Torque Reaction Helicopter Models-further experiments
By: Roy L. Clough Jr.

Thus far in discussions of model helicopters most reports have stuck pretty closely to single rotor machines, or those in which a rotor, or pair of rotors support the weight symmetrically.

However, for model work we find that duplicating the rotor arrangements of the big craft is not very practical except in rubber or jet power configurations, both types being unfortunately of short-lived duration. If we wish to use gas engine power, at this stage of the art, we must find some method of using a power plant, which grinds out several thousand rpm without getting into too much complication. One method of doing this is by designing our ships to the torque-reaction drive specifics, the system whereby the engine torque spins a large rotor in opposition to the rotation of a smaller prop on its shaft. (This, incidentally, should not be confused with true co-axial systems, which utilize equal-sized rotors turning in opposite directions.)

Very good performance is possible with torque-reaction drive although it has two major drawbacks: 1) it is not very efficient because of low mechanical advantage; 2) the system does not behave in classical fashion—that is, we have a new and different set of forces and reactions to deal with. Objection #2 is not serious if we remember to keep the reactions of this type isolated in our minds from the reactions of standard types and not confuse them.

Torque-reaction drive helicopters are queer birds. They are almost as removed from conventional helicopters as, for example, an autogiro. The reason for this is that torque-reaction drive helicopters split flight duties between a large, slow-moving rotor and a prop attached to the engine shaft. The engine shaft prop is generally standard and it has one main function-it provides 99% of the lift. In some cases it may be used to contribute to stability as well, but the primary function is to lift the machine. Its gyroscopic effects are completely negated by the much larger mass of the engine and big rotor whirling around in the opposite direction underneath it. The function of the large rotor is to provide a torque drag on the engine, a device with which to secure stability and control, and finally, to serve as a parachute to let the machine down without damage when the power stops.

This division of labor produces an unusual condition because, under power, the large rotor is operating in a substantially unloaded condition. Its blades are not damped by a strong aerodynamic pressure as they would be if the weight of the machine was being supported by them. As a result, control and stabilizing reactions assume an altered aspect. The builder who does not understand this may find his model crashing repeatedly despite his efforts to re-rig it for normal flight, because the control reactions, in most flight regimes, are actually reversed. If we build a very simple helicopter, with rigid, un-pivoted blades without tip weights and adjust it to fly forward we find that it starts to slide ahead, then noses upward sharply, slides back and repeats the pattern with increasing amplitude until it crashes. The reason for this is that the advancing blade produces a high lift force when it encounters the relative wind; this lift processes 90 degrees forward tilting the nose up, which kills forward speed, then the model slides back with what was the retreating side of the rotor now producing a lift which will move 90 degrees, or to the tail, riding the tail up then sliding back, etc., etc.

So we now pivot the blades and fit them with dynamic balances. Now when the model moves ahead the air pressure on the front of the disc makes the rotor blade twist its pitch angle upward, 90 degrees ahead that is the retreating side, and downward, that is 90 degrees behind on the advancing side. When this happens the change in pitch 90 degrees to the side produces a force that is moved another 90 degrees, so that the rotor disk tends to tilt up at the rear and down at the front. When the model is in a state of balance the forces cancel out and the machine flies forward without riding up at the nose or going into a dive. This is due to the upward force of the relative wind striking the advancing blade being leveled out by the pre-cessive pitch shift in the blades produced by the pressure of the relative wind, which tends to nose the rotor disk down. This is the way it should work, and does work when the CG is properly located. However, if the CG is improperly located trouble develops, and this trouble is usually a dive. Why?

Suppose the builder flies his model once or twice and it works quite well, moving forward steadily. He then wishes to see it rise vertically. It would seem reasonable then, to add a bit of ballast to the tail to kill off the forward motion? Unfortunately it does seem very reasonable. We have the past precedent of fixed wing models; we have the precedent of single rotor helicopters, which fly forward if the weight is moved forward and back if the weight is moved back. Seems reasonable. So weight is added to the tail, the model rises up, starts forward faster than ever, noses down and crashes. Why was this?

We just said that torque-reaction helicopters are a special case because of the unloaded condition of the rotor, which does the controlling. Here is what happens: We have noted that air pressure on the rotor results in a cyclic action which resolves to cancel the nose up effects of that pressure, that is, relative wind effects are self-nullifying. But, any force applied to the rotor reacts in cyclic control, the blades shift in an effort to nullify the applied force.

Now, when we add weight to the tail we are placing a steady pressure on each pivot blade as it passes over the tail-the CG has shifted—and by reference to gyroscopic precession laws we see that this force will result 90 degrees further on, or at the side. Thus the blade advancing tilts down and the blade which is retreating on the other side, tilts up. This tends to twist the rotor laterally, but again referring to gyroscopic rules we can see that this twist, moving 90 degrees, resolves to push the nose down! Thus if we take a helicopter which is adjusted to rise vertically, and move the CG aft a little bit the model will now fly forward—BUT if we move the CG too far aft the model will overdo it and dive into the ground. This is because we have two cyclic instigators working, the CG imbalance, plus the normal cycling produced by forward flight.

A model of this sort therefore is fairly sensitive to CG location, too sensitive, as a matter of fact, so it is customary to build in a safeguard which will allow a wider altitude of CG travel before diving or tail sliding occurs. A good example of this is the Berkeley kits, which use two different methods of obtaining the same result. In the D model we note that two of the blades are fixed in pitch. Thus, as the model moves forward the lift build, caused by increased relative wind meeting the stiff blades tends to push the nose up, while the cyclic action tends to push it down. Since the up couple is a bit stronger we also have a drogue on this job, which increases the cyclic reaction of the pivot blades, and, secondarily slows the model down. '

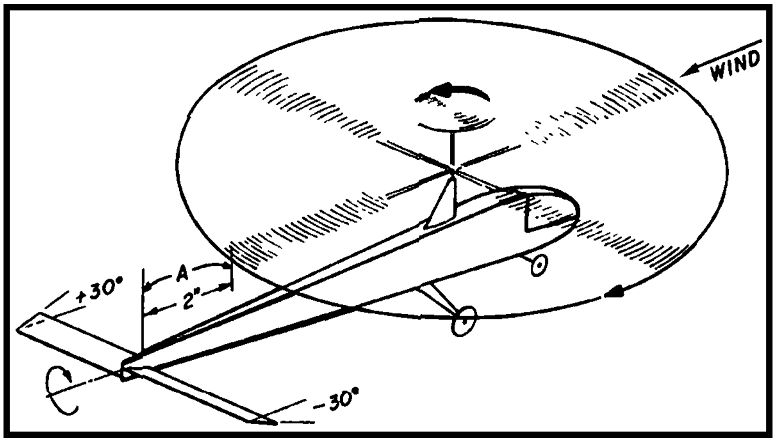
Thus, within allowable CG travel the tilt angle of the machine is self-governing. If it slows down the cycling action, which is fully automatic, tends to speed it up, if it goes faster, the stiff blades bring the nose up, slowing it down. This governing action is pronounced enough to permit flight in surprisingly high winds and gusts without getting into trouble. However, if the CG is moved too far aft, the balance of forces is upset and the model will dive in. Ordinarily the model D gives no trouble—except where the builder has put on several heavy coats of dope and has not re-checked his CG afterward. The CG position shown on the plan, incidentally, is for absolute maximum top speed. To climb vertically it must be moved ahead with ballast.

The other model, the TR, has four pivoted blades and uses a swivel prop to provide a recovery couple. When the tilt is to the right, changing the lift vector, which puts a side load on the rotor which induces a cyclic shift which pushes the nose upward. This model has a tail rotor to control heading, and a few words on this: A rudder will not make a helicopter turn. A positive side thrust is required; hence a tail prop is needed to push the tail around or to hold it steady. A rudder will only crab the ship slightly while it continues in substantially the same direction. Another method of obtaining turn without a tail rotor is to tilt the rotor mast toward the side toward which turn is desired. Don't get confused on this, the model does not slide that way, but the downwash rebounds from the side of the fuselage at a different angle, tending to roll the model over—but again by gyroscopic reference, the roll is resolved at 90 degrees into turn.

There are many ways in which a torque-reaction helicopter can be set up. One thing, which is quite important, is to respect the fact that the fuselage lies in the downwash of the small prop, and exposed areas should balance, or very nearly so or there may be serious trouble. The use of small fins in the prop wash to obtain turn, or to reflect the wash' backward for reactive forward propulsion meets with some success and one can use a twisted stabilizer which tends to put torsion on the fuselage with increased forward speed, to induce nose-up cycling, relative wind strikes the prop edge it as a corrective force couple.

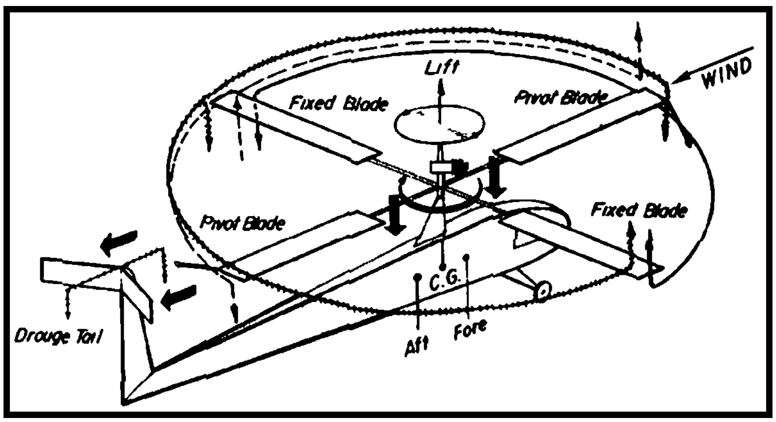
When designing originals it is a very good idea to include always some governing factor on forward speed. Rig it either with a swivel prop, a stiff, alternate set of blades, or torsion fins. Speed of forward flight will vary with the design and power plant, and will not be as high as a fixed wing model—a good fast walking pace is about right with present designs. —ROY L. CLOUGH, JR.

THE USE OF TORSION FINS



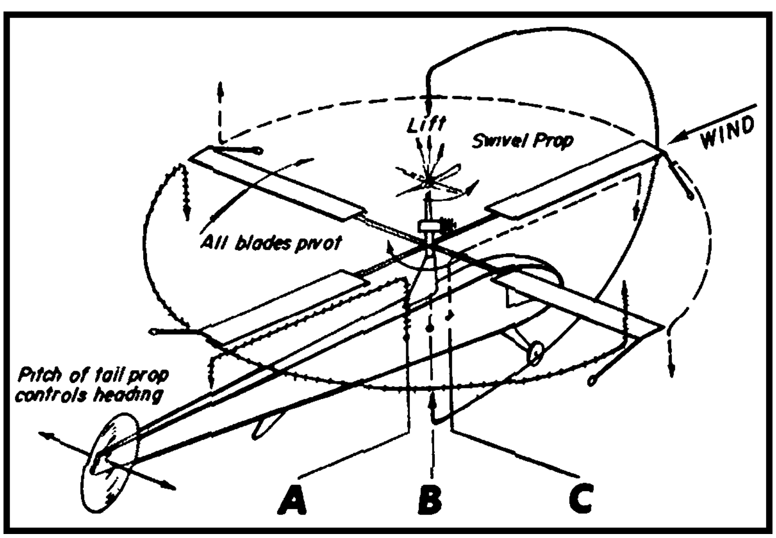
"A" must clear rotor disk. Fins may be either horizontal or vertical. As forward speed builds up, fins tend to roll fuselage to right, which induces nose-up cycling moment.

FORCES ACTING ON TYPICAL HELICOPTER



Barred lines: drag of drogue tail produces down pressure on balance weight of pivoted blades which induces cycling action which tilts blade down at side and pushes nose down. Dash lines: fixed pitch of this blade encountering relative wind produces lift at side, but since rotor functions as a gyro the reaction moves 90 degrees, producing nose-up tendency. Solid line: wind pressure on pivot blades reacts at 90 degrees to make pitch change shown to hold nose down. Thus, if CG is too far aft it induces cycling in the pivoted blades which reinforces down control of drogue tail and wind impingement on pivoting blades and overrides nose-up tendency of fixed blades and the model will dive in. Centered CG has no cyclic effect and model will rise vertically. CG too far to front will cause model to back up or tail-slide. NOTE: CG is usually slightly aft of mast CL in order to balance fuselage effect and promote forward flight.

FORCES ACTING UPON TYPICAL SEE-SAW PROP HELICOPTER



A) CG rigged tail heavy induces cycling in pivoting blades which causes nose-down forward motion (barred lines). B) With CG centered, model rises vertically. C) Nose-heavy CG will cycle blades into backward flight (dash lines). Wind pressure on blades produces precessive pitch change at side position preventing nosing-up (solid lines). Role of the swivel prop: wind pressure on front of see-saw prop, by gyro precession, causes it to tilt to model's right, which angles lift vector to right. Side thrust on rotor system produces cycling which makes nose of model ride upward, thus limiting forward speed and preventing dive (assuming CG is correct). Seesaw prop must be mounted to rock freely for best results. (Seesaw prop can be eliminated if two opposite blades are fixed pitch with counterweights removed.