MODEL HELICOPTER TECHNOLOGY

by Dieter Schlueter, Engineer,
winner of the first R/C Helicopter Contest September 74/lSth, 1968; translated by permission of "MODELL", Germany.

Author's winning entry at 1st Helicopter International, Harse-Winkel, Germany. Four-blade, main rotor is 47 ½ in. dia. Super Tiger G60 R.C. engine

A helicopter operated in the same manner as a conventional radio-controlled model aircraft-that must be the dream of many modelers and whenever this subject is raised, there are endless discussions. It would be marvelous to be able to let such a plane take off right by one's front door. There would be no more flying space problems! Who has not dreamt of this before? But the word "dream" is the key which immediately brings one back to earth. As far as I know, there is as yet no model helicopter which, when radio-controlled, comes anywhere near to these expectations.

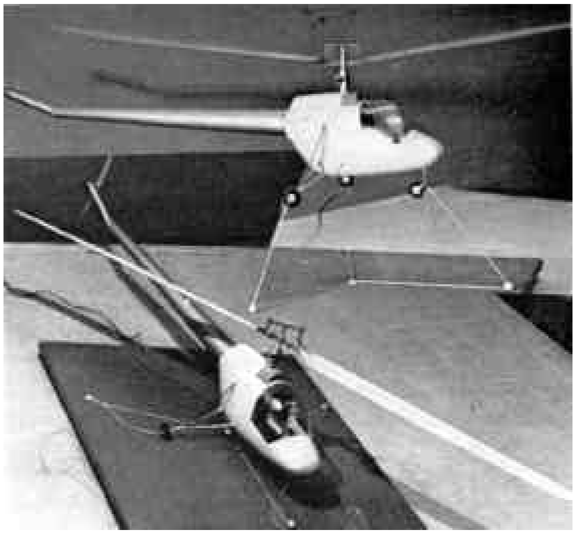
From the numerous discussions on this subject one realizes how many people who are involved with building helicopters do not fully understand the technology. Theories, which lack any fundamental technical knowledge, are postulated and these are doomed to failure from the beginning. Nobody would think of building a model aircraft without having at least some idea why such an aircraft flies at all today there is such wide knowledge in building conventional models that their construction can be based on long experience.

Builders of model helicopters face new frontiers and virtually have to design test and build every part themselves. A certain measure of imitation of real helicopters is, therefore, unavoidable, at least in the beginning.

What then is a helicopter and why does it fly? Let us start with the main rotor. Mounted on the rotor head are the rotor blades. These are long and slender blades; mostly there are at least two, often more. As a result of their rotation, due to profile and angle of incidence, they create lift.

Here we meet the first problem because the blades near the rotor hub move very slowly into the air, whilst at their tips they move quickly. This is the big disadvantage of the helicopter in general, since the speed at the far tips of the blades is, of course, limited. The ideal rotor blade would therefore be constructed in such a way as to give maximum lift everywhere. This is done partly by differing profiles and a decalage of the blade (or rotary bending). Since this has its limitations, some designers completely do away with the profile at the rotor disc and start the actual lifting surface approximately halfway along the blade. These considerations are only applicable to a helicopter hovering in the air. If the helicopter moves forward (or sideways or backwards), airflow by the forward movement is added to the actual speed of the rotor blade at the end of the blade. The advancing blade receives additional airflow so that this blade is under even higher strain. This is also the reason why helicopters are restricted in speed. Attention has to be paid to a far more important factor, which raises considerable problems, even at low flying speed. The air stream -does not only blow onto the blade when it is advancing, but also when the blade is retreating, and this happens with every rotation. Each blade, in the course of rotation, works alternatively with head and tailwinds. The result of this is that the blade turning against air-stream derives more lift than the one working with tailwind, so the lift is unequally

Ing. Biesterfeud's remarkable scale Bell "Huey" UH D-1. Rotor r.p.m. 840. Tail rotor 4,200 r.p.m. Main rotor 65 in. dia. Weight 3.6 kg. Webra 0.61 10c.c. engine. Helper is tracking rotor.



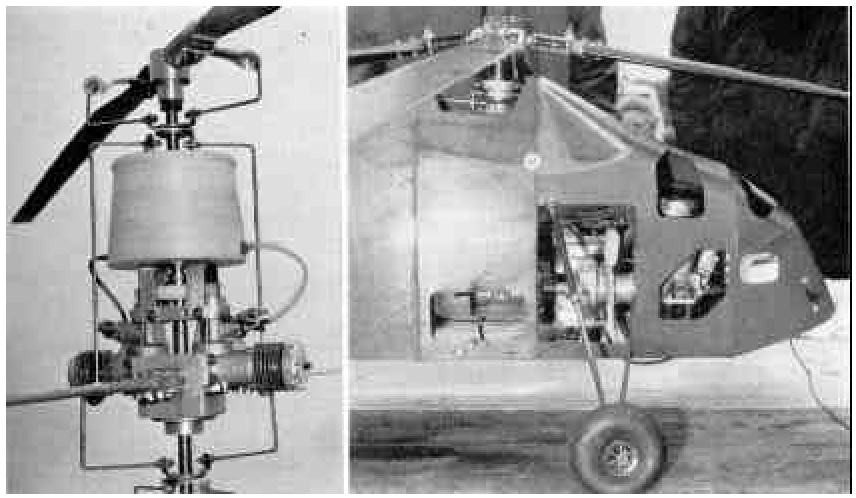
Electric driven from external source on A. Kouznetzov’s (Leningrad) experiment. Main rotor is 43.2 in. dia,, 1,800 r.p.m. Tail rotor, 4¾ in. dia., 11,000 r.p.m.Weighs 1 lb.

distributed over the rotor disc area.

This explains the many failures of models with a simple rigid rotor head. Those who do not pay attention to this will notice that their helicopter may lift vertically, but as soon as it gathers speed it drops to one side. This could be averted by a controlling movement, but in practice it is impossible since other control movements have to be applied as well. Besides, there is the additional factor regarding lack of experience in controlling a new model. These very problems also relate to real helicopters and one cannot, therefore, avoid building a complicated rotor head to eliminate the problem.

Flapping hinges

The rotor head is not only equipped with a device for the adjustment of the angle of incidence of the blades but also with an additional linkage called the flapping hinge, which allows - each blade to incline. The blade is not rigidly fastened to the hub but can move upwards, to 30 degrees and more. Weight of the blade and the speed of rotation result in a considerable centrifugal force, which prevents the blade from completely "flying" upwards. Consequently the blades, depending on the ratio of lift and centrifugal force, form a kind of V-shape known as the cone angle. In the case of real helicopters, this is between 3 degrees to 7 degrees and is comparable to the dihedral on the wings of model aircraft. This, however, is not to be confused with stabilizing model aircraft by means of dihedral. The success of the flapping hinge on the rotor hub is due to the fact that the blade turning against the wind does not transfer extra lift as torque direct onto the rotor head and consequently onto the model, but flexes upwards. It is only kept reasonably straight by centrifugal force. On the other hand, the blade with tailwind has less lift and flex downwards. Therefore the rotor head-and consequently the model plane-is not centrally suspended by the blades. Besides, the flexing of the blades results in a change of the angle of incidence, and of course places a considerable strain on the flapping hinges. This explains the problems of the head construction. If you listen carefully to a real helicopter, you will be able to hear the flexing movements very clearly. Since the flapping hinges give the rotor blades greater flexibility, there are, as a result, very undesirable and strong resonance effects which have to be compensated by shock absorbers.

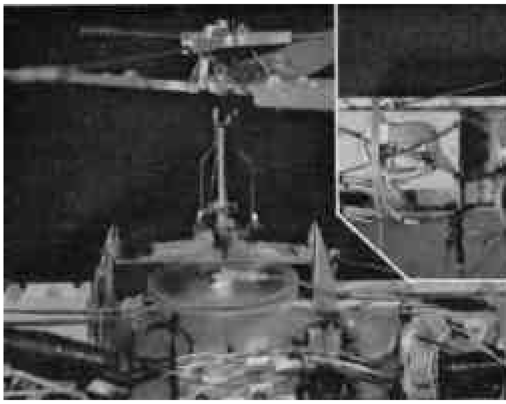
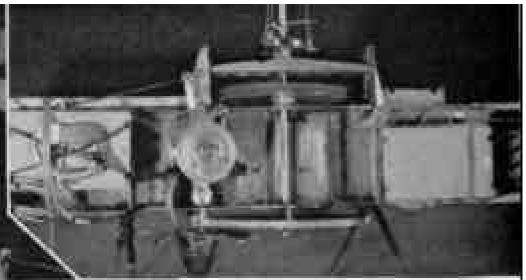


Author’s Sikorsky S-58 nose. Shows Super Tiger installed, weight 9 lb. Above, left: Contra-rotating rotor by Ing. J. Stehr, two Super Tiger G. 21/46 engines, 78 in. rotors, weight 8 ½ lb.

Ing. J. Berkenkotter’s tri-bladed 52 in. diameter model is 9 lb.; used Super Tiger G. 60 engine, 700 r.p.m. main rotor, 3,500 r.p.m. tail rotor.

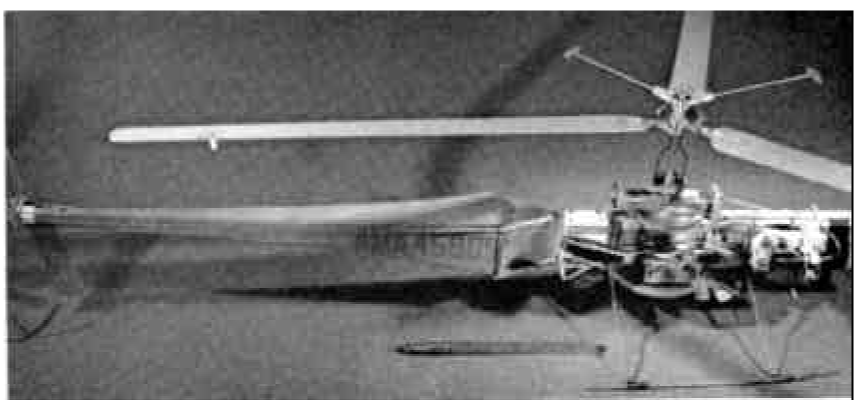
Blade lag

The flexing movement of the blades has a very undesirable effect. We have all seen a skater performing a pirouette. He accomplishes this pirouette by turning and slowly bringing his arms towards his body. He is, in fact, bringing the weight of his arms towards the center. The same applies to the rotor blades.

Detail of Burkam "Super Susie" Shows T.D. 0.049, fan/flywheel gearing, throttle servo and rotor drive.


Above left; Power unit on the Plested "Whirl-wind" with central box structure housing R/C and rotor drive. Above right; Gyro bar and rotor hub of "Susie" shows pitch links from bar to blade pitch arms. Below; John Burkam's (U.S.A.) "Super Susie" tri-blade rotor has 32 oz. Thrust, carried four servos. Fuselage is open channel 0.032 in. alum. Gross weight 29 ozs.



Due to the upward and downward flexing of the blades the centre of gravity comes either nearer to, or moves away from the rotor axis. This results in an acceleration or deceleration of the speed of rotation about the rotor axis. The upward-flexing blade, therefore, tends to turn more quickly, whereas the downward-flexing blade wants to turn more slowly. The blades, therefore, counteract each other in their rotation about the rotor axis. This, in its turn, results in an enormous additional strain on the rotor head and the flapping hinges. For this reason a blade lag is built in which makes it possible for the blades to move forwards or backwards. Through this blade lag movement, one accomplishes-in addition to the flapping movement-a better distribution of lift when it is windy or during forward flight. The blade turning into air stream has to overcome greater resistance than the blade working with wind. By means of the blade lags, it can, therefore, lag slightly behind the rotation movement. This means that for this particular part of the rotation, it becomes slower and produces less lift. Once it has overcome headwind, the blade stretches out again, becomes quicker, moves forwards into the direction of rotation of the rotor hub and, so to speak, overtakes the rotor hub. During the out-of-wind phase the blade is momentarily quicker than the rotor hub and consequently compensates the tailwind slightly. I am not sure myself if blade lags are necessary for model helicopters. I built them into my last model (which flew at Harsewinkel) and have had favorable results.

Thus, the main rotor consists of the actual hub, the flapping hinges and blade lags with shock absorbers. The blade linkages in their turn must be rotating in order that the angle of the blades during rotation of the head can be adjusted. The blade connections end at the angles of adjustment, which are connected to push rods. These have to rotate as well. Due to the fact that the blade connections adjust not only as far as the angle of incidence is concerned but, by means of flapping hinge and blade lag movements, execute very complicated maneuvers; the push rod connections are not simple-either. This is a factor, which causes great difficulties in building a model.

Blade Control

In order to effect a forward, sideway, backward, upward or downward movement of the helicopters an adjustment of the blade angle is nears firstly let us consider the blade adjustment necessary for upward and downward movement. This is achieved by a so-called "simultaneous blade adjustment". Let us assume that the blades are in rotation. For the time being let us ignore the question of power. Initially the blades turn at a definite speed of rotation. If the angle of incidence of all rotor blades is changed, the strength of lift is altered.

As the angle of incidence of the blades is slowly increased lift increases, until the point where the helicopter hovers in the air is reached. Under the rotor there is an air cushion, which supports it above the ground. This is the so-called "ground effect". The helicopter rests on this cushion, and in order to free itself from the ground effect slightly more lift is required-which means that the angle of incidence has to be increased further.

Keith Plested's Merco installation and rotor head on semi-scale Westland Whirlwind, which has passed initial tests satisfactorily.

The helicopter now rises upwards and can be kept hovering if, by means of carefully calculated adjustments to the angle of incidence, lift is kept the same as the weight of the helicopter. The first essential requirement for vertical lift and descent is, of course, that the centre of gravity of the helicopter lies exactly in the rotor axis. If this is not the case, the helicopter will incline according to the position of the centre of gravity, and there would be a shifting movement around the centre of gravity. With this, we have arrived at the first possibility of control-ling forward, backward and sideway flying of the helicopter controlling the centre of gravity. This kind of control is, however, not used on helicopters -at least not on real ones.

Centre of gravity control

Let us assume that the centre of gravity of the helicopter is exactly in the plane of the rotor hub and that there are no other external influences. By making an appropriate blade adjustment, the helicopter takes off vertically. If the centre of gravity is changed the helicopter will incline. The plane of the rotating blades will now incline as well, and the pull of the rotor blades is not just vertical but also towards the C.G. displacement. This will result in a corresponding movement. For this, however, the angle of incidence of the blades has to be adjusted since a small part of the former lift will now be used for movement. The centre of gravity control is not suitable for effecting sudden movements of the helicopter.

Rotor head control

The rotor head control is an addition to the centre of gravity control. In this case there is no shift of weight in the helicopters but the rotor head is adjustable, which means that the centre of gravity in relation to the rotor axis can be moved.

Head tilt control

In this case, the rotor head can be tilted in relation to the fuselage and the rotor disc inclined. A series of earlier helicopters were controlled in this way, and this especially applies to "Autogiros", which have no rotor drive. This kind of control is, however, very costly for powered rotors since the drive and all the other controls have to be flexible. This control can still be found today on smell helicopters. In most cases, a hand-operated control lever is connected direct to the rotor tilt link. All three types of control mentioned virtually have a rigid rotor head. The additional disadvantage is that there is no precise means of control. A rigid rotor behaves like a spinning top. If the position of a spinning top is altered by an external force, it will be displaced. This means that the top will try to move away at an angle of 90 degrees. This is, of course, highly undesirable in the case of rotor control.

Cyclic blade control

The varying air speeds of the individual rotor blades in horizontal flight necessitate the use of flapping hinges-as already explained. One utilizes the hinges by producing an additional flapping movement of the blades through cyclic blade adjustment. If a forward movement is desired, the individual rotor blades are controlled in such a way that, when in forward flight, the blade seen at the back lifts, whereas the front blade drops. This results in an inclination toward the front and consequently the addition to actual vertical lift of a forward component. The aircraft will move forward and the fuselage leans forward. Blade adjustment is no longer affected and all blades take up the same angle of incidence. If one wishes to change this, the angle of incidence of the individual blades has to be adjusted in such a way as to lift the front blade and lower the rear one, until there is no forward flight. The helicopter now has to be controlled at an even angle of incidence so that it will hover. Analogous with this forward and backward movement, movement to the left and right is possible as well as every combination of forward and backward flying. There is also periodic blade adjustment. Imagine you are looking from the top onto the rotor disc and this would be divided into a numbered clock face. The blades turn clockwise. On purely vertical take-off the blades have the same angle of incidence in relation to every dock reading, say 10 degrees. We now want the helicopter to fly forward, i.e. in the direction of 12 o'clock. The rotor circle plane, therefore, has to be tilted forward by periodic blade adjustment at the rotor head. Now let us follow the movement of any blade and start at 12 o'clock, i.e. at the beginning. The blade is now set at 10 degrees. It begins to move from 1 o'clock over to 2 o'clock to 3 o'clock and is meant to be higher at the rear (6 o'clock) than at the front. This is done by, beginning at 1 o'clock, slowly increasing the angle of incidence of the blade, which, at 3 o'clock is no longer at 10 degrees, but, let us say, at 11 degrees. Owing to its increased angle of incidence, the blade is inclined to lift (which it does). It lifts and while continuing to rotate over 4, 5 to 6 o'clock, the angle of incidence decreases again to 10 degrees. The blade, however, is now higher at the rear-in other words; it has been lifted by the flapping hinges. It now runs through 7 o'clock, 8 o'clock, during which time the angle of incidence decreases to 9 degrees. The blade, therefore, moves down and recovers its original 10 degrees then the cycle starts again for each blade in turn. It might be difficult to under-stand that the adjustment of the angle of incidence occurs at 90 degrees at 3 and 9 o'clock and that the effect only becomes apparent at 12 and 6 o'clock respectively. One has to understand that, through the flapping hinges, the rotor system is not rigid but quite flexible. The periodic or cyclic blade adjustment is not in any way parallel with the aileron of a conventional model aircraft since that is a rigid system. Unfortunately the cyclic blade adjustment interferes with the flapping movement when it is windy or at increasing speed. If, in our example, the rotor turns clockwise and the blades meet the wind, the retreating blade will drop at 3 o'clock whereas the one advancing with "head" wind will lift at 9 o'clock. This results in a slanting position to the right of the rotor, which will interfere with the forward tilting. The helicopter will, therefore, no longer fly straight forward in the direction of 12 o'clock but more in the direction of 1 o'clock. This can, of course, be compensated by moving the cyclic blade adjustment slightly more to the left, i.e. largest angle (11 degrees) at 2 o'clock and smallest (9 degrees) at 8 o'clock. Together with the flying speed or head wind, this produces a straight flight towards 12 o'clock. If the speed is decreased, the cyclic blade adjustment is altered accordingly. It will be appreciated that this is quite a complicated affair and these problems apply to real, as well as to model, helicopters. It is maddening if one wants to fly forward and the helicopter starts altering its course since, apart from this, attention has to be paid to the attitude at which the model is flying, the torque compensation and the engine control. One's hands are very full!

Rotor head controls

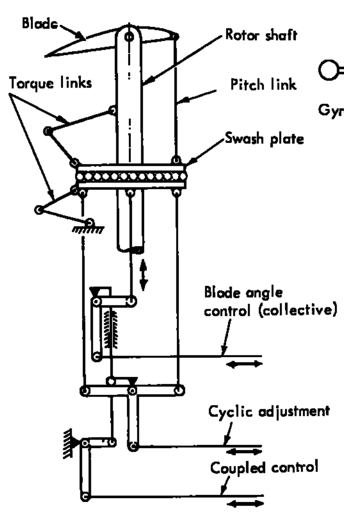
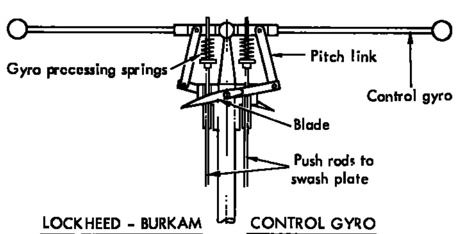
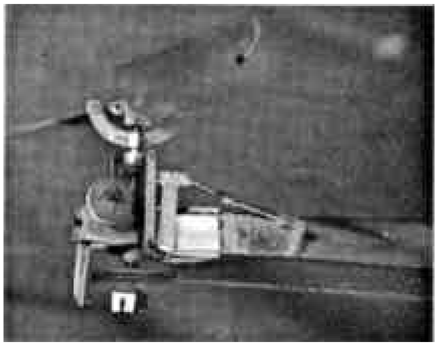


Diagram of basic controls as advised and described.



Burkam system of rotor control

How then is the cyclic adjustment of the angle of incidence affected? There are two possibilities, by means of the spider or the swash plate. They differ purely in construction but not in their effect. I had better start by explaining the swash plate, which is the more frequently used one of the two. The swash plate is suspended under the rotor head, which means it can be swiveled in any direction. The upper part of this plate is turned by means of the rotor head. The lower part remains rigid and is connected to the rotating part by a large ball bearing around the rotor shaft. The leverage from the joystick ends at the rigid part of the swash plate. The joystick is a conventional part and can be moved in all directions. By pressing it forward, the rotor blades drop towards the front. This means forward flying. A transverse movement effects flight to the right or the left. The joystick movements are transmitted to the rigid part of the wobble plate, which will then incline accordingly. Due to the bearing, the rotating upper part of the swash plate moves in the same way. The push rods controlling adjustment of the



"Super Susie" tail rotor and controls. Yoke connects to pitch arms on the blades and controls collective pitch.

individual blades are connected to this upper part. Apart from the fact that the swash plate tilts, it can also be moved up and down. This is achieved by the blade adjustment lever, which is positioned by the side of the pilot, like the handbrake on many cars. If this blade adjustment lever is pulled up the swash plate moves upward for higher angle of incidence. This corresponds to the vertical take-off of a helicopter, providing that the wobble plate is horizontal. If one now tilts the swash plate it means that the blade adjustment linkage periodically runs upward on the one side of the tilted plate (depending on rotation of the rotor) and downward again on the other side. When running upward the angle of incidence increases and when running downward it decreases. This produces the cyclic blade adjustment and, according to the magnitude and direction of the tilting movement of the swash plate, also an inclination of the rotor disc and the direction of movement of the helicopter. This, not very simple, blade control has the advantage that it is extremely precise and sensitive and the helicopter responds quickly since only relatively small parts of the blades have to be moved and not the whole rotor head. The pilot requires only relatively little strength to operate the joystick, and no auxiliary devices are necessary for this, up to medium-sized helicopters. This would also benefit radio-control since our little servos are also limited in power and by the time it has reached the rotor blades a lot of the power has been lost in leverage.

And now, briefly, to the "spider". The effect is the same as that of the wobble plate, with the difference that the spider consists of a thin lever which runs right through the hollow rotor shaft. It comes over the rotor head and is positioned there in a sphere. On this lever are the spider arms, one for each blade. A leverage connects the spider arms to the blade for adjustment. If one lifts and lowers the spider this results in simultaneous blade adjustment; if one lowers it, it results in cyclic blade adjustment.

John Burkam, *U.S. Model R/C Helicopter exponent, who has written a revealing address, reprinted in the 1969 D.C.R.C. Symposium papers, has the following comments*:

The Germans have done marvelously well in the short time they probably have been working on the problem. And they probably don't have a helicopter, or even an aeronautical background. Dr. Schlueter, at least, is finding out that model helicopters with no stability augmentation are just too fast at turning over for a human pilot to keep up with, even if there were no time lag in the radio control system. Ing. F.W. Biesterfeld with his Bell Huey and its stabilizer bar at least has a chance, if the bar is hooked up right and has enough inertia.

This side by side or the tandem rotor helicopter is very difficult to stabilize. The moment that one rotor moves into the area previously occupied by the other rotor, the still-down-moving air causes a decrease in lift of the following rotor. That side (or end) will drop causing the model to start moving the other way and the process repeats, only worse. I've had a tandem rotor rubber powered helicopter turn over in just one oscillation-'end over end! The single main rotor and tail rotor configuration, or the co-axial rotor helicopter has the best chance of success. Even the co-axial has some sticky control problems, but stability can be achieved by a stabilizer bar on the top rotor, just like a single rotor machine.

Flying a full scale machine is not going to help a model "pilot" much, unless it is done by radio control while sitting on the ground! I let a full-scale helicopter pilot who is also an expert R/C airplane pilot try to fly my model helicopter several times. He got crossed up in the controls worse than I did. That was in hovering. Maybe in forward flight it would have been a different story. Another licensed helicopter pilot tells me that the seat of the pants feel and the view out the window are everything. He and another pilot could both fly a moving base flight simulator but when they stopped the motion and gave the visual display only, neither one could fly it! I still think my method of starting out with the model tied to the end of a counterbalanced boom is best. Practice flying on the boom until it gets automatic, then go to free flight, possibly with someone else helping on the controls at first.

A word about different kinds of rotors. Some kind of stability device is a must on any kind of rotor, to slow its response time down to a human pilot's capability and hopefully to make the helicopter stable by itself. The Bell, the Hiller, the Lockheed type gyros will work on models, provided they are used with the type rotor they were designed for; that is, teetering or hinge less. The Bell and Hiller are probably the most stable but the model is prone to tipping over on any but the best landings. The tip weight and servo tab system used by most builders of the action less co-axial helicopter on their large rotor would work on R/C helicopters if one could figure out how to put cyclic control into the blades, or out to the trailing edge servo tabs.

Any rotor with lag hinges which allow the blades to lead and lag in the plane of rotation like some full-scale helicopter blades do is liable to encounter ground resonance, which will destroy the helicopter (like some full scale helicopters do). Even if the blades do not have any lag hinges but are flexible in the lead-lag direction (like Dr. Lee Taylor's 1967 and 1968 Nats model) they are likely to encounter ground resonance. The rule of thumb to use here is if the sum of the blade lead-lag frequency (while rotating) plus the pylon (shaft) natural frequency equals rotor speed then ground resonance will develop very quickly. This appears as a circular motion of the rotor centre together with a sequential lead-lag motion of all the blades, which in two or three seconds builds up to damaging amplitudes.

Another recommendation, which Ray Jaworski (U.S.A.) and I heartily endorse, is to use either very durable and indestructible gears in the transmission or use gears that are readily obtainable and easily replaceable. These one-cylinder motors pound heck out of 'em in a very short time!

Don't waste time on an overrunning clutch and pitch change device for autorotation. Those can be added later after you've spent hours and hours flying close to the ground learning to fly the darned thing. You'll probably want to build a much better or larger model soon anyway. That's another point; start with rubber powered models to learn about the stability problem, work up through small free flight engine powered 'copters to learn about transmissions and cooling and starting problems, then go on to R/C, and lots of luck!

Ist International R/C Helicopter Contest, Harsewinkel, West Germany, I4th and I5th September 1968

E. Deittrich has “normal” torque reaction 59 in. helicopter with MicroMax ekectric drive to tail-rotor. Webra 61 engine on rotor shaft, weight 8 ½ lb.

Credit for the initiative in running this contest must go to Walter Claas, owner of the firm of SIMPROP-Electronic in Harsewinkel. Specs were for a helicopter with a fuselage. Models were required to hover and fly in all four directions without turning the fuselage. Not one of the 13 entries flew in this manner. Some models had made some hops before at home that was all.

Most models were designed with the main rotor over the e.g. and a rear rotor to control torque. Some had contra-rotating rotors, or one rotor with contra-rotating engine with an airscrew like the well-known free flight helicopters.

Most precise in starting was Ing. F. W. Biesterfeld with his well made Bell UH D-1, an excellent replica of this type. He lifted the model only a few millimeters with both skids sliding on the earth. He then turned the fuselage in both directions by altering the pitch of the rear rotor. But when he gave some more pitch to lift the Bell, at same time the fuselage turned clockwise round the rotor-axis. The torque came so suddenly and as it seemed powerfully that the human reflex of counteracting controls was too slow, even by one so long experienced with experiments as Herr Biesterfeld, the well-known Delta flyer.

Biesterfeld received the 1st prize for design (and styling) and a special prize of £50. from Gunther, Count of Hardenberg, who is the owner of the firm Motorflug Ltd., the German importers of Bell helicopters. For his flying Biesterfeld received the 2nd prize, after Ing. Dieter Schulter with a model of the Sikorsky S-58. Also a well-made machine, similarly without luck at flying. At first attempt the model lifted nearly 6 feet, the fuselage turned around the axis of the main rotor, then rolled to the left and crashed. Time was a mere 3 seconds, rotor blades were broken but gear and motor safe. After some hours of repair, the model flew again. Perhaps a second longer 2 or 3 feet higher but now the fuselage turning clockwise and then rolling the fuselage to the right- more crashed blades. ~ These two flights were the longest and it won the 1st prize for flying of,`150. £1,330 un-awarded prize money will be paid at the next international R/C Helicopter Contest, perhaps, in 1970.

Heinemann Bros.’ Test rig for 63 in. dia. Super Tiger 60 powered entry, 1,200 r.p.m., weight 9 lb.