	7.98	6.71	10.10	8.29	12.47
30	15.59	1.82	2.76	4.10	6.22	7.29	11.05	9.23	13.98	11.40	17.26
35	17.96	2.00	3.05	4.51	6.86	8.01	12.19	10.14	15.43	12.52	19.04
40	20.21	2.13	3.25	4.79	7.32	8.51	13.01	10.77	16.46	13.30	20.32
45	22.34	2.19	3.37	4.93	7.57	8.77	13.46	11.10	17.04	13.70	21.03
50	24.32	2.19	3.38	4.93	7.60	8.77	13.52	11.10	17.11	13.70	21.12
55	26.12	2.12	3.29	4.78	7.40	8.49	13.16	10.75	16.65	13.27	20.56
60	27.74	1.98	3.09	4.47	6.95	7.94	12.36	10.05	15.64	12.40	19.31
Degrees		Servo Torque (oz-in)									
Gadd: Chuck Gadd at “MN Scale mad Giant Scale R/C”											
NACA: CB 5B05											

Figure 5. Elevator Servo Torque Estimates

Surface	Aileron	**Span**	12	**Av. Chord**	1.5	**%Chord**	14.29	**Servo Arm**	0.65	**Control Arm**	0.8	
		Velocity (mph)										
		40		**60**		**80**		**90**		**100**		
Servo	**Surface**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	
10	8.11	0.69	0.81	1.54	1.82	2.74	3.23	3.47	4.09	4.29	5.05	
20	16.13	1.33	1.58	2.99	3.55	5.32	6.32	6.73	8.00	8.31	9.87	
30	23.97	1.88	2.27	4.24	5.12	7.53	9.09	9.53	11.51	11.76	14.21	
35	27.78	2.11	2.57	4.75	5.79	8.44	10.30	10.68	13.03	13.18	16.09	
40	31.48	2.29	2.83	5.16	6.37	9.17	11.32	11.61	14.33	14.33	17.69	
45	35.07	2.43	3.03	5.46	6.82	9.71	12.13	12.28	15.35	15.17	18.95	
50	38.49	2.50	3.16	5.62	7.12	10.00	12.66	12.65	16.02	15.62	19.78	Unused
55	41.73	2.50	3.21	5.63	7.22	10.00	12.84	12.66	16.25	15.63	20.06	
60	44.72	2.42	3.15	5.45	7.09	9.68	12.60	12.26	15.95	15.13	19.69	
Degrees		Servo Torque (oz-in)										

Figure 6. Aileron Servo Torque Estimates

Surface	Rudder	**Span**	5.5	**Av. Chord**	2.5	**%Chord**	35.71	**Servo Arm**	0.65	**Control Arm**	0.8
		Velocity (mph)									
		40		**60**		**80**		**90**		**100**	
Servo	**Surface**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**	**Gadd**	**NACA**
10	8.11	0.87	1.21	1.97	2.72	3.49	4.84	4.42	6.13	5.46	7.57
20	16.13	1.69	2.37	3.81	5.33	6.77	9.48	8.57	11.99	10.57	14.81
30	23.97	2.40	3.41	5.39	7.67	9.59	13.64	12.13	17.26	14.98	21.31
35	27.78	2.69	3.86	6.04	8.69	10.74	15.44	13.60	19.54	16.78	24.13
40	31.48	2.92	4.25	6.57	9.55	11.68	16.98	14.78	21.49	18.25	26.53
45	35.07	3.09	4.55	6.95	10.23	12.36	18.19	15.64	23.02	19.31	28.42
50	38.49	3.18	4.75	7.16	10.68	12.73	18.98	16.11	24.02	19.89	29.66
55	41.73	3.18	4.81	7.16	10.83	12.74	19.25	16.12	24.37	19.90	30.08
60	44.72	3.08	4.72	6.93	10.63	12.33	18.90	15.60	23.91	19.26	29.52
Degrees		Servo Torque (oz-in)									

Figure 7. Rudder Servo Torque Estimates

Some discussion on the two methods used in figures 5-7 is needed. There are many elements that can affect the hinge moments: fuselage and wing interference, hinge sealing and gaps, airfoils, control surface edge shape, angle of attack and others. In the case of the NACA data, scaling in terms of speeds and size (Reynolds number) are an issue as well. I did find one reference that suggested that at low Reynolds numbers (model aircraft) hinge moments would decrease with Reynolds number. This suggests that the NACA predictions here might be worst case since they were developed for full size WWII aircraft. Also, such aerodynamic data is reduced to coefficients that represent data linearized about zero deflection and hence suffer from accuracy at angles beyond 10-20 degrees. With respect to the "Gadd Equation", without any understanding of how it was developed, I believe the Gadd equation may be underestimating the hinge moment. So, all I can take from all these numbers is that a "standard" servo with a torque capability of 40-55 oz-in has a safety factor of about 2 against the worst of these predictions….and they always seem to work in a model of this size. Here we are looking at total servo weight difference or 2-3 oz. so I went with standard servos (Futaba S004). At the time I made the servo selections I was far enough along in the build process to feel that I could give up this weight versus using smaller servos.

8. Weight Results and Static Testing

The planes came in on the weight targets with a 6s 3300mah battery. The first one built-out at 74 oz and the second around 72 oz. So, with a bit of a surprise the first goal in replicating the Muddiman Flying machine was accomplished. Below in Figure 8, are the static power and thrust results. Seeing that we are bumping up against the 50 Amp capability of the ESC we are not going to go to the full 9.5 inch diameter propeller. We can guess since the RPM's are slightly lower than quoted for the original, and since that the propeller is a half an inch smaller, that we will be slightly slower than the original. However, since we don't have the drag of the tuned exhaust system and also have a much cleaner cowl, perhaps the only "deficiency" in the electric rendition will be a slightly lower static thrust to weight ratio and hence a slower vertical speed.

BadAss 3520-790 Motor				
9 x 6 eAPC	**eCalc**	**MotoCalc**	**Manufacture**	**Measured**
Thrust (oz.)	94-103	78-96	87.65	91
Amps	33-36	36-44	42.08	49
Watts	663-857	759-1069	934	1100
RPM	14653-15428	15652-17792	15313	15840

Figure 8. Static Performance Comparisons with a 9x6 Electric APC Propeller

Note that for the eCalc and MotoCalc predictions the battery, ESC, and propeller characteristics were varied to account for not having the actual brand components I had selected in their data bases. The equipment other than the propeller was not specified by the manufacture and a fully charged battery was used while MotoCalc defaults to 3.7 volts per cell. Also, I measured the thrust using a luggage scale tied to the tail of the plane and the measured electrical data was taken from the Castle ESC readouts. The one surprise in the measured data was the current levels, my experience in general is that the prediction tools overestimate the current, which was not the case here. Owing to the limited volume aft of the Flying Machine's firewall I built these planes with a 50 AMP Castle Edge ESC. To help with the cooling, the ESC was mounted so the heat sink was placed in a hole in the bottom of the fuselage so it would be exposed to the free stream air flow. The measured data and the manufacture's data agree and indicated 200-230 watts/pound. Sill more Yikes!

9. Flight Results and Adjustments

The first flights of the Flying Machine during early summer showed that while perhaps not as fast as Don Muddiman's videos would seem to indicate, that the electric Flying Machine has at least achieved our goals. Within the weights reported for the glow version we were flying fast, could fly vertically out of site within 4-5 seconds (see also model rocket) and snap rolled at rates nearly a blur. The flight times were acceptable being in the 7-9 minute range depending on how many high speed passes and vertical ascents were flown. The major surprise if there was one was that the motor currents were higher than the prediction tools indicated. I my dozen or so electric builds to date usually the current estimates were higher that actual. However, I have only recently started using "Castle" motor controllers that log current, RPM, etc. data and previously relied on estimates of current loads from average data deduced from battery amp-hour usage. Inspection of the motor controller by touch indicated that externally it was cool, but the downloaded data from the Castle controller showed internal temperatures that were higher than expected given the external "feel" of the controller. Without on-board telemetry, the motor temperature was investigated "by-touch" and seemed "hot" compared to again experience. The baseline for the cowl on the Flying Machine was per the original, that is, a fully cowled motor with air exits at the rear of the cowl and aft fuselage. An electric or air-flow spinner was used. As shown in table 9, a prop-nut was used in lieu of the spinner to assess the effect of opening the airflow through and across the entire motor diameter and this did indeed result in a cooler-to-touch motor. Subsequently I greatly enlarged the air exit at the bottom of the cowl to expose a fairly large portion of the motor can and this also had a good effect on improving the motor cooling. Keep in mind that this motor was selected because it was one of the few, if only, motor in this size range that was quoted to handle 6s batteries at 50Amp current levels (1260 watts) so a "warm-to-hot" motor should not be unexpected. Also, the motor manufacture quotes magnet and winding temperature specifications in excess of 300 degrees F and maximum 6s power levels of 1550 watts. So far after a summer's flying neither Flying Machine has shown any motor issues with the spinner or prop-nut configuration. Figure 10 shows the final cowl configuration with a prop-nut installed. I did use the Flying Machine's baseline 9.5x6" propeller for one flight. The reported ESC temperature of 200 degrees F close to the Castle specified maximum of 212 degrees so for flying except in cool weather I will use the 9x6 propellers. The motor current and power levels are lower that static due to the unloading in flight.

BadAss 3520-790 Motor					
Propeller	**Imax**	**Motor**	**T-start(F)**	**T-max(F)**	**P-max(W)**
9x5 sport	43	Hot	86	186	943
9x6 e	45	Hot	82	185	1002
9x6 sport	36	Hot	87	173	817
9.5x6 sport	43	Very Hot	89	200	985
9x6 sport-propnut	40	Cool	82	170	902

Figure 9. Some Flight Results

Figure 10. Final Cowl and ESC Configuration

Figure 11. The Flying Machines Electric

10.Final Thoughts

The electrification analysis here for the Flying Machine is likely a bit over the top and exceeds what I have typically done in converting a glow/fuel plane to electric flying. Certainly, the effort on hinge moment analysis can be questioned owing to the lack of precision in any of the estimating tools and the large body of experience and example that we all have putting servos in various models. The excuse for all this besides having time last winter, is that building two, I wanted to get it right and not have to carve up two completed planes making the changes that might be needed to get acceptable flying qualities. Regarding the latter, Don Muddiman's design I believe has been honored here. This electric version flies amazing well at slow and fast speeds, goes straight up forever, snaps like a demon, is not at all hard to control and lands easily without much drama. Ernie has said he thinks the glow version that he also owns will still outperform this electric rendition……………the fly-off is still pending.

-Gordon Collyer
12/18/2020