LOCKHEED XH-5IA

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For the RC'er who wants the ultimate, here's a scale 70″ diameter rigid rotor helicopter for full house proportional. The author's text and engineering drawings will provide you with a sound basis for advanced experimentation.

I. INTRODUCTION

HERE'S one for the fellows who are bored with things like multi-engine carrier landings and piggy-back sailplane launchings. It's an eight pound, four control, 70-inch diameter rigid rotor helicopter. It can be flown as a rectangular fuselage section experimental job and then finished up with a fuselage shell of balsa or fiberglass to be a scale model of the Lockheed XH-51A helicopter. Here's a model you can literally fly in your own backyard.

The model was made as small as possible to carry full quad proportional gear and still have light enough disk loading for safe vertical autorotational capability. One of the design objectives was to keep the machine work as simple as possible. Well, all I can say is you should have seen it before it was simplified. The model is about one order of magnitude more difficult than a multi-engine scale airplane, and should be attempted only by an experienced and clever machinist. Estimated time to build is about six months, spending most of your spare time on it. It took two such full months to design the thing. First came the preliminary specs and some aerodynamic calculations to determine size, hovering power, rotor rpms and autorotation capabilities. Then some preliminary designing and weight and balance estimates. Next came detail designing and working out the many technical problems, along with a little stress work. The C.G. was kept track of during the many changes. Finally came the work part, putting the design on Mylar so that other people could build it.

II. DESIGN FEATURES

A. Rotor

The rigid rotor and stabilizer bar were chosen not only to give stability in the air but also to minimize roll over on landing. A teetering or flapping rotor could have been made stable in the air by a gyro stabilizer bar, but they give no roll or pitch damping to the fuselage in the event of a sidewise or forward speed landing. The aircraft would bounce once and roll over, creaming the blades. The rigid stabilized rotor tends to hold the fuselage attitude constant regardless of external influences.

B. Controls

This model has more coupled controls than most full scale single rotor helicopters have. Not only is the throttle coupled to the collective pitch of the main rotor but also to the tail rotor pitch. When the pilot gives an up-collective control motion, the engine throttle is also opened a little and the tail rotor thrust is increased to take care of the added torque. Another servo is connected to the tail rotor control like a trim servo to give independent yaw control. The lateral and longitudinal servos serve the purpose of exerting a tilting moment or force on the stabilizer bar, not a displacement. The bar then precesses or tilts in the direction 90° later around the azimuth from the point where the force was exerted. The pitch links from bar to blades then change the blade pitch cyclically and the rotor responds immediately, tilting the fuselage also.

C. Radio Gear

Although proportional gear has been shown, a reed system should work very satisfactorily, using trim type servos for throttle-collective and yaw and self-neutralizing for the lateral and longitudinal control servos. The antenna extends out in front like a yaw boom on a real helicopter. This position gets it away from interference-producing mechanisms, puts it near the receiver, and helps get the C.G. forward. For nearby flying, hovering and slow forward flight, the antenna could be shorter than three feet.

D. Performance

Calculations indicate that only 1/4 horsepower from the engine is required for hovering at 8 pounds gross weight, out of ground effect. Of this 1/4 horsepower, only .168 is required by the main rotor, the rest going into transmission and cooling losses and tail rotor power. At full power from the Veco .45 engine, the helicopter should be able to lift over 15 pounds total!

E. Tail Rotor Drive

The tail rotor is driven by a flexible shaft (1/16 diameter music wire) supported at four places by Teflon tubing. This system keeps the drive train within the envelope of the scale helicopter and eliminates one gear box or universal joint at the bend in the tail boom. Torque limiting clutches connect the shaft to the gear box at each end and prevent twisting off the shaft in case the tail rotor strikes something while the main rotor is turning. The tail rotor incidentally is two inches larger in diameter than scale size because a suitable pair of 6:1 ratio bevel gears could not be found. If the builder wishes to drive the tail rotor at six times main rotor speed by suitable changes in gearing, the diameter may be reduced to 12 inches and the blade chord reduced in proportion.

F. Flywheel and Clutch

A centrifugal clutch is built into the flywheel whose inertia is approximately equal to that of a 15 inch propeller. Engage speed is set at something above idle speed (say 3,500 rpm) so that the engine can be started without turning the rotors. Assuming needle valve adjustments have been previously made, the engine is started in idle position, and the pilot retreats to a respectable distance with transmitter in hand. The throttle is advanced slowly, the rotor comes up to speed, the aircraft becomes light on the skids, the pilot checks the trim of the cyclic controls as he watches the model, and then as the throttle is advanced still further, the model lifts off the ground. Autorotational descents with engine running can be performed merely by closing the throttle (slowly). The tail rotor is driven directly from the main rotor and downstream of the free wheeling clutch so that directional control is maintained during autorotation. Recovery from autorotation while engine is running can be made by advancing throttle slowly, to avoid large shock torque as the engine catches up with the rotor.

III. CONSTRUCTION

Hard balsa, hard aluminum and hard plywood should be used in construction. Where an aluminum bracket has bends in it, half hard should be used. Where set screws are used to hold gears and hubs to shafts, Loctite or epoxy should be used to hold them in. In many cases links and levers are connected by means of washers epoxied to the wire on either side of the link. To prevent rust all exposed steel surfaces should be painted with epoxy paint or zinc chromate primer. It is suggested that due to the extreme complexity and large number of parts involved, construction be done in an order such that parts can be assembled soon after they are made. Also, partial assemblies can be tested and if necessary changed before the complete helicopter is assembled. Such an order of construction and testing is as follows:

Construction

1. Fuselage and landing gear
2. Engine mounting
3. Flywheel-clutch
4. Cooling fan drive
5. Fuel tank
6. Transmission
7. Free wheel clutch and shaft
8. Tail rotor take-off
9. Pylon and upper controls
10. Swashplate and push rods
11. Main rotor and stab, bar
12. Radio and Servo instil.
13. Tail rotor drive shaft
14. Tail rotor gear box
15. Tail rotor
16. Tail rotor controls
17. Horizontal stabilizer
18. Covering

The following are suggestions for specific construction problems of the model:

1. Fuselage and landing gear: The crosspieces in the tail boom are mostly 1/16 x 1/4 balsa strips cemented on the inside surface of the longerons. Then 1/16 x 3/16 strips are cemented edgewise to the 1/16 x 3/14 strips to strengthen the latter and support the covering. Larger glue area and much better strength-to-weight ratio result from this type construction. Some covering can be done to strengthen the fuselage for interim testing.
2. Engine mounting: Pre-drill the hardwood for wood screws to avoid splitting. Epoxy cement is also advised. Take care to get crankshaft perpendicular to plywood top deck for smooth running coupling between the clutch and transmission.
3. Flywheel-Clutch: Accurate balancing is essential for smooth running. Balance each part before assembly and then balance on assembly, piece by piece. By calculation, if 1/8 diameter solder in pieces 3/16 long, is closely packed in the coil spring with no gaps, and if the preload in the connected spring is 1% pound tension when slipped over the inner ring of the pressure plate, engagement should occur at 3,000 rpm. It may be desirable to set this speed higher by increasing spring tension.
4. Cooling Fan Drive: Gears should have a few thousandths of backlash. Pre-lubricate teeth and shafts with Lubriplate light grease. It will be thrown off the teeth but the surfaces will be plated somewhat.
5. Fuel Tank: Fasten in with several wraps of soft copper wire and twist ends, unless you can find some fuel-proof rubber bands. Fill by removing fuel line from nylon filter.
6. Transmission: Since ample power is available, a sleeve bearing drill gear reduction could be used in place of the ball bearing one shown. The ratio should be about 20:1, which is about what most 3/8" drills run.Two-stage reduction is essential to turn the rotor the right direction. Be sure the input shaft (part of the armature of the drill motor) is supported against cocking by two bearings. Quite a bit of weight can be pared off the case with saw and rotary file and hand file, depending on ambition.
7. Free Wheel Clutch and Shaft: The brass bevel gear is clamped to the main rotor shaft rather than set-screwed to it, to avoid distorting the thin tubing and binding the sleeve bearing. That bearing should be a close fit to minimize wobbling of the rotor shaft. Try to get nearly equal pressure on both pawls of the ratchet.
8. Tail rotor takeoff: Be sure the spring one-way clutch is wound the right direction to tighten up when the engine is driving the tail rotor. Limit the maximum driving torque to about twice normal driving torque by limiting the number of turns wound on each side of the parting line between 1/8 shaft and 1/8 sleeve over the drive shaft.
9. Pylon and Upper Controls: The pylon is attached by screws into the transmission case and screws through flanges resting on the plywood deck of the fuselage. The upper controls should move freely in the direction to tilt the swashplate by at least 4 or 5 degrees. It is important that the resistance to tilt felt by the stabilizer bar be kept to a minimum to avoid feeding back unwanted precessional forces into the bar. Otherwise the bar would have to be made larger. Small rubber washers are used in various places to prevent side play of links and yet allow some angular motion. The special screws have unthreaded lengths where links ride on them, for more bearing area and longer life of the links.
10. Swashplate and Push Rods: The heart of the swashplate, its ball bearing, may have to be ordered from the manufacturer, Split Ball Bearing, since most jobbers don't carry that line. Be sure screws are cemented in before extensive running is done. A lost screw here in flight could be disastrous.
11. Main Rotor and Stabilizer Bar: Balance each part individually before assembly. Be sure all blades have the same built-in coning angle. Assemble blade spindles and set at exactly 120° angles to each other before drilling 1/16 rivet hole. This rivet shears if a blade strikes something. Then attach blades and pattern at 120° to each other before drilling screw holes in blade retainers. Stabilizer bar should pivot freely on ball joint in the center, but also have very little looseness. Lubricate well with Lubriplate grease. Balance rotor by adding weight to the blade tips. Balance bar by removing weight from the tip (by drilling into the nose of the tip weight and filling with balsa).
12. Radio and Servo Installation: The Micro-Avionics system dimensions were used for the drawings. Any good quad-proportional system could be used, or even a reed system, using trim type servos for throttle and tail rotor and self-neutralizing for the lateral and longitudinal controls. Whichever system is used should fail-safe with lateral, longitudinal and tail rotor controls in neutral and throttle in idle position. Model should then autorotate at a vertical rate of descent of 13 ft./sec. or less and at a forward speed depending on the C.G. position and cyclic control trim.
13. Tail Rotor Drive Shaft: If only three foot lengths of We music wire are available, solder two pieces together with a split sleeve available in hobby shops. Put the joint outside of the supporting tubes. Have a slight compression in the shaft to hold the ends in their sockets. Wire should be as straight as possible to start with.
14. Tail Rotor Gear Box: Cement assembled gear box in place in holes cut in the balsa side pieces at the top of the tail fin.
15. Tail Rotor: Assemble blades and pitch links by first screwing on blades to proper position. Put wide ends of pitch links on Z-shaped wire bracket which is not yet cemented to 1/8 control tube. Slide Z-bracket one way and slip that link over blade pitch arm. Slide other way and slip the other one on. Some bending of the Z-bracket will be necessary.

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(Continued from page 66) Then center it, check that both blades are at same pitch and (epoxy) cement Z-bracket in control tube.

16. Tail Rotor Controls: Keep backlash to an absolute minimum, yet make controls easy to operate.
17. Horizontal Stabilizer: It may be desirable to add some hooks to the leading edges and use fish line to hold the stabilizer halves on, especially if the dowels become loose in the sockets. Stabilizer is needed only in high speed forward flight, to aid stability and improve longitudinal control.
18. Covering: Cover main fuselage with 1/32 plywood with suitable cut-outs for tank, batteries, cooling, starting, needle valve, etc. Cover tail boom with 1/32 balsa with grain at 45°. Cover that with silk and then dope or Hobbypoxy. Keep tail boom and all parts back there light to avoid having to add four times that excess weight at the nose.

IV. RIGGING AND TESTING

A. Test clutch and flywheel on an electric motor with some kind of tachometer. Hold the output hub and check speed at which clutch engages. Spin the flywheel at 15,000 rpm (no higher) to check its ability to hold together. (May be eight screws are needed instead of six.)

B. After enough controls are completed to hold the main rotor at any given collective pitch, check the power and collective pitch setting required to give 8 pound thrust at 562 rpm. Also check throttle settings for idle at 2,200 engine rpm, driving the rotor at 535 rpm in flat pitch, and developing 8 pound thrust at 562 rpm and required collective pitch. These settings are used in coordinating throttle and collective pitch.

C. After the throttle servo has been installed juggle the wheel position and length of slot in the collective pitch link to satisfy the settings found in B above. The pin should travel from one end of the slot to the other while engine speed increases from idle to 9,500. Then both collective pitch and throttle should increase to the settings for 8 pound thrust and 10,000 engine rpm.

D. After tail rotor controls have been installed for tentatively 10° tractor thrust and 20° pusher thrust, find tail rotor pitch settings to equalize main rotor torque at 0° collective, 535 rpm, and 8 pound main rotor thrust at 562 rpm. Juggle point at which the bellcrank end enters the mixing lever between collective pitch link (to main rotor) and tail rotor servo. Movement of main rotor collective from 0 to 8 pound thrust setting should change tail rotor pitch from position to position required to keep main rotor torque balanced while tail rotor servo is held stationary. Then choose pin position in tail rotor servo wheel which gives about plus or minus 10° tail rotor collective pitch while main rotor collective is held stationary.

E. After installing lateral and longitudinal control servos select tension springs of a length and strength that will give an increase in tension from say 16 oz. minimum to 21 oz. more or 37 oz. maximum when stretched by the distance traveled by the end of the servo arm. When both springs and fishlines are connected from servo to bellcrank and the servo is rotated to end of travel one way, the moment exerted on the stabilizer bar should be about 8 inch ounces. This will give a bar precession rate and aircraft pitch or roll rate of about one radian per second.

F. After model is fairly complete, check rotor stability as follows. Hold model overhead while engine is running and main rotor collective pitch is set for hovering. Gently tilt the model forward and backward while noticing whether it wants to tilt sidewise of its own accord. Also notice how much resistance to tilting it offers. If it offers lots of resistance to fore and aft tilt and wants to precess or tilt 90° to the way you tilt it, it means that the blades will have to be swept forward slightly relative to the spindles. Remove all but one blade retention screw from each blade root, move blade tip forward a quarter of an inch, redrill holes if necessary and reinstall screws. Check rotor balance roughly by checking blade pattern (distance from tip-to-tip). Again hold model overhead and tilt it gently. When the model stops wanting to precess and still offers some resistance to tilting, it should be stable in the air. The larger and heavier the bar, the more stable it will be in the air.

G. Check rotor response to lateral and longitudinal control input by holding it overhead loosely while it is practically supporting itself. Have someone slowly move the longitudinal control only. If the model pitches forward or backward only, you are lucky. Similarly for the lateral control. If the model tilts forward slightly while it is tilting laterally, you can either always put in a little longitudinal control with your lateral to get pure lateral response, and put in a little lateral with your longitudinal to get pure longitudinal response. Or you can reposition (rotate) the upper controls on top of the pylon by the amount necessary to give pure unmixed control response. I hope I guessed right for the necessary amount of lead and precession when I laid out the drawings.

H. Theoretical or calculated control ranges are as follows: Main rotor — Autorotation at +2%° collective 8 Ib. thrust at +8° and 562 rpm. Tail rotor — Balance main rotor in flat pitch and 535 rpm by +2-1/2° tail rotor pitch (in pusher direction). Balance main rotor in hovering by +10° of tail rotor collective. Allow additional + 10° for directional control. Engine throttle—Unknown. (Not time to find out experimentally.)

V. FLIGHT TESTING It is suggested that a practice landing gear be used for training and test flights. This consists of bamboo or aluminum tube extensions tied with rubber bands to the model's own landing gear. These extend the effective length and width of the landing gear out to about 3/4 of the rotor diameter and help prevent turnovers. Also tie the model down to a steel or aluminum plate weighing about ten pounds, allowing about one foot of slack in the line. The line should be fastened near the C.G. of the aircraft and also of the plate. Testing should be done on smooth concrete or macadam so that the plate will slide if the model gives a jerk on the line. As proficiency and confidence increase, the length of the line can be increased. Judging by the length of time required to learn to fly a real helicopter, probably twenty hours of tie-down time are reasonable before attempting a solo or free flight. Many bugs will need eliminating also; which might have caused a crackup if they were not discovered during tie-down.

Thought for the future: Rigid rotor helicopters have the potential capability for sustained inverted flight. This would require changing the collective pitch controls to give as much negative pitch capability as it now has positive. This may stimulate the modeler to imagine other exciting world's firsts for radio-controlled helicopter models.