Design of a Competitive Heliroc

Research and Development Report, NARAM44

By CHEDAR_1++ Team

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Abstract

In this report we describe our approach to design of a competitive heliroc duration model. In our point of view, competitive model is a model capable of achieving both high qualification rate and long duration times.

In the theoretical part, we examine typical heliroc design (RotaRoc like heliroc), focusing on its problems and possible solutions. We strive to find a simple solution which increases both the performance and the reliability of the design without complex changes and expensive tradeoffs.

In the design part, we introduce a free spinning minihub design developed by our team and we describe its applications both in external rotor and internal rotor designs. In this part we also compare the difficulty of building an internal rotor heliroc against the construction difficulty of an external rotor heliroc and we show that there is no significant difference between those two seemingly very different designs. A complete plan for building internal rotor heliroc is also included.

In the experimental part, we first compare the performance of folding blades against the performance of nonfolding blades to prove that the mechanism added does not present significant performance decrease. Drop tests from the 45′ high watch tower at Lapham Peak, WI, were used for this test.

In the main experimental part we build a number of helirocs, all derived from the same base design but with varying frontal area, blade type (folding vs nonfolding) and overall design (internal vs external rotor design). All rockets are flown and their altitude is measured using a standard two station tracking setup. Reliability data are also recorded.

Rocket altitude simulator (computer application wRASP) is then used to determine apparent drag coefficients for each design and further comparisons of the altitude performance of the designs are performed.

1 Research motivation

Our main motivation is an understandable desire for worry-free heliroc model, which will be easily scalable to all classes of heliroc duration event and will perform steadily in competition.

Our other reason for publishing this report is to offer competitive alternatives to classical designs (e.g. RotaRoc[5]) that more then a decade after their introduction still dominate the field of entries. The DQ rate in heliroc duration events is still high and the main DQ causes are well known problems (e.g. burn string release failure or nondeployment due to an ejection after apogee). Solutions for those problems are known for a long time but apparently not well spread.

2 Heliroc Design Analysis

2.1 Parts of heliroc

Typical heliroc consists from three main parts (cf. Fig. 1 on page 2):

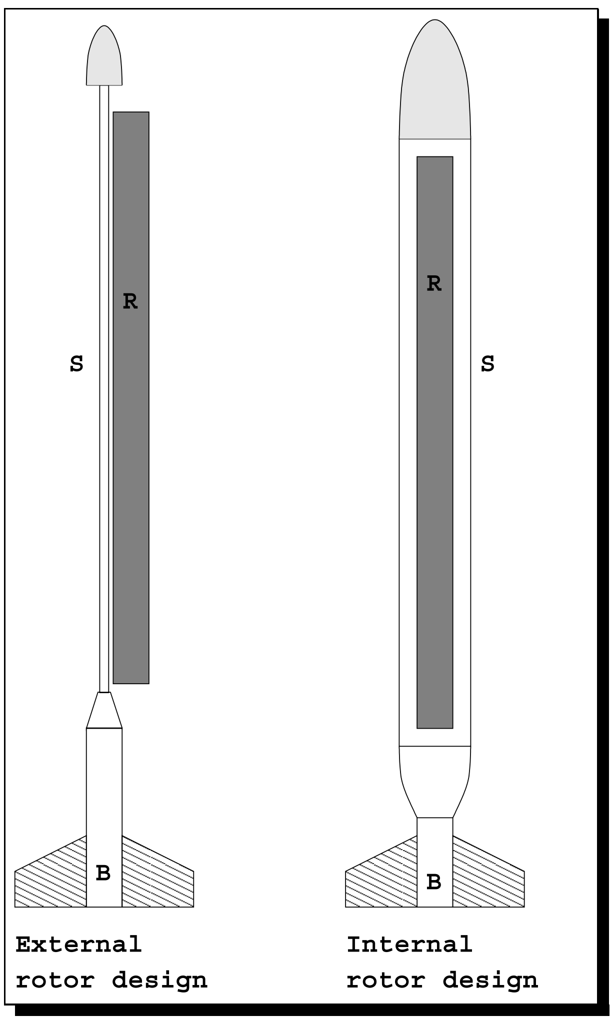

Figure 1: Main parts of helirocs. **B** — booster, **S** — support, **R** — rotor (simplified)

Booster: this part holds a motor and in most cases serves also as a fin can. During boost this part acts as any other booster but during the autoration descend the booster provides a weight which together with rotor dihedral helps the heliroc to descend in the correct position.

Rotor: this part is usually the most complicated part of the heliroc. On boost, rotor blades are usually folded along the axial axis of the heliroc. At the ejection point, the deployment mechanism (usually consisting from rubber bands or metal springs) opens the blades to recovery position and the airflow causes the rotor to engage in autorotation. Rotor blades (unless confined in a tube) and deployment mechanism (unless hidden in drag shadow) are major contributors of unwanted drag.

Support: this part provides a spine for the whole design. In external rotor designs the spine is usually made from a body tube of small diameter that is hidden between blades in boost position. Some external rotor helirocs (such as John DeMar's *Whirl-A-While*[3] or Art Rose's *Rose-A-Roc*[2]) use a birch dowel for their spine.

Internal rotor designs have their spine surrounding the rotor. The structural support is provided by a body tube (usually of larger diameter) which carries the whole rotor to the ejection point. While increasing the frontal area, internal rotor heliroc has drag comparable to a normal rocket and also provides protection for its rotor, which becomes increasingly important in higher impulse classes. Typical example of an internal rotor heliroc would be Gary Miller's *MillerCopter*[13], unfortunately this design was not published yet.

They are exceptions to the scheme above, for example nonmoving parts heliroc such as Tasmanian Devil[6] or Moon Satellite[8]. Both designs use their fins as their rotor. An example of a heliroc without the spine would be Chris Pocock's Revolution #4. But none of those designs offers performance and/or reliability of modern competition designs.

2.2 Reliability issues

The three most commonly cited problems of classical designs are:

Burn string failure: the ejection charge fails to burn a burn string, blades are not released, heliroc turns nose down and being aerodynamically stable, continues in its flight without any recovery device.

Ejection after apogee: helirocs ejecting after apogee often fail deploy their rotors due to aerodynamic drag holding the blades close to the spine. The result is a high speed landing in a negative altitude.

Flipping during rotation: helirocs with incorrectly set rotor dihedral, deploying after the apogee or being hit by sudden wind gust, may flip and continue in the rotation with the rotor upside down. While this still produces a qualified flight, the rotor does not operate in an efficient mode and the duration is significantly shortened.

All of these issues can be addressed by a simple modification of the design — *booster-rotor separation.*

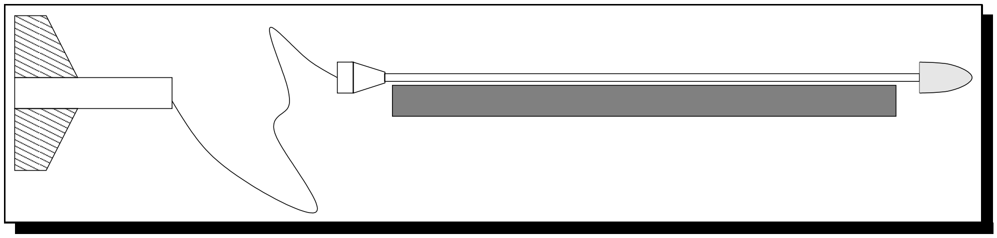

Figure 2: Booster-rotor separation

2.3 Booster-Rotor separation

This is a simple technique that destroys the aerodynamic stability of a heliroc at its ejection. The heliroc splits into two parts which are connected by several feet of Kevlar shock cord (see Fig. 2 on page 4). In our experience, 150# Kevlar is strong enough to resist the heat from A–B motors, 200# Kevlar will work well with C motors and above this impulse class, we use 300# Kevlar line. At four years flying booster-rotor separating design, we recorded only one failure (200# Kevlar did not survive D12-5 motor ejection).

The resulting object is not aerodynamically stable and will not streamline to the ground even if the rotor completely fails to deploy. The model is more likely to tumble and this will at least save the heliroc from a damage caused by a high speed impact.

If the booster-rotor separating heliroc eject after apogee, it will start to tumble and it is very likely that the rotor will eventually open. In our experience, the duration achieved on a flight with post-apogee ejection is about 25% shorter than the duration for the same model ejecting close to and before the apogee (assuming that a booster-rotor separation is built into the model).

Using the booster-rotor separation also calls for different blade locking mechanism, thus eliminating the burn string. Tabs (as on Fig. 3 on page 5 or described at *Chicago Chopper* design[18]) or ring holding the blades during boost can be installed on the booster. The reliability of such mechanism is close to 100% (as observed by our team). In our informal survey on the INTERNET, people using a burn string as a blade locking mechanism often admitted the failure rate as high as 30%.

When designing a booster-rotor separation heliroc, attention needs to be paid to relative weights of the booster and the rotor. The rotor part should be lighter than the booster part. If the rotor and the booster are of an approximately same weight and the booster starts tumbling (instead of just hanging down from the rotor), the overall stability and effectiveness of the rotor can be greatly impaired. The *Chopper Charlie* design[19] addresses this problem by using a body tube of a small diameter for its spine and moves the separation point as high as possible (cf. Fig. 4 on page 6). This modification however requires careful packing of the shockcord to prevent plugging of the spine tube. Alternatively, we can avoid the problem of a limited space inside the support tube completely by changing the design to an internal rotor heliroc.

2.4 Internal Rotor Heliroc

This kind of design encloses the whole rotor and the deployment mechanism in a larger body tube. The support tube is now surrounding the heliroc, protecting the blades against the effects of high thrust, and decreasing overall drag. The weight of the support tube becomes an important

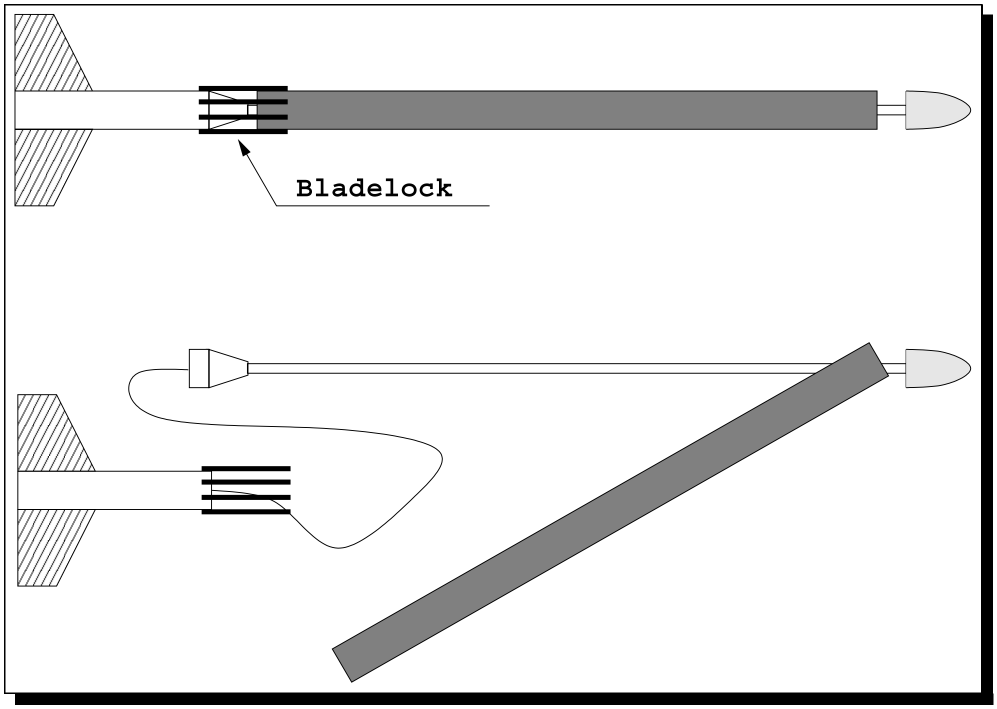

Figure 3: Blade tabs (locking mechanism), upper — blades locked, lower — unlocked

factor to consider. However, the blades packed inside the tube provide partial structural support too and thus lightweight tubes can be used. (For a simplified picture of an internal rotor heliroc, refer to Fig. 1 on page 2).

The most cited problem of internal rotor designs is the unreliable ejection of the blades out of the tube. This problem can be easily solved by using an ejection facilitator, such as foam plug, balsa disk, or most simple of all, a ball of paper wading.

Another argument against internal rotor helirocs is a close contact of ejection gases with the rotor blades. However, the blades are already protected by the ejection facilitator, more wading can be added and situation is not much different from parachute or streamer duration models, where much more delicate parachute or streamer are exposed to very similar hazards.

As it can be seen from our gradual introduction of models, there is a nice progression from models with external rotors to completely enclosed internal rotor designs. However to make completely closed internal rotor model two additional constraints must be satisfied:

1. The rotor hub and the blade hinges cannot use any external surface on the nosecone

2. Frontal area of the rotor in boost position must be completely covered by the frontal area of the nosecone

This basically means, that if we look at the nosecone of an internal rotor heliroc with the rotor in boost position, from its tip, we should not see any part of the rotor or the deployment mechanism.

These additional constraints will be satisfied by using folding blades and selfcontained mini-hub.

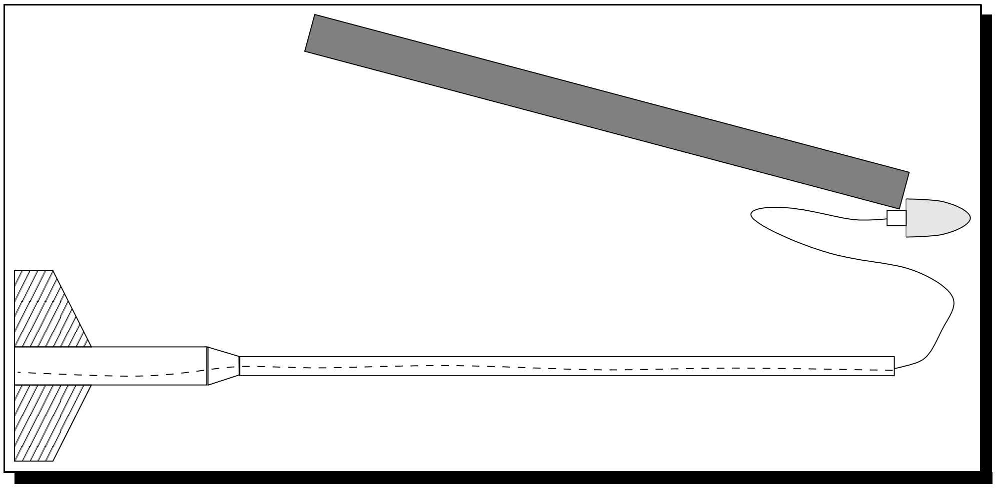

Figure 4: Separation point moved to the uppermost position

3 Internal Rotor Helicopter Design

In this part we first introduce folding blades and selfcontained minihub as the means of satisfying the design constrains for internal rotor designs. Later in this section we will introduce our internal rotor heliroc design (*The MidWest WeedWhacker*) and also present a comparison of construction difficulties for external and internal rotor designs.

3.1 Folding blades

Our literature research shows that lengthwise folding blades were first introduced with the Rose-A-Roc design. This easy technique allows modeler to pack the rotor blades in much smaller space, thus greatly decreasing the overall drag and required storage volume (in the case of internal rotor heliroc). In the experimental section we present experimental data that show that folding the blades brings the benefits at minimum cost. The example of folding blade is shown at Fig. 5 on page 6.

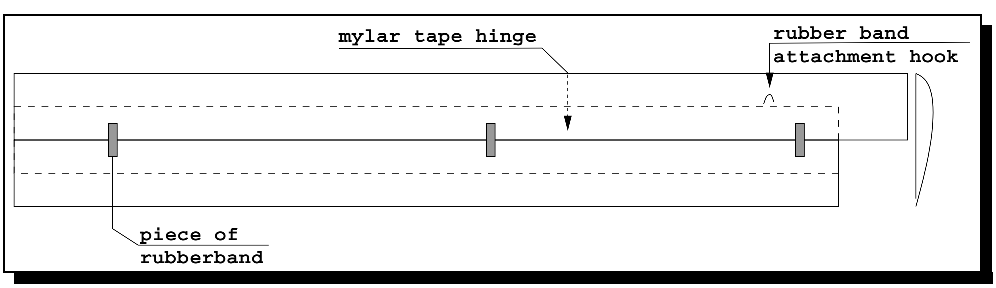

Figure 5: The folding blade

Folding blade is created by cutting the normal blade in half (lengthwise) and then reconnecting both halves back by (usually) a mylar tape hinge on the bottom side of the blade. To ensure proper unfoldment, small pieces of a rubber band are glued to (usually) equally distant places at the top side of the blade.

3.2 Verifying the performance of folding blade

Adding an (un)folding mechanism to the blade does add little of weight and unwanted drag (unless the rubber bands are sunk into the blade, which is not easy to do). To verify that adding the folding mechanism does not have a significant negative effect on the blade performance blades, we conducted series of drop tests from the 45′ high watch tower, using the same rotor with two different sets of blades (folding and plain (nonfolding)). The results of the drop tests are tabulated in Tbl. 1 on page 7.

Given the spread of values in each dataset (0.8s for folding blades and 0.95s for plain blades) and the difference between average drop time for each set of blades (0.10s/1.82% in favor of plain blades) we conclude that the possible performance loss is not significant.

Drop #	**folding blades**	**plain blades**
1	5.90s	4.98s
2	5.31s	5.44s
3	5.10s	5.93s
4	5.59s	5.87s
5	5.54s	5.71s
Avg	5.49s	5.59s

Table 1: Drop tests comparison of folding and plain blades

3.3 The minihub

The decision to use a freewheeling minihub is based on the results of the R&D project of Alex DeMarco[4], presented at NARAM43. The project compared drop times for a rotor with a freewheeling hub against the rotor with a fixed hub and it was determined that correctly constructed freewheeling hub can increase drop times (the project results showed 5% increase, we believe that even better improvements can be achieved with more effort invested into the hub design).

The selfcontained minihub itself is one of the results of the development and research work inside our team. The minihub was originally designed for Chicago Chopper designs but later modified for Chopper Charlie and finally this year the minihub was successfully tested in an internal rotor heliroc.

The main advantages of the minihub are its size, versatility, scalability, and the fact that it contains all parts necessary for full rotor deployment (except the rubber band hooks on the blade side). The minihub is displayed on Fig. 6 on page 8 and it's use is shown on Fig. 7 on page 9.

The minihub does not provide any angle of attack for blades. Each blade is constructed with the angle of attack build into it (using a balsa wedge between the blade and the hinge, as illustrated on Fig. 8 on page 10). This allows us to use the same minihub with blades of

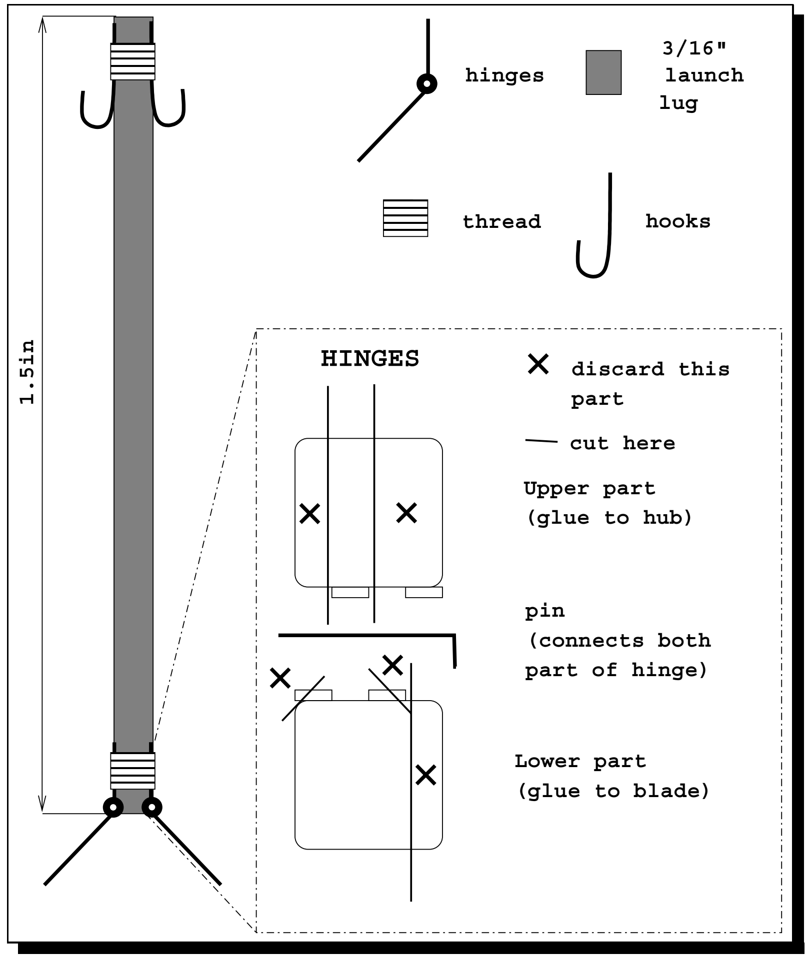

Figure 6: The selfcontained minihub

a different pitch (this is useful both for the research and competition strategy purposes). The effect of the blade pitch is discussed in R&D reports of Tim Barklage[1] and Ellis Langford[10].

On the same figure (Fig. 8 on page 10) important safety device can be seen. The Kevlar thread stitch is used to sew the hinge, the balsa wedge and the blade itself together. If any of the glue joints breaks during the flight, the blade is still attached to the hinge and while the rotation will be less than ideal, the flight will still qualify. This technique was not developed by our team, we learnt it from Gary Miller.

3.4 Comparison of an internal and an external rotor design

Having satisfied both design constraints for internal heliroc (see pg. 5) we can complete the internal rotor heliroc model. At this point, we can already see, that the difference in difficulty between internal and external rotor design is small. Let us take a closer look at different parts of the heliroc and compare the amount of the work necessary.

Rotor blades: the main difficulty in making rotor blades is sanding the airfoil (however, we find interesting ideas in the report of Bruce Markielewski[11] who presents experimental

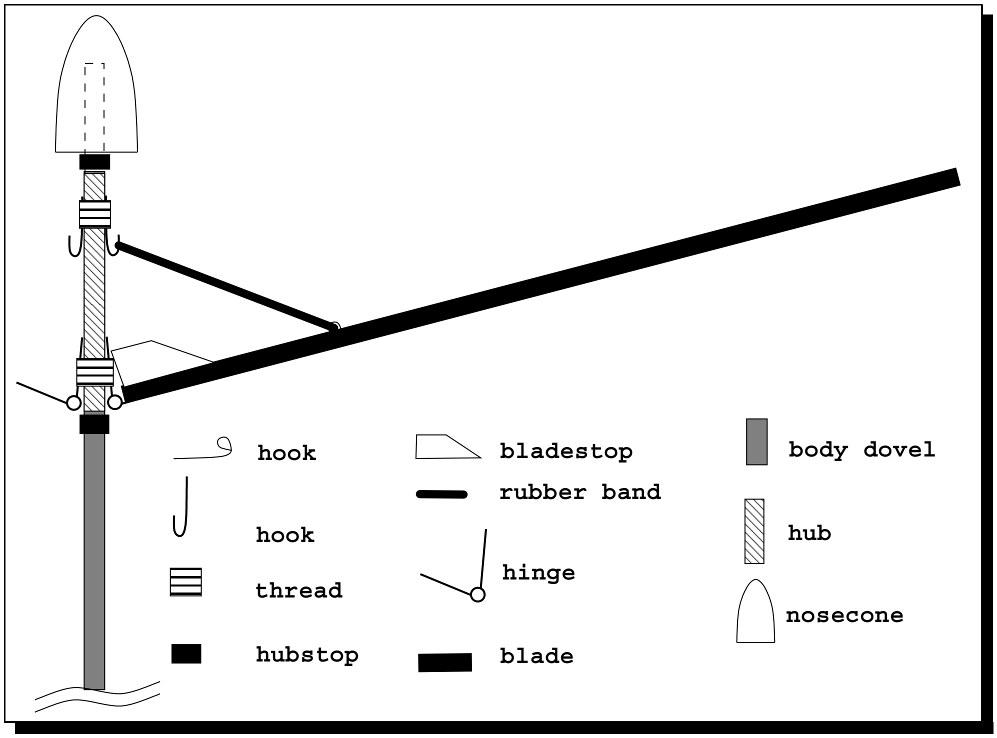

Figure 7: A rotor using the minihub

data in the favor of flat blades). Airfoil or not, the blades need to be made for any heliroc design. Converting plain blades into folding blades looks difficult but in the reality is quite easy. It will be shown in the experimental part of this report that using folding blades can almost double the boost performance of the model and we believe that folding blades should be used on any competitive heliroc model.

Rotor: this is another major difficulty in heliroc construction. However, the rotor is a basic part of any heliroc design (with the exception of noncompetitive no-moving-parts designs). This reports includes plan for relatively simple but well performing rotor assembly which will work both on internal and external rotor helirocs.

Blade locking and release: Blade locking and release is actually easier on internal rotor helirocs, where the body tube holds blades in boost position and no other locking mechanism is needed.

Rotor deployment: Rotor deployment needs to be solved both for external and internal rotor heliroc models. Internal rotor models imposes additional constraints (cf. pg. 5) but one of the solutions is presented in this report and does not require more work than most of other rotor deployment mechanisms.

Booster construction: some additional difficulty is added here. Internal rotor helirocs usually use larger booster with a shoulder from the body tube to the motor tube (or a boattail). However, fins have to be made for any helicopter and thus the only additional work is

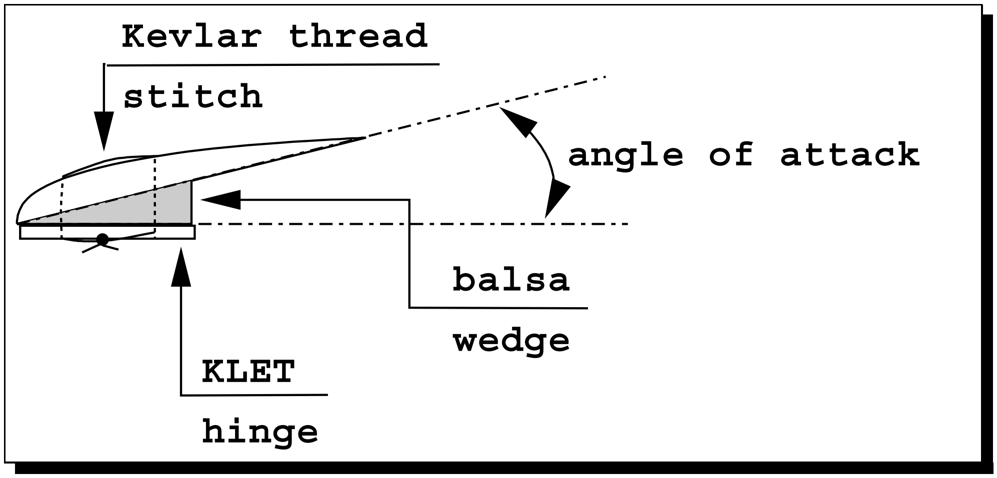

Figure 8: Detail of a blade mounted on the hinge with certain angle of attack

making the shoulder and attaching the motor tube to main body tube (using centering rings).

Preparation for flight: it is actually easier to fold blades and insert them into large tube than try to get them into a blade lock or tie the burn string.

The easy and straightforward conversion from the external rotor heliroc to internal rotor heliroc (assuming the minihub and folding blades are used) is depicted on Fig. 9 on page 11.

To encourage modelers to get their own experience with internal rotor helirocs, we include a fully detailed plan for building *The MidWest WeedWhacker* (see Fig. 10 on page 12). If more detailed information is need for building this design, the Chicago Chopper article[18] provides detailed instructions for difficult parts.

To successfully fly an internal rotor heliroc, reasonable attention has to be paid to its flight preparation. We recommend to prepare the model as follows:

1. Use at least 5′ of 300# Kevlar line for the shockcord.

2. Pull the shockcord through the tube.

3. Insert two crumpled halfsquares of Estes wading paper into the motor tube. They will protect the Kevlar line against direct contact with burning particles.

4. Insert a motor into the motor tube.

5. Secure the motor by a Lariat loop and masking tape. It is important that the motor is secured well.

6. Insert three to five crumpled squares of Estes wading from the top end into the body tube. Make sure you get a nice ball of wading paper inside the tube, it will function as a piston that will push the blades out.

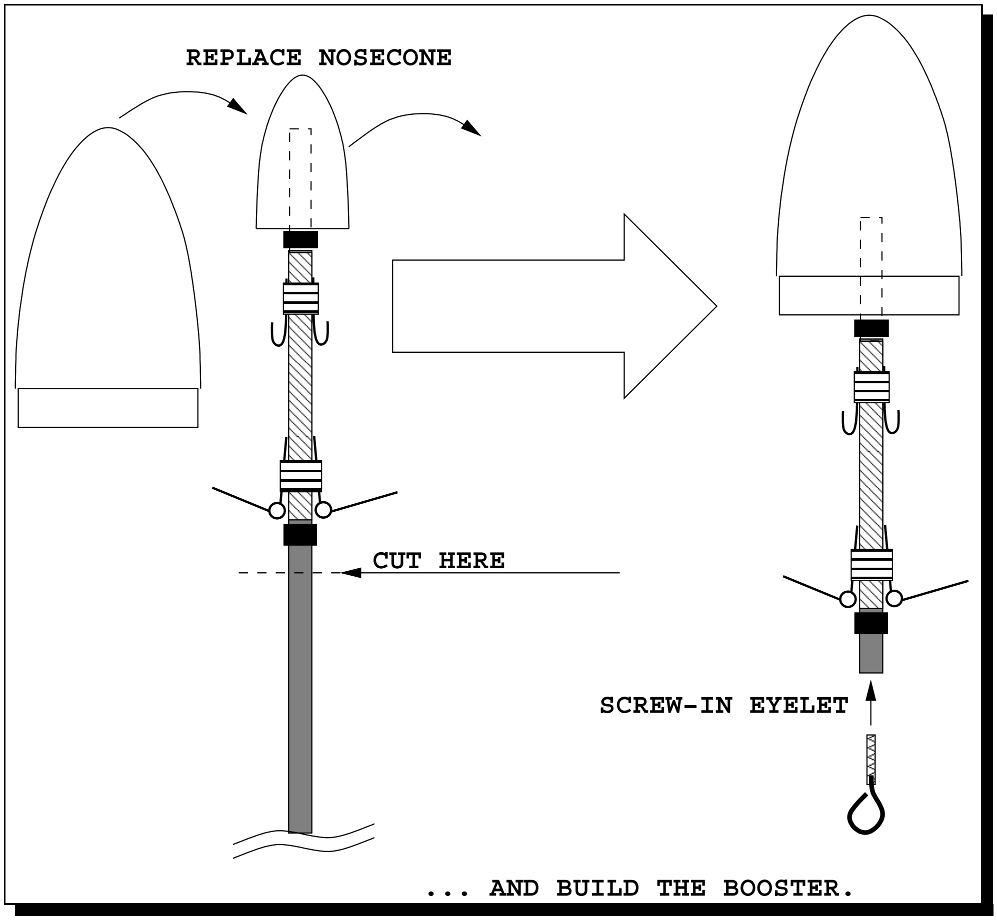

Figure 9: Conversion of external rotor to internal rotor

7. Using your favorite shockcord poking method, move almost all of the shockcord into the body tube.
8. Tie the upper end of the shockcord to the metal eyelet. Make at least five knots and secure with a drop of CA.
9. Fold the blades (but do not hook up the rubber bands yet) and make sure that the Kevlar line is running between the blades. This important to prevent an entanglement.
10. Before you insert blades into the tube, put one square of wading paper on the tip end of blades. This will prevent entanglement of the shockcord that is stored just below the blade tips.
11. Insert blades into the tube, just about halfway in.
12. Hook up the rubber bands to the the minihub.
13. Insert the blades completely into the tube, close the nosecone. The nosecone fit should be a little snug, to allow the ejection gases to pressurize the tube and then shoot the nosecone

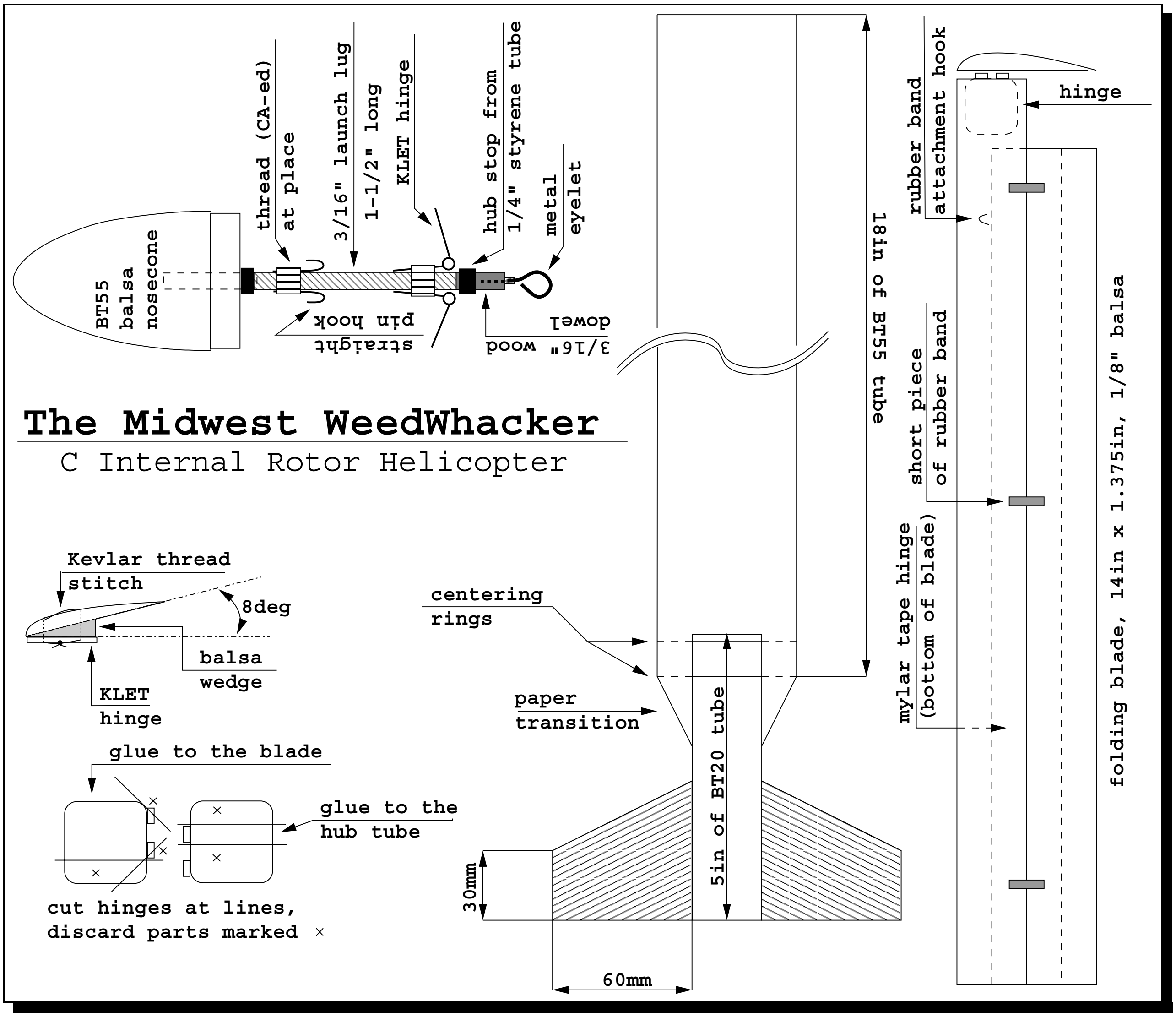

Figure 10: Internal rotor heliroc plan

out of the tube at high speed to ensure that blades will get out of the tube. The model is ready now.

The method is very similar to preparing parachute duration model. It may take one or two flights to get familiar with the method but the method is known for its reliable results.

4 Experimental flights

The experimental flights and their results are described in this section. But first of all, we will take a look at the factors that affect total duration of heliroc flight.

4.1 Heliroc flight duration

The total duration time of the heliroc model can be expressed as a simple equation:

$$t = t_b + t_d + A/r \tag{1}$$

where:

t .... total duration of the flight
t_b .... duration of motor burn
t_d .... delay of the motor
A .... ejection altitude
r .... the average rate of descend

We can assume that the boost and coast part of the flight last much shorter than the recovery part, i.e. $t_b + t_d << A/r$. Further, we have little control over the boost and coast parts, thus we will focus only on recovery part (which is a combination of ejection altitude and the rate of descend).

In plain English, the equation Eq. 1 on page 13 reads: "Fly high, descend slow". The "fly high" part can be achieved by minimizing frontal area, drag and total mass of the model. The "descend slow" part is a matter of using effective rotor and low mass model. For the purpose of this research, we assume no thermals.

4.2 Models used

Six different variations of the base design were compared in their altitude performance.

ER20n: External rotor, BT20 nosecone, nonfolding blades. It is not difficult to correctly predict that this model will be the lowest flying from our set of tested models. However, we decided to include it to see how much we can gain by using folding blades and internal heliroc design.

ER20f: External rotor, BT20 nosecone folding blades. We expect this model to be the highest flyer. The model has low mass and small frontal area. Still, the exposed blades can contribute a lot to drag and decrease the altitude reached.

ER50f and ER55f: both models are identical to the ER20f model with the exception of nosecone size (BT50/BT55). We want to see if a larger nosecone will create a "drag shadow" for the exposed blades and thus help to decrease the overall drag.

IR55c and IR55f: both models are internal rotor designs, identical, with the exception of nosecone and shoulder shape (IR55c: conical, IR55e: nose elliptical, shoulder parabolic).

All models are of the same height (with the exception of nosecone) and all have a rotor of the same design, same weight and same size. However, as we want the models to be typical models, we do not add weight to lighter models. The simplified drawings of the tested designs are on Fig. 11 on page 15.

Design	**Liftoff Wt** [g]	**Altitude** [m]	**Duration** [s]	C_d	**Min Wt Alt** [m]	**Notes**
ROUND #1						
ER20n	56	n/a	n/a	n/a	n/a	unstable
ER20f	59	130	n/a	1.107	136	
ER50f	57	110	n/a	1.674	111	
ER55f	60	121	n/a	0.725	125	rotor tangled into shockcord, but performs a few revolutions
IR55cf	74	107	n/a	0.558	141	
IR55ef	74	107	n/a	0.558	141	
ROUND #2						
ER20n	54	85	44	2.717	85	
ER20f	55	152	37	0.867	153	ejection past apogee, booster tumbling
ER50f	54	134	71	1.190	134	hot motor?
ER55f	56	113	63	0.875	114	
IR55cf	69	120	99	0.502	148	lost to thermal
IR55ef	69	120	55	0.502	148	
ROUND #3						
ER20n	55	79	34	3.064	79	a blade broke from the hinge, safety stitch holds fine, rotor works
ER20f	54	95	35	n/a	n/a	hit by a wind gust on boost (data not considered)
ER50f	54	111	59	1.732	111	
ER55f	57	105	42	0.980	107	
IR55cf	n/a	n/a	n/a	n/a	n/a	already lost
IR55ef	70	123	61	0.464	153	one rubber band broke, but the other two blades are enough to start the rotation, the third blade eventually reaches the rotation plane and the rotor performs well

Table 2: Results of experimental flights and computer simulations. Altitudes were measured, drag coefficients (C_d) and minimal weight altitudes were computed using program wRASP[24]. Minimal weight altitude is the altitude that the heliroc would reach if it would have the weight of the lightest model in our set of models (54g).

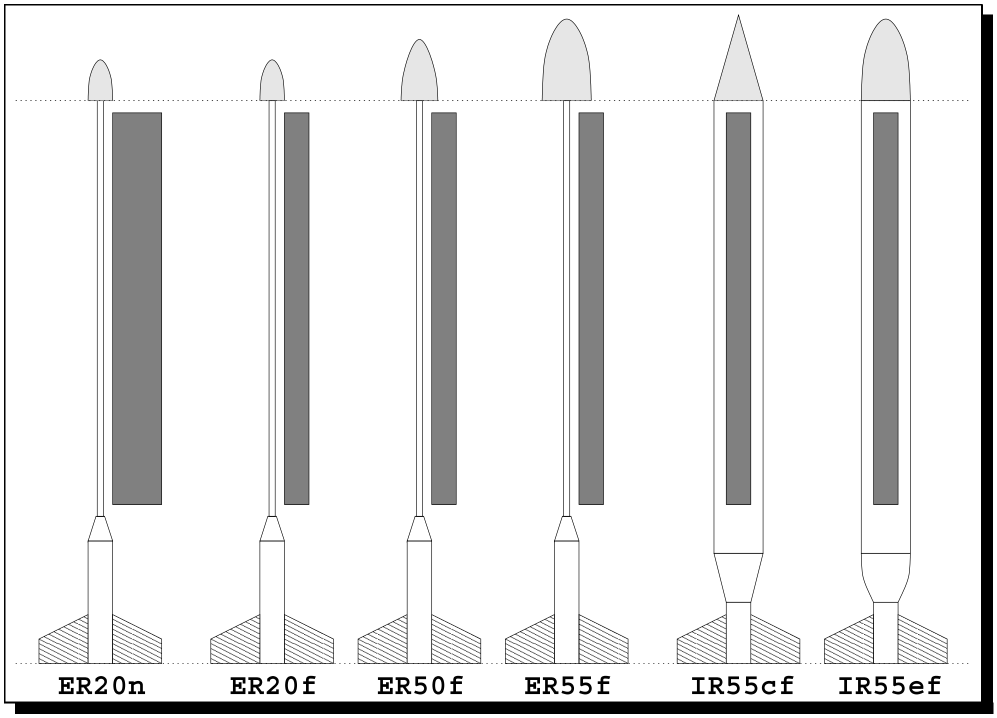

Figure 11: Models used in experimental flights

4.3 Flights

Before each flight, the weight of each model was measured with 1g precision. Each model flew three times using an Estes B4-4 motor and the altitude of each flight was tracked using two tracking station with a 300 meters long baseline. The duration of flight was also recorded, but because the thermal activity was high, we do not compare durations. For the purpose of reliability measurements, all glitches in each flight were also recorded.

5 Results

5.1 Data reduction

Because of a limited number of flights, we decided not to average the results but rather to present ranges of values. As it can be seen from figures and tables, the definite trends are nicely visible.

The Contest Manager[9] application was used to convert the tracking data to altitudes. The altitude ranges reached by each design are compared on Fig. 12 on page 16.

Simple “divide and conquer” handdriven parameter estimation with the wRASP application as a simulation engine was used to determine drag coefficients for each design and each flight. The final results consists from the range of drag coefficients computed for each model and are shown in Tbl. 2 on page 14 and on Fig. 13 on page 17.

Additionally, we computed minimal weight altitude for each design. Minimal weight altitude is a theoretical altitude (as computed by program wRASP) that would model achieve should it

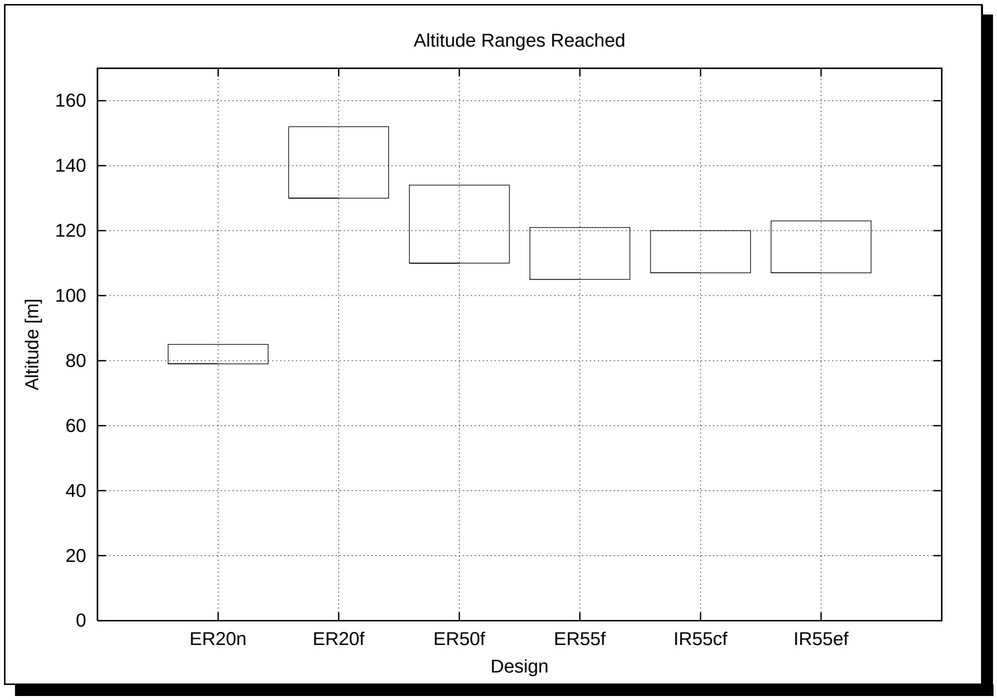

Figure 12: Altitudes reached by each design

have the weight of the lightest model in our set of models (54 grams). Minimal weight altitudes are compared at Fig. 14 on page 18.

5.2 Discussion of results

5.2.1 Folding blades effect

It is clear that the ER20f design outboosts every other design and some by a large margin. It flies almost twice as high as the ER20n design. The only difference between those two designs are folding blades of the ER20f. Also, all other designs outboosted ER20n design on every flight. And from reliability notes we also see that ER20n design is responsible for the only disqualified flight (unstable on boost).

Converting plain blades into folding blades is matter of half an hour of work, it adds stability on boost and increases the maximal reachable altitude by a large amount. As we proved earlier in the drop tests, adding the (un)folding mechanism to the blade does not negatively affect its performance, thus, we strongly recommend this design modification.

5.2.2 Drag coefficients

From the Tbl. 2 on page 14 and Fig. 13 on page 17 we see that IR (internal rotor) design have the smallest drag coefficient. However, as Fig. 12 on page 16 shows, they do not reach the highest altitude. The main reason for this is an increased weight of the model and larger frontal area. However, as the simulation results depicted on Fig. 14 on page 18 show, should we be able to decrease the weight of an IR design to the weight of an ER design, we could match the

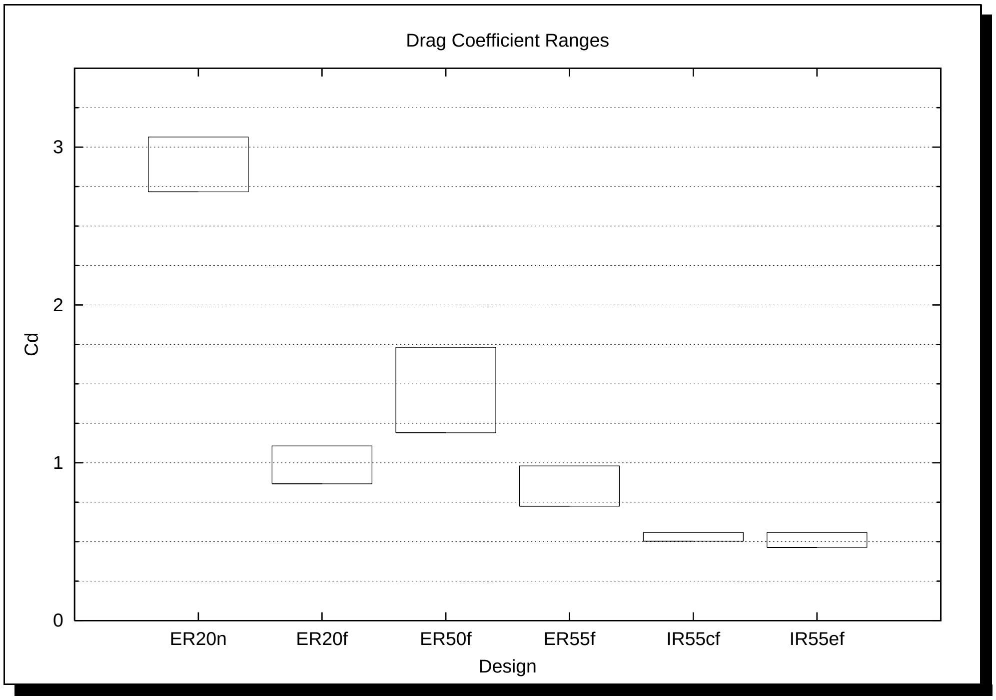

Figure 13: The range of drag coefficient for each design

performance of ER20f design (even with larger frontal area). The possible weight reductions will be discussed later.

Fig. 13 on page 17 shows an interesting fact. ER55f design (external rotor, folding blades with BT55 nosecone) has the lowest drag coefficient of all ER designs. We can only guess that a large nosecone creates a drag shadow for all external parts and thus the overall drag is lower. However the larger frontal area causes the model to fly lower even with the benefit of drag shadow. Larger nose also adds more weight to the design, but even computed minimal weight altitude is lower than for other ER/f designs.

5.2.3 Weight reduction

While our ER models are quite minimalistic and there is little that can be taken off or replaced with lighter components, our IR designs have lots of room for weight reduction. The possible modifications leading to a lower weight are:

Replace the balsa nosecone with an FAI style VacuForm nosecone	$-4g$
Replace the balsa transition with a vellum paper transition	$-3g$
Replace the body tube with a vellum tube	$-12g$
Use smaller fins	$-1g$
Total weight savings	$20g$

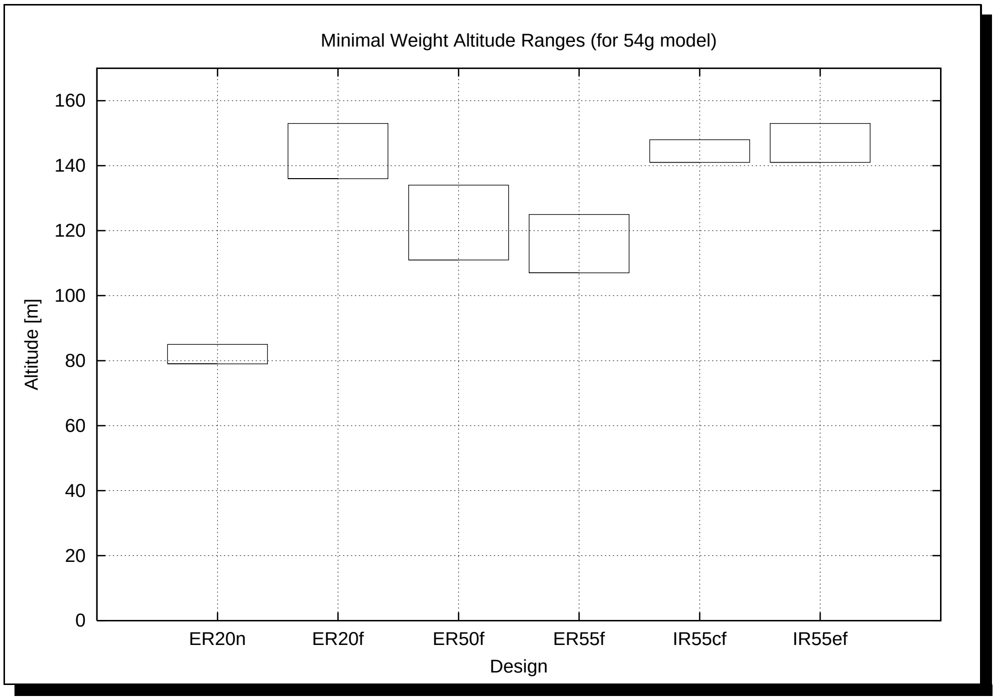

Figure 14: The minimal weight altitude range for each design

Smaller fins can be considered a weight saving against ER/f models. We designed all models to be as similar as possible and thus IR models have fins of the size needed to keep ER models stable. Computer simulation shows that IR models have 2 caliber stability and fins 33% smaller could be used.

The question of course is: will be the lightweight model still robust enough? With the exception of the nosecone (BT55 VacuForm nosecones are not available at the time of writing), we have built the lightweight version of the IR55cf model and launched it. We noticed no problems on boost, it was very straight, but unfortunatelly the tracking was not available at that time.

5.3 Reliability notes

In Tbl. 2 on page 14 are recorded all glitches and problems observed during our experimental flights. Let us to present a more detailed information.

5.3.1 Boost stability

The only unstable flight was recorded for ER20n design (nonfolding blades). The fins had to be increased by 33% for subsequent flights.

Internal rotor designs boosted very straight, even by the end of the day, when the wind started to pick up.

External rotor designs boosted straight at nowind condition, however experienced minor problems in the windier part of day. The ER20f model was hit by a wind gust on its last flight (which really affected the altitude) but still deployed properly.

5.3.2 Rotor unlocking and deployment

The usual burn string was replaced by the blade tabs (cf. Fig. 3 on page 5), which lock blades into boost position. At the ejection, when the booster separates from the rotor, the blades are released from the tabs and the deployment mechanism deploys the rotor. Internal rotor design do not need any locking mechanism, the rotor blades are held inside the body tube.

Blades were properly released on all 17 flights. At only one case (the ER55f design, flight #1), the shock cord got entangled in rotor blades and the rotor did not fully deploy. However the rotor still managed to spin a few times.

5.3.3 Rotation

Most of flights recovered in proper position (booster hanging below the rotor). Model ER20f once deployed past apogee, booster began tumbling and the model never achieved the optimal vertical position. However, the rotor functioned properly and the model recorded a 37s flight.

One of the rubber bands slipped off the hook on the last flight of the IR55ef model. Two remaining blades deployed correctly, which was enough to bring rotor to full rotation and eventually the third blade lifted itself into rotation cone and the model recorded 61s duration.

5.3.4 Safety stitch

On the ER20n model, on its last flight, the blade broke off the hinge, however the safety stitch held the blade and the hinge together. The rotor still rotated, however the duration was shortened to 37s.

5.3.5 Reliability summary

Out of 17 flights we had only one disqualified flight (94% qualification rate). All safety devices that we researched in the design part of this work, functioned properly and on number of occassions changed what would be probably a disqualified flight into qualified flight with an acceptable duration. Therefore, we conclude that the designs developed by our team and discussed in this work offer sufficient level of robustness and reliability.

5.4 The overall performance of the design

Altough the design was flown on the motor of smaller impulse than it is designed for (this was done to ensure high return rate of models), the performance was satisfactory. Tbl. 2 on page 14 shows that typical dead air time (on a flawless flight) was about 60s for B4-4 motor. The models are dimensioned for the C-HD event and we expect them to reach close to 120s in dead air (on C6-5 motor). The MidWest WeedWhacker design (with a small modification in the hub construction) currently holds US record in C-HD in T-division (after edging out another internal rotor design by mere 4 seconds). We expect even better time from the lightweight version but this is still in the development.

6 Further improvements

In our report we focused mainly on reaching high altitudes and upto certain extent we neglected the descend rate of the model (the r variable in the Eq. 1 on page 13). It is obvious that there are two main ways of making the model to descend slower:

1. Decrease the weight of the model (we have already discussed this aspect)
2. Increase the effectiveness of the rotor

Equations for heliroc descend rate are in great detail discussed in the R&D report of Tim Van Milligan[16]. Ellis Langford[10] in his R&D report designs and tests optimized rotor. He, as number of other researchers in this field, arrives to the conclusion, that optimal rotor has strongly negative angle of attack at the hub (to induce the autorotation) and zero or slightly positive angle of attack at the tips (to provide lift). However, Langford concludes that despite its superior performance, the twisted blade is difficult to make and can add more drag to the model.

We confirm that making twisted blades is not trivial. Twisting itself is not difficult but setting the proper angle while also accounting for the tendency of balsa wood to untwist complicates the process.

We also agree with the conclusion that twisted blade can add additional drag and exposed twisted surfaces can also have negative effect on the boost of the model. However, none of the boosts concerns are valid when an internal rotor heliroc design is used. In such a case, the blades are hidden inside the tube and their shape has no effect on the boost performance.

As a part of this report, we made several sets of twisted blades. Each set had zero angle of attack at the tips and $-10°$ to $-60°$ angle of attack at the hub. All blades were of the same size as the nontwisted blades used in this project ($14'' \times 1\frac{3}{8}''$). We converted each blade to folding blade (thus proving that it is possible to do even with twisted blades) and then tried to install them on the minihub and insert into the body tube. No further modifications on blades were necessary upto $-40°$ twist, blades with $-50°$ and $-60°$ twists needed small modification at the hub part to be able to get fully into the tube. Thus we conclude, that the minihub is versatile enough to host a large variety of twisted blades (which are currently considered optimal). Using optimized rotor will provide even more performance to the design.

7 Survey

As a part of our research project we posted a survey on several discussion groups on the INTERNET. It needs to be admitted that the response to the survey was low (15 entries), but because of the strong trends in responses, we decided to include its results in this report.

Design most used by competitor: 60% of respondents is flying RotARoc- or RoseARoc-like design. 20% of competitors is using a design where the booster and the rotor separate at the ejection (but stay connected by the shockcord), 20% of fliers is using internal rotor helirocs.

Most common failure cause: the failure to burn the burn string is a leading cause of the disqualification (almost 50% of respondents complained about this problem). This is closely followed by 30% of fliers suffering from nondeployment of blades due to past-apogee ejection . Remaining 20% consists from shred on boost, vertical flip on descend (the model descends rotor first) and an unstable boost. One respondent also observed, that unstable boost happens once in while for no apparent reasons (this respondent flies external rotor designs only).

Did the respondent ever build an internal rotor heliroc, and if not, why? 5 of 15 respondents built an internal heliroc model but only three are using them as their primary models. Most common reason for not building one is a lack of plans closely followed by being affraid of the complexity of such design.

Will the respondent try to build reasonable complex internal rotor design? All but one respondent are willing to build an internal rotor heliroc if a reasonable complex plan is available (difficulty should not exceed the difficulty of Rose-A-Roc design) 3 respondents expressed their doubts about having "that much time".

Did the respondent ever designed a heliroc model? 5 of 15 respondents answered yes to this question. 4 respondents did not create a whole design but cloned and/or modified existing design.

Most reliable/most succesfull design: RotARoc designs are named as most reliable and most succesfull by a full third of all respondents. Estes Skywinder is noted as the most reliable design by three competitors. Two competitors voted for internal rotor helirocs being most reliable and most competitive, two competitors prefer booster-rotor separation designs.

While the amount of responses was too small to draw any solid conclusions, we should not overlook the following:

- RotARoc-like designs are most popular. The same designs suffer from two most common DQ causes: burn string failure and ejection after apogee. Three survey participants noted as much as 30% DQ rate, yet they still consider this kind of design the best heliroc in their fleet.
- Almost all survey participants are willing to build an internal rotor heliroc design, but they did not yet, because plans are not easily available.
- 60% of all participants either designs their own models or strives to improve existing designs through modifications.

We can conclude that contestants are willing to try new designs but there is a shortage of information in this field. We hope that this report will contribute to a remedy of this problem.

8 Conclusions

- We researched available materials about heliroc duration models, identified the most common problems in existing designs and researched their solution. We implemented suggested solutions and proved their functionality during test flights.

- We created an original design that addresses most of the problems. The main portion of the original work is a rotor minihub design, which is sufficiently versatile to host blades of different designs and sizes and serve different kinds of of heliroc designs (e.g. external and internal rotor helirocs).
- We created three different designs that are using this minihub and used them succesfully in competition. As of presenting this report, detailed plans for two of the designs (Chicago Chopper and The MidWest WeedWhacker) are available. The remaining design (Chopper Charlie) is explained in this report in a sufficient detail.
- We have discussed construction of the internal rotor helirocs in a sufficient detail for a reader to be able to construct and succesfully fly such model. We believe, that internal rotor helirocs have great performance and reliability potential and we strive to make them more known to a larger number of contest fliers.
- We measured and compared the altitude performance of different heliroc designs, namely designs with folding vs plain (nonfolding) blades, designs with an internal vs external rotor. In regard to folding blades we strongly recommend their use as the altitude performance was doubled in our test flights and the rotor performance does not seem to be affected by the additional elements in the blade design. When comparing external and internal rotor designs, we found that well designed internal rotor heliroc has the potential to match and even surpass altitude performance of strongly competitive external rotor designs with folding blades. The internal rotor designs also offer great protection of rotor blades especially in higher impulse classes. More complex blades, which could impair the boost performance of external rotor designs (mainly because of the exposed twisted surfaces) can be carried inside the internal rotor heliroc and thus completely hidden from the airflow around the heliroc.
- Using a simulation software (wRASP) we computed drag coefficients for all tested designs. We used computed coefficients for predicting the altitude of minimal weight model (the model with the weight equal to the lightest model in the set). Minimal weight altitudes were used to compare models of a different weight without having to add dead weight to the lighter models.
- We surveyed a current status of heliroc competition field and found that competition fliers are willing to try new and innovative designs but generally the information is not readily available. We contribute to the remedy of this problem by publishing this report, including the internal rotor heliroc design.

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