W3MH HOME PAGE

Practical Theories

Colin Mill

Parts 1 & 2

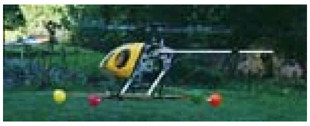
Helicopter aerodynamics

In future issues of W3MH I will be concentrating on aspects of helicopter aerodynamics and I would very much appreciate your suggestions for topics of interest. I guess that, unlike many of the other contributors to this magazine, I am one of the back-room guys who is not too well known so for this first issue and at the risk of boring you all I thought I would spend some time explaining my background, how I got involved in model helicopters and what it is about them that fires my interest. As for my background, I was until recently a lecturer in a university physics department. My research interest was in atmospheric physics and teaching mainly electronics and computing. I am now running my own design company, CSM, whose main product at the moment is the Northern Helicopter Products (NHP) heli/aero simulator, so if you are looking for an unbiased view of flight simulators *(Ed: or latterly, Piezo Gyros...)* don't ask me.

Colin did much of his early learning on an MFA Sport 500. The crossed sticks for learning have long since been discarded... (ClickPic for larger view)

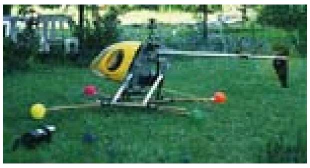
My interest in radio control dates back to the late '50's. I was about 5 years old when my father built an R/C model boat (a Veron Marlin for those who remember them). This he fitted with ED valve (thermionic) single channel gear modified to give a single proportional channel by variable mark-space ratio modulation. The modulator was, believe it or not, mechanical! The mark/space ratio may have hovered around 50/50 but the work/fail ratio of this gear was closer to 1/99. The unreliability killed my father's interest in R/C but I was totally hooked. Given the performance and reliability of early R/C gear I suspect anyone suggesting radio control for model helicopters at this time would have been instantly locked up. For me the progress towards better R/C gear was not that fast, being a mixture of home build and second-hand. My first R/C gear of about '65 vintage still used a valve at the transmitter end. Come to think of it, my first multi-channel set, a 10 channel reed outfit, still used a valve in the transmitter output stage. I never rated the reliability of these early R/C sets and confined it to boats while flying control-liners and free-flight.

Involvement in models came to a halt during my undergraduate years but was revived when, as a post-grad. student, I found myself working with Ian Stromberg, a keen R/C flier. I still have the slope soarer (a Soarcerer) that I built then, complete with its home built Micron 27MHz radio. The servo amplifiers in this were a work of art and used discrete transistors which you had to file down a bit to get in the available space. Helicopters didn't even figure in my thinking at all until around 1987 when by chance I read an article in Radio Control Models and Electronics on the cyclic controls of helicopters. I had, up to that stage, what seems to be the typical fixed-wing fliers attitude towards helicopters - they're expensive, all you can do with them is hover, they're as interesting as watching paint dry, and I don't want anything to do with them. My attitude didn't change over night but I did find myself reading the helicopter articles in the model magazines rather than skipping them. The final spur to venture into helicopters came in 1991 when the University turned down my promotion. I felt I really would have to work much harder - on my hobbies! Within days I had an MFA Sport 500 collective, a set of Futaba Challenger Heli radio, a stack of Model Helicopter World back issues, and some R/C helicopter books. Luckily, Ian Stromberg decided to go along with my insanity and bought an identical set of gear so we could learn together. The reading matter made us realise just what a challenge we had let ourselves in for. The more we read the more daunting the flying seemed to be. The consensus seemed to be that it would cost a fortune in broken bits before we could even hover.



A lot of us learnt to hover in the back garden, there's not far to travel to repair it! (ClickPic for larger view)

A simulator seemed like a good idea. I had a 486 PC but, at the time, the only simulator available in the UK was not available for the PC. Buying a simulator and a machine to run it on was outside my budget (remember, I hadn't got the promotion!) In 1986 I had used a Sinclair QL to numerically model propellers for optimising electric flight, but the speed at which this program ran (walked?) made me wonder if there was a realistic chance of a proper numerical model of a helicopter running in real time even on a 486. Some quick 'noddy' programs showed just how much processors had progressed from the 68008 of the QL. It looked as if the sort of sums needed could indeed be done with enough time left over for the graphics, and so the idea of writing my own model helicopter simulator was born. Although I had a fair understanding of fixed wing aerodynamics, all I knew of helicopters was what I could guess from the propeller theory used earlier. I got a copy of Rotary-Wing Aerodynamics by Stepniewski and Keys (ISBN 0 486 64647 5) to bone up on the subject. Now the interest became an obsession. The more I read the more fascinating the whole subject became. A couple of months of frantic reading and programming followed and resulted in my first and very user aggressive simulator. Definitely for private use only! I used this for about 40 hours before daring to try the real thing. Having set up the helicopter on a test stand it took me one fairly unproductive flying session to get used to the different feel of a real transmitter after using the simulator with a couple of IBM joysticks, but on the second session I got the thing into a reasonable tail-in hover and held it till the tank was almost out. I guess anyone who has learned to fly a heli will know the sense of achievement at that moment. There are just so many manoeuvres a heli can do that you can keep on getting a buzz from doing something new with no chance of ever running out of challenges.



(ClickPic for larger view)

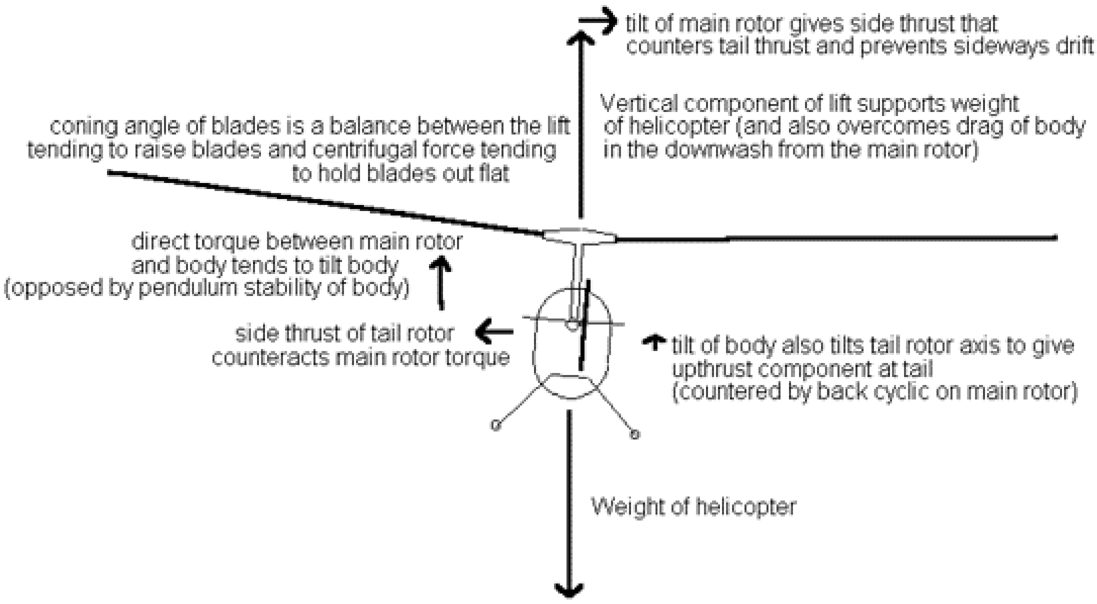
Just in case you are thinking of trying R/C helicopters here are my list of tips for beginners, though I bet every W3MH contributor will give you a different one.

- ***Resign yourself to the expense.*** If your starting with no existing gear at all you need £700 minimum to get up and running. Crashes average £70 a time. Its cheaper to learn Indian club juggling with (full) Champagne bottles.
- ***Read all you can.*** I found 'Learning to fly Radio Control Helicopters' (ISBN 1-85486-025-9) and 'Setting up Radio Control Helicopters' (ISBN 0-85242-975-4) both by Dave Day to be very helpful.
- ***Learn with a friend.*** Having someone at the same level as yourself to bounce ideas off is really great. Experts can be very depressing.
- ***Use a test stand.*** This allows you to set up the helicopter (especially the engine). You can't go through life getting the model shop/ local expert to set up your heli every time you bend it so you might as well start doing the job from the start. My test stand is a 'WorkMate' and some rope.
- ***Get a training undercarriage.*** The usual 'crossed sticks' type (shown in photo fitted to my Sport 500) will allow you to get away with murder. Shorten sticks progressively to wean yourself off the training gear - 'cold turkey' removal is too much of a shock.
- ***Get a collective pitch helicopter.*** Although they are cheaper, fixed-pitch machines are much harder to fly than collective pitch ones. Some of the fixed-pitch machines are great fun but I have seen a world-class flier have real difficulty doing a circuit with one.
- ***Get a gyro.*** Although it is possible to fly without a tail rotor gyro, it is a lot harder. The pioneers who learned to fly fixed pitch and gyroless have my full admiration.

Simulators

Now, given my financial interest, you wouldn't expect me to miss simulators off this list. Just a few hours on a sim can save a lot of time on the flying field. If you can, borrow a friend's. That way you get to drink their coffee and burn their electricity. For me, improving my understanding of why helicopters behave the way they do is almost as important as improving my flying. By way of a short introduction to heli dynamics for those who have never given much thought to how helis fly, I have shown in Figure 1 just some of the forces acting on a helicopter in the hover.

Figure 1 Some of the forces at work on a hovering helicopter



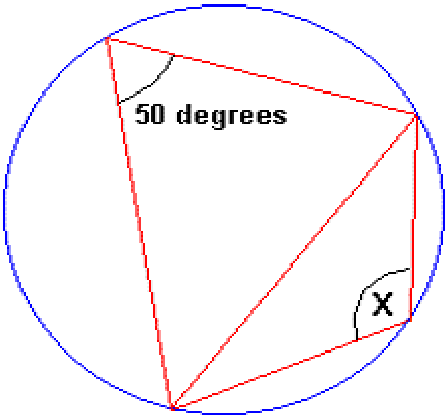
Next time I'll look at the way the main rotor generates lift and the power needed to drive it.

Part 2 *(Originally published November 1995)*

I know last time I promised to talk about how the main rotor generates lift but our editor has had a number of requests for articles aimed at the beginner. He suggested that I do 'something' about setting up linkages so here it is.

OK, do you need to read this? Try this simple test.

Find 'X'

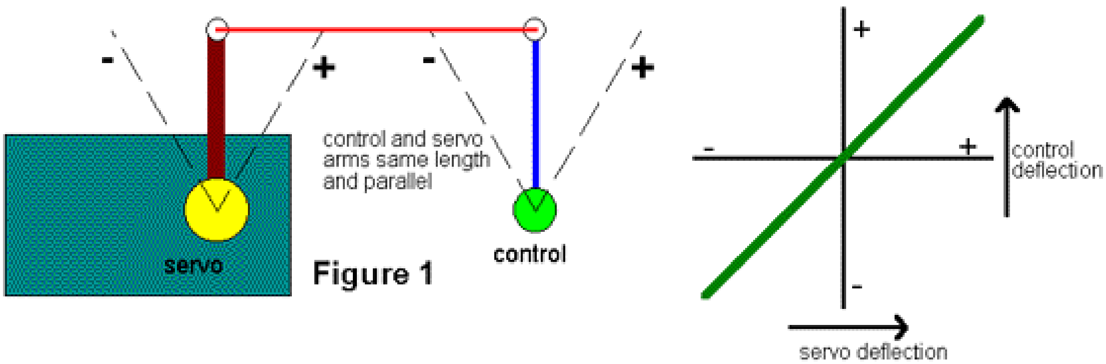


1. If your answer was 130 degrees you might want to go and read Bruce Naylor's article instead.

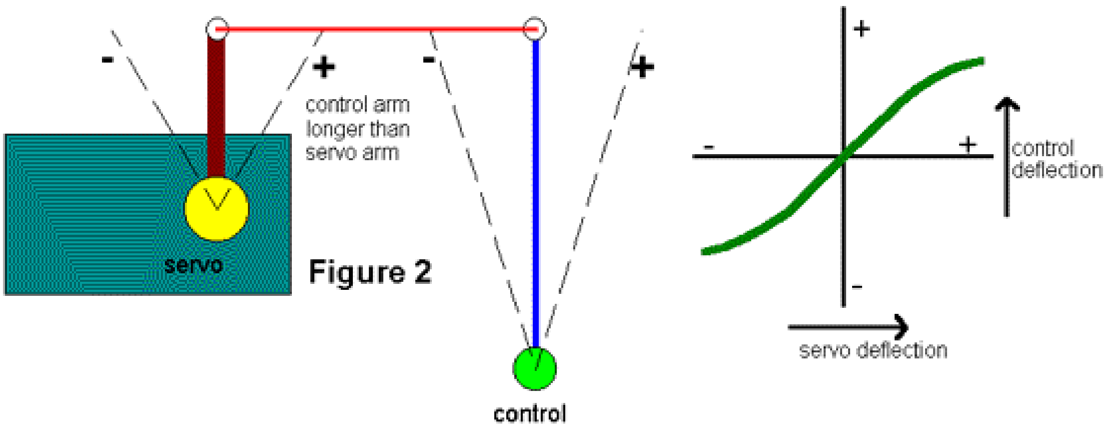
2. If your answer was 'in the bottom right hand corner' you may feel more at home with the Baywatch home page.

3. If your answer was anything else and you are a heli beginner (and especially if you haven't a computer radio) read on!

First let's look at the geometry of the linkages themselves. I know this sounds boring but a few minutes spent understanding this can save a lot of wasted time in setting up a helicopter. This is because the linkage geometry usually introduces non-linearities in the controls, some of which we can use and some we can well do without.



In this case the angular deflection of the control accurately matches that of the servo however, any other arrangement introduces non-linearity into the control movement.



In figure 2 we have a control arm that is longer than the servo arm. If course, the angular movement of the control is now less than that of the servo but the sensitivity of the control movement falls off near the extremes of movement.

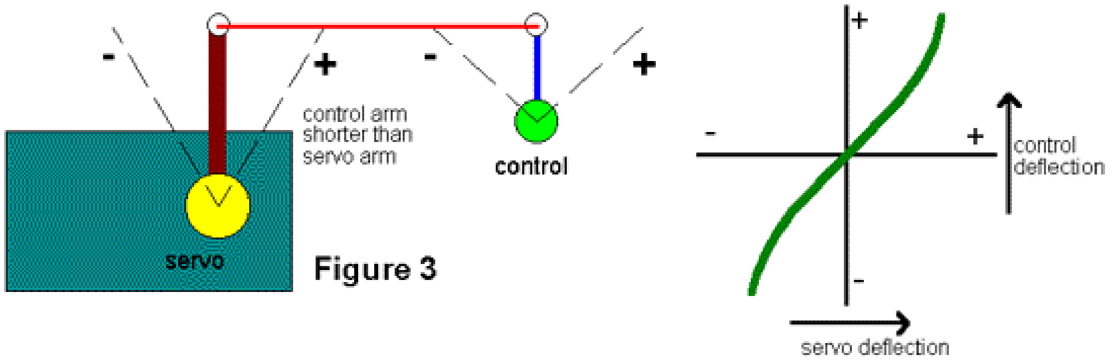


Figure 3

Conversely, a control arm shorter than the servo arm moves through a bigger angle than the servo with an increasing sensitivity towards the ends of the servo travel (see figure 3).

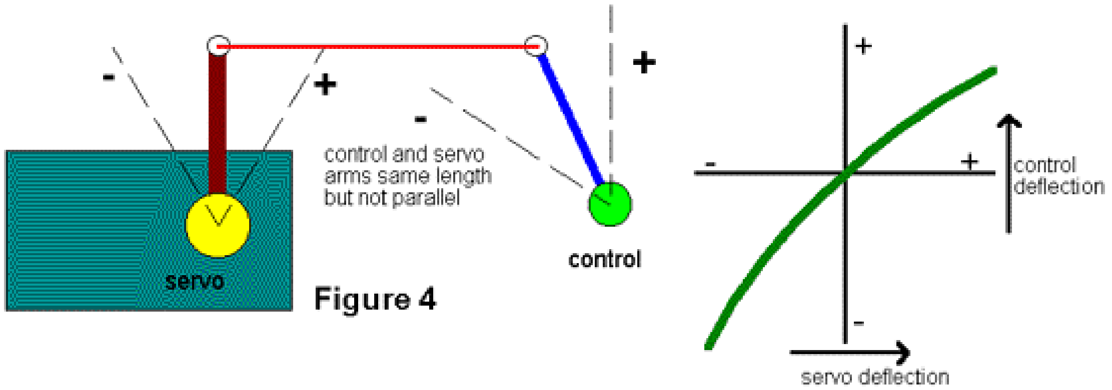


Figure 4

Even if we stick to having the servo and control arms the same length we can get non-linear control movements. Here in figure 4 the shorter-than-ideal push-rod causes a bigger movement of the control arm when it is being pulled towards the servo than when it is being pushed away. The reverse is true with an over-length pushrod. Now we could go through all the combinations of long and short control arms with long and short push-rods but starting from these diagrams I guess you can probably see what these combinations are going to do.

Now, if you look at the linkages on a real model helicopter things look much worse than these simplified diagrams. For a start, the servo and control arms may well rotate in different planes making it harder to see what's going on. Usually the control gets passed through several linkages before it gets where its going.

As a first rule, with the servo in the middle of its travel get the push-rods at right angles to the arms like this

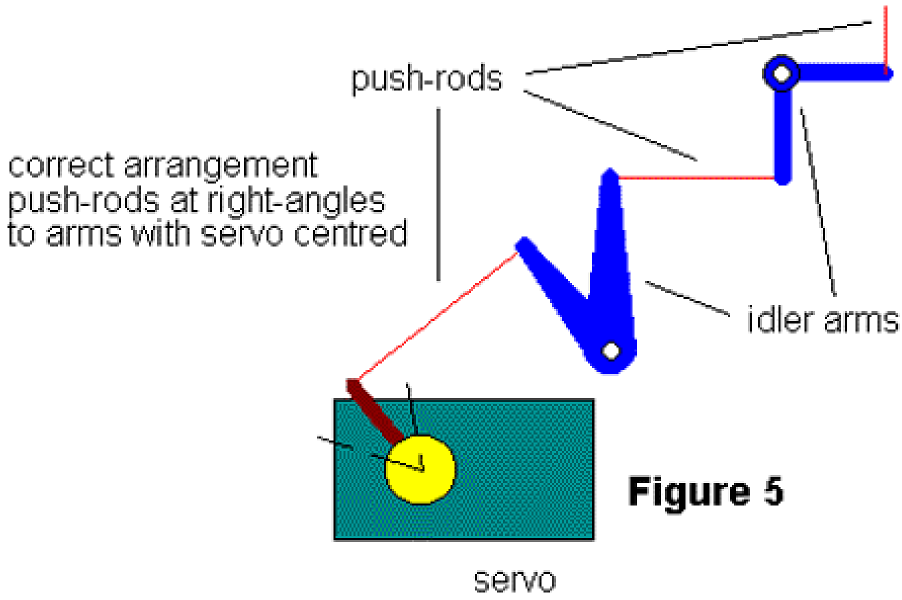
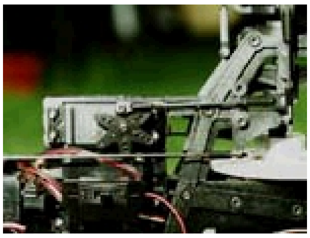


Figure 5



Cyclic control linkages. The roll servo is mounted vertically at bottom left and fore-aft cyclic servo is mounted horizontally (picture centre). Note the pushrods are at right-angles to servo arms and bellcranks. *(all pictures hotlinked)*

Sometimes compromises in the linkage geometry have to be made. Ideally this bellcrank should be right-angled.

Here the bellcrank angle has been dictated by the need to clear the sideframe. Unfortunately, to get the pushrod to the servo at the right angle to this bellcrank it needs to be attached directly to the output shaft without any arm at all. This give perfect linearity but leaves the pitch range woefully short.

There's no excuse for not getting the servo arm pointing in the right direction. The servo manufacturers have provided a really fine adjustment. Taking Futaba as an example, they use a 25 tooth spline on the output shaft of their servos. Lets assume we are using a six arm star on the servo. If you move the star round four points on the spline you move it 4/25 of a turn or 57.6 degrees. Since the arms are 60 degrees apart the effective movement of the star is just 60-57.4 or 2.4 degrees. This is only about 3% of the total servo movement.

In selecting the servo arm length the required control throw is of course the primary factor. However, where you have a choice, use the longest arm length you can. This means that the forces on the push-rods, ball links, servo output shaft bearings, and servo mounts are all minimised. By using long arms you also minimise the effect of any slop in the bearings or links and any flexing of the helicopter frame or servo mounts. So even on the throttle linkage use the outermost hole on the throttle arm. The collective pitch control probably generates the highest servo loads and so long arms are most important in this linkage. The longer the arms the softer the servo mountings can be and the less grief the servos will have to put up with. However, the effect of backlash in the servo gears is not changed by arm length.

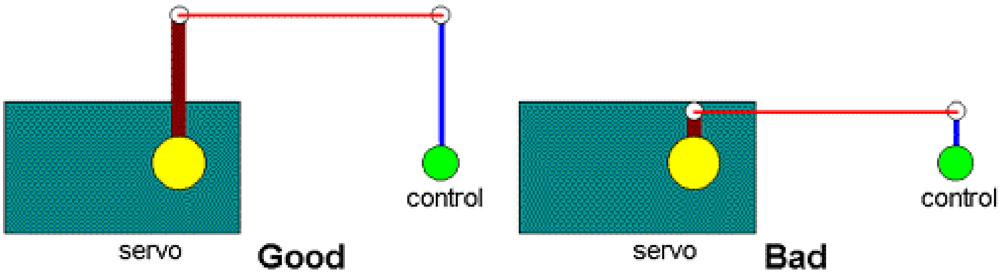


Figure 6

How you go about setting up your linkages will depend quite a bit on the facilities you have on your radio. Computer sets certainly have facilities that make life easier but a computer set should not be seen as a substitute for making a decent job of setting up the linkages though there are quite a few flyers I've seen who seem to treat them this way. I think it is far better to get your linkages set up well first, with the transmitter at its default settings, and then use its facilities to fine tune things.

If you have a good computer set then you have such facilities as 'travel volume' by which the throws (either side of centre) can be independently adjusted for each servo. This allows you to fine-tune the total travel of each control without fiddling about with servo arm lengths. Because it can be separately set for each direction of throw it can also be used to compensate for unequal travel such as seen in figure 4. 'Exponential' is a facility which allows the sensitivity of the controls to vary between the mid stick position and full travel. This allows controls to be made fairly insensitive to stick movements near the middle while retaining full control authority at full stick. 'Exponential' can also be used to overcome the sort of non-linearity in linkage seen in figure 2.

Next time I'll (hopefully) look at setting up the collective pitch range.

Colin Mill

(Originally published October/November 1995)

Practical Theories

Colin Mill

Parts 3 & 4

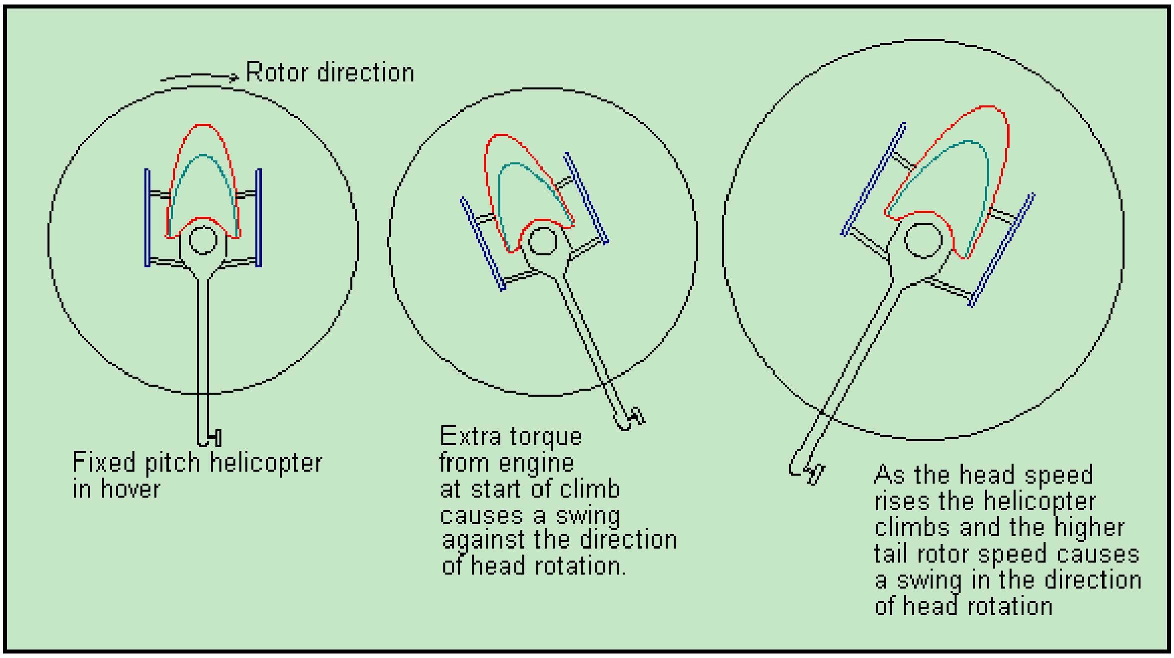
Setting up the Collective pitch / throttle

Now this is where I start to get into trouble! Why? well how you set up the collective pitch/throttle curves of your helicopter depends to a large degree on what sort of flying you are going to do and this is not just modelling its politics! I saw a meeting recently between two well known model heli pilots, one a fine scale pilot, the other shall we say, not unknown for speed. The topic of flying style had not been going long before some very basic Anglo-Saxon terminology was being exchanged. Suffice to say, in the eyes of the other, they were respectively members of the 'Antiquated Flatulence' Brigade, and 'Rectal' School of flying. So I have resigned myself to getting 'flack' pretty much whatever I say here. Since this article is quite a bit heavier going than my previous W3MH offerings I would be interested to hear if this is the sort of thing you want. You can contact me by Email as colin@nhpltd.co.uk *(Ed: Please note this was written some time ago...)*

Fixed Pitch handling

Before I get into the actual setting up of the pitch/throttle relationship I think it would be handy to start by looking at what's 'wrong' with having fixed pitch in order to see what we want from our collective pitch systems. I say 'wrong' in quotes because there have been (and still are) some quite respectable fixed pitch designs.

With a fixed pitch helicopter, the lift can only be controlled by changing the rotor RPM. So, to go from the hover to the climb we have to accelerate the rotor. Because of the inertia of the blades we have to increase the torque being transmitted to the main rotor. Now this doesn't instantly increase the revs it just causes them to build steadily so there's a delay between opening the throttle and the heli starting to climb. This sort of delay accompanies all the lift changes of the fixed pitch machine and needs to be compensated by some anticipation on the part of the pilot, especially in descents! The change in the main rotor RPM also means a change in the tail rotor RPM. Now, in going from the hover to the climb the initial increase in torque to the main rotor demands more thrust from the tail rotor and hence more tail rotor pitch. Once the RPM builds up the torque from the motor falls back somewhat and the extra revs make the tail rotor more effective so less tail rotor pitch will be needed. So the transition from hover to climb is accompanied by a tail swing first in one direction and then in the other. This makes control of the tail on fixed pitch machines more 'interesting' for the pilot.



Ed: Hi Colin, why is the helicopter on the right hand side bigger?
Csm: Because it's climbing towards you, dummy....
Ed: Oh........

The Collective Alternative

With a collective pitch model we have the opportunity of trying to maintain a constant rotor RPM. If we achieve this our example of transitioning from the hover to the climb goes like this. The collective pitch of the main rotor blades is increased to create the extra lift while the throttle is opened so the engine provides just the right amount of extra torque to 'pay' for this extra lift. In this way the model settles into a steady climb quickly without any change in head speed or the delays associated with them. There will still need to be an increase in tail rotor pitch to compensate for the extra engine torque. But since the RPM of the tail is constant the efficiency of the tail will not change and maintaining a steady heading will be easier. Another advantage is that, with suitable gearing, we can ensure that the engine is constantly run at its optimum RPM so full power is immediately 'on tap'.

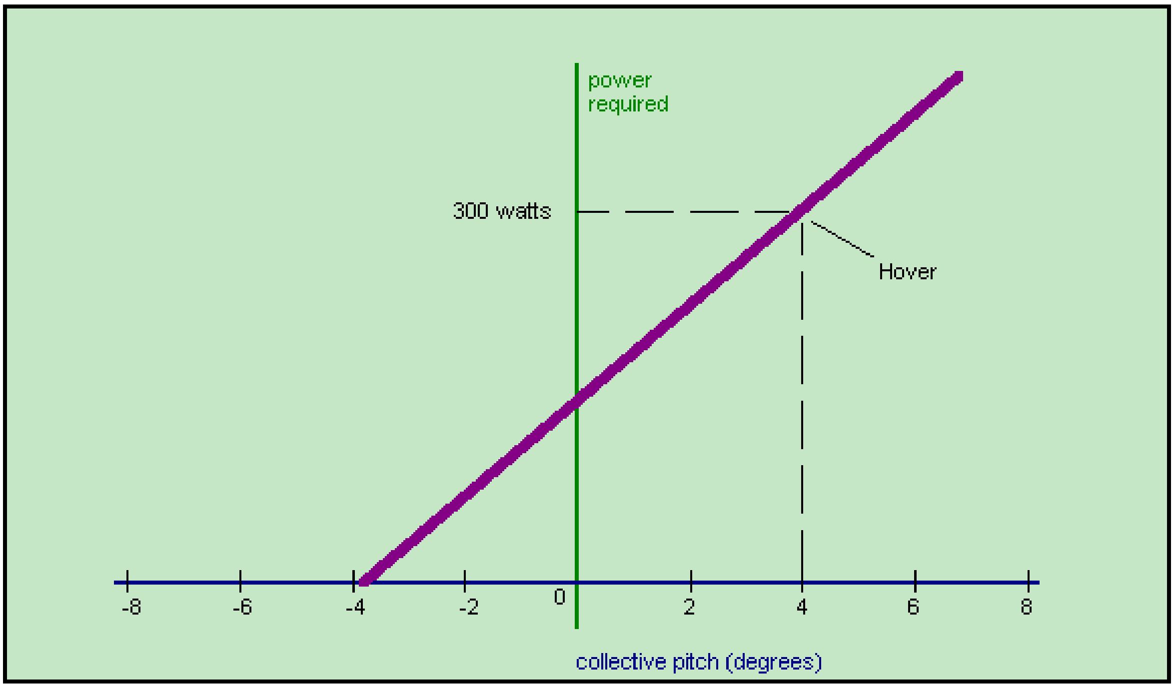
Where does the power go?

I suppose the next thing we need to know is where the engine power goes. This can be a very involved study and I'll come back to it in later articles but for now I'll just apologise for the minor bits I'm going to miss out. Broadly speaking we can split the power requirement up like this. First we need some power simply to drive the main blades through the air even when they are not producing any lift (This is called Profile Drag Power). Next, to produce lift we need to throw air downwards and this also takes power (called Lift Power or Induced Power). We also need power to drive the tail rotor and, in forward flight, power to push the bodywork through the air (Parasitic Drag Power). Finally, in a climb we need power simply to raise the weight of the helicopter. I don't want to put anyone off by going into the equations but I think some typical figures could be handy. Taking a '30' sized helicopter with a rotor span of 1.25metres and weighing 2.75kg hovering with a head speed of 1750 RPM we get:

1. Profile Drag Power = 210 watts (0.28 HP)
2. Induced Power = 90 watts (0.12 HP)
3. Tail Rotor Power = 25 watts (0.03 HP)

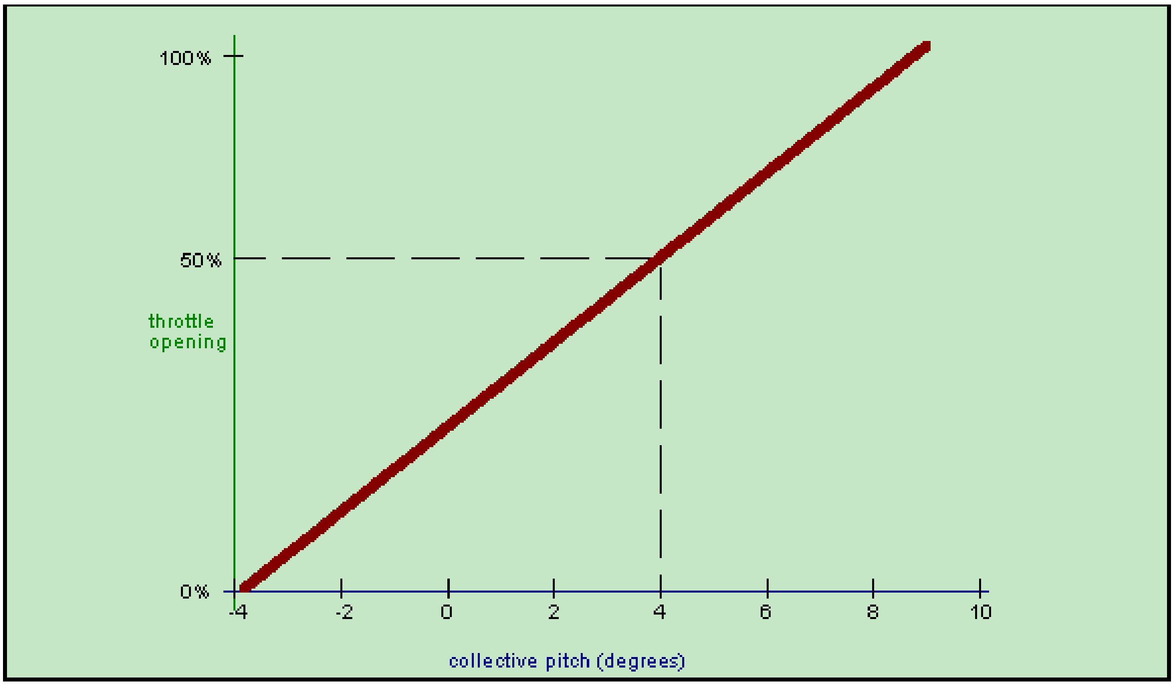
Every 1Metre/second rate of climb will need about a further 25 watts so we need about 325 watts from the engine to hover this helicopter; conversely, a descent will provide about 25 watts for every 1Metre/second rate of fall.

As yet we haven't tied the power to the actual collective pitch. Again, without going into the equations the heli in this example will hover at 1750 RPM at a collective pitch of about 4 degrees. Also, If the collective pitch is reduced to about -4 degrees the rotor speed will be maintained in an autorotation with the power required coming from the falling weight of the helicopter. So at last we have two points that we can use as a guide to the power required at each collective pitch setting. I say 'ideal' because this is only ever going to be a compromise since forward flight will modify the requirements and such things as 'vortex ring effects' also ruin this simple picture.



To complete the picture we need to know something about the engine. According to the manufacturers a typical '30' motor puts out roughly 750 watts (1HP). However the manufacturers usually don't quote the conditions under which they measured the output. I would bet that these figures are often for 30% nitromethane (even nitroglycerine perhaps) and an open exhaust. Anyway, if we knock off a bit for the manufacturers optimism and a bit for losses in the gears etc. we can perhaps rely on 650 watts actually getting to the blades. If we assume that the power output of the motor is proportional to the throttle opening (and that's a pretty big assumption) we can see from these figures is that we are going to need something like one third throttle just to provide the Profile Drag Power needed to get the blades going through the air at the required speed. To provide the induced power for the hover needs about a further sixth of throttle movement taking us to about half throttle at the hover.

So at last we get a likely pitch/throttle 'curve' like this



This gives us a basis for a typical 'normal' pitch/throttle curve that will, in level, upright flight give us a substantially constant head RPM as we climb or descend. There are a variety of other arrangements.

A Trainer Setup

Now, if your a complete beginner who is just at the hopping-about-on-the-ground stage you will have some slightly different priorities and I would suggest you use a somewhat different pitch/throttle arrangement. Why? Well, until you learn the error of your ways, your natural panic reaction will be to shut the throttle sharply. If this also applies say -4 degrees of collective pitch the machine is going to dump itself very firmly onto the ground. In all too many cases this will result in a 'boom strike' (one of the main blades, going at about 200mph, coming into contact with the boom) I would suggest that, initially, you use a pitch range with a low point of say +1 degree. This will reduce the chances of a boom strike until a suitably gentle touch with the throttle can be learned. At the risk of making this sound like a commercial, a few hours spent on a simulator at this stage can save you a lot of hours spent rebuilding your heli. Before progressing to flying circuits its a good idea to get used to having more negative pitch available. If you try flying a circuit without enough negative pitch then extra care will be needed as you lose height since descent is going to be accompanied by a fall in head speed.

Having a reduced head speed at the bottom of the descent will reduce the amount of lift available to arrest the sink and you could just find the ground intervening in the equation. The beginner may also want to restrict the top end of the pitch range somewhat to reduce the maximum rate of climb, however, if you take this to extremes you are in danger of re-inventing the fixed pitch helicopter, complete with the handling! If your Tx allows you could reduce the top of the throttle curve to go with the limited top end pitch.

I guess that's about enough for now. Next time I'll look at alternative pitch/throttle arrangements and tie this in with tail rotor compensation. Unfortunately, I don't think I've been controversial enough this time so let me just leave you with this. So far I have not made any reference to the position of the throttle stick, and that's because, so long as you get the relationship between the throttle and the pitch right, it mattereth not about the stick position. (The distant rumble you can now hear comes from the legions of the 'A.F.' Brigade getting out their quill pens for battle).

Part 4 *(Originally published January 1996)*

OS32SX - First impressions

I recently replaced my venerable OS32FH motor in my Concept 30SR with the later model OS32SX. I hasten to add this change was not prompted by the old motor being clapped out. In fact it still looks in great shape after 3 years hard use and I think I would have to beat it to death with a hammer if I wanted to get rid of it!

So far the SX promises to be just as fine a purchase. I have married it up with the Hatori 30HTS-2 tuned pipe and header as I understand Hatori have designed this pipe with the 32SX in mind. I was expecting this combo to require about 5% nitro but so far it has proved to have superb throttling even on straight fuel so for the moment that's what I'm using. I was hoping by now to give you a more detailed report on this motor, however things have conspired against it. Having had a few gentle flights to run it in and get the carb set up I took the machine out to give it a real work-out. This flying session showed quite clearly that the SX has a significant power advantage over its predecessor despite its having the same displacement. This gave me the confidence to bring my tumbles much lower than before in the perhaps misguided belief that the new reserve of power would help me climb out of any trouble I might get in to.

Anyway, I had about four flights in which I pushed my luck more than normal and still had an intact heli at the end. However, immediately after this flying session I discovered a new and novel way to crash a helicopter: put it in the boot (trunk?) of a car and crash the car!! This method has the merit of smashing both the model and the flight box without the need for precision through-the-pits flying! I now have the heli back in one piece, and have removed the 12 volt starter battery from inside the canopy where it was causing a bit of a CG problem. I now find that the PCM receiver suffers from random lock-outs..........

Setting up the pitch/throttle curve in practice

Last time I discussed the ways in which a helicopter uses engine power and applied this to identify a sort of 'ideal' normal pitch/throttle relationship for which the head speed is constant. To obtain this in the descent the throttle is closed progressively as the pitch is reduced (and thus increasing the descent speed) so that by the time the heli is in a full autorotation and the blades are being driven by the falling weight of the helicopter, the engine has been throttled back to a tick-over. Conversely, as pitch is added to climb the throttle is opened to provide the extra power to raise the weight of the helicopter.

Since the throttling of the engine is to some extent an unknown quantity, the only way to fine-tune the pitch/throttle relationship is by flying the machine. Start by getting the head speed how you want it at the hover point. I found an optical tachometer very handy as, to start with, I just could not judge what the head speed was like. I know this kind of 'kit' is expensive (and being mean I made my own tacho) but It all comes back to my **Tip Number One For Beginners - *Resign Yourself to the Expense*** (see October's issue). So, if you're starting out, get yourself a tacho, get yourself a good pitch gauge and keep notes on your set-ups so you know how to get things back the same way again after the inevitable 'rotivations'.

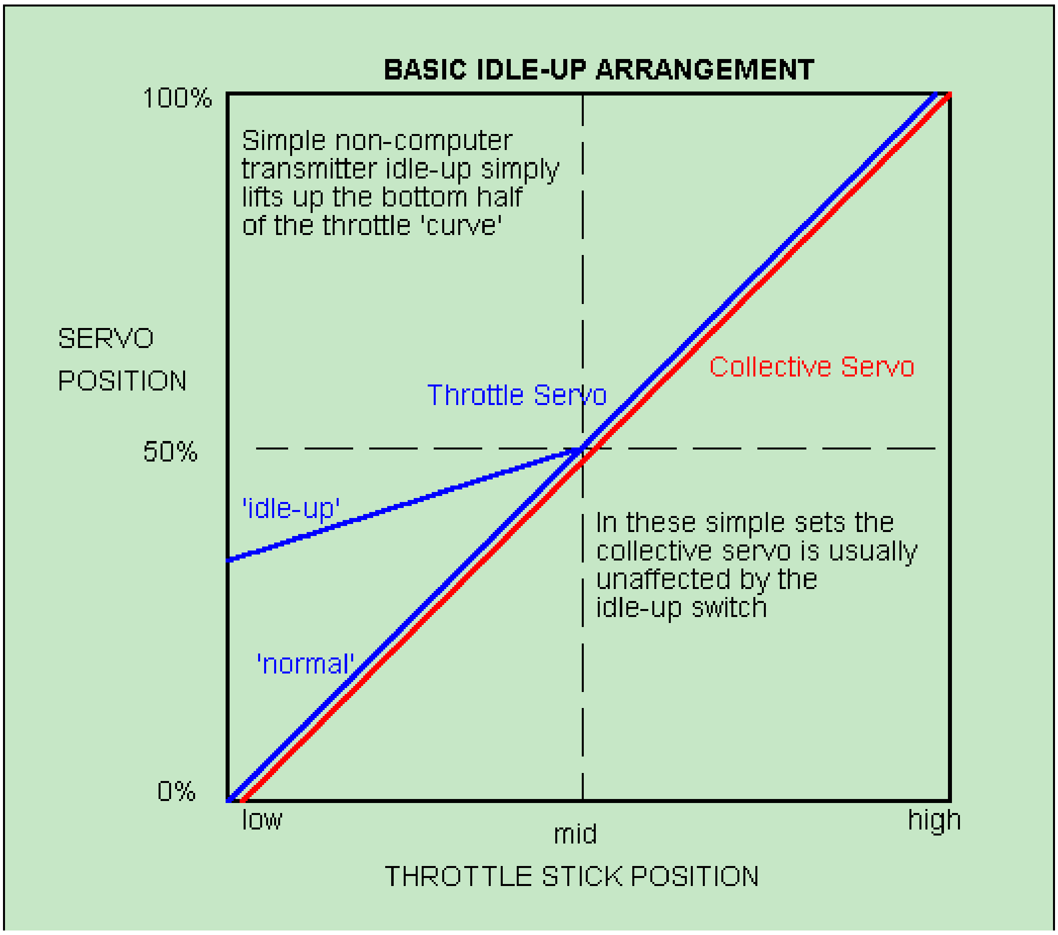
Choice of head speed is somewhat a matter of personal taste. Higher head speeds give a crisper response to both collective and cyclic commands but also make the machine more responsive to turbulence as well. Personally, I aim for a head speed of about 1850RPM on my Concept 30SR. 60 size machines tend to be run at somewhat lower head speeds of around 1700RPM. Once the hover point is right a full-power vertical climb seems to be the normal way of establishing the top end pitch. If the revs sag significantly in the climb the top end pitch needs to be reduced while a rise in revs indicates that more pitch can be used. Monitoring the head speed in the descent allows the bottom end pitch to be set. It's not too easy judging this as with the motor throttled back you don't have so much 'din' to go on. If, as you arrest the descent smoothly back to the hover you find you are having to push the throttle a long way beyond the hover point and you also find the nose swinging to the left (to the right for anticlockwise rotation helis) then you know the head speed has dropped and you need more negative pitch at bottom stick.

There are several points to bear in mind in doing the setting up. Firstly, the set-up can only be a compromise. Since the induced power (that's the power used in chucking air at the ground) decreases with increasing forward speed of the helicopter, a set-up perfected for vertical climb and descent will be imperfect for forward flight etc. In forward flight, head speed can be maintained with a greater top end pitch than can be employed in the vertical climb. Also, when the helicopter is manoeuvred, 'g' pulled in turns, and cyclic commands applied, the loading on the engine will vary and ruin our careful set-up. Luckily there are several things that make the set-up less critical.

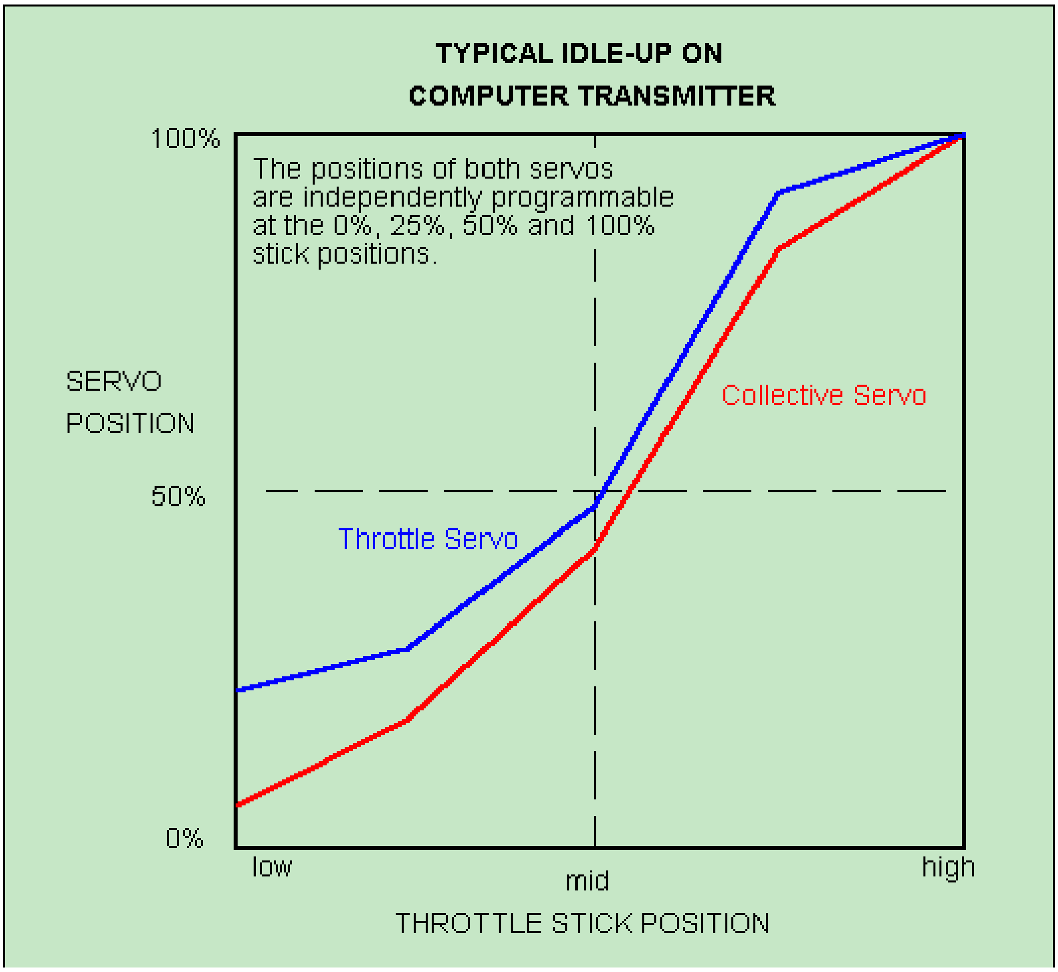
The drag power (the power used simply to drive the blades through the air) increases with the cube of the rotor speed. This means that a 10% increase in rotor speed increases the drag power by about 30%. If there's an excess of engine power tending to increase the rotor speed this will fairly rapidly get 'soaked up' by the extra drag power as the head revs rise. This helps to limit the variations in head speed from imperfections in the pitch/throttle relationship. We can also help stabilise the head speed by running the engine at, or preferably slightly above, it's peak power revs. If we do this then unloading the engine will cause a rise in revs which in turn will take the engine away from its optimum RPM and reduce its output. This of course helps reduce the amount of overspeed. We are more than somewhat dependant on the helicopter manufacturer to select the gearing of the helicopter so that the engine can be run in the right rev range though we can help ourselves by the choice of exhaust system we use as this allows us to shift the power curve of the engine somewhat. This is perhaps one reason why tuned pipe exhausts, with their peakier power curves, are popular among heli pilots, especially since changing the length of the pipe can change the peak power RPM.

Idle-Ups

For 'normal' upright flight the beginner has little need for more than the one pitch/throttle curve. Even loops can be performed quite happily using the 'normal' curve. However, once further aerobatics (rolls, stall turns, inverted flight etc.) are being contemplated other pitch/throttle curves will be needed. Even the most basic of helicopter transmitters allow for at least one so called 'idle up'.

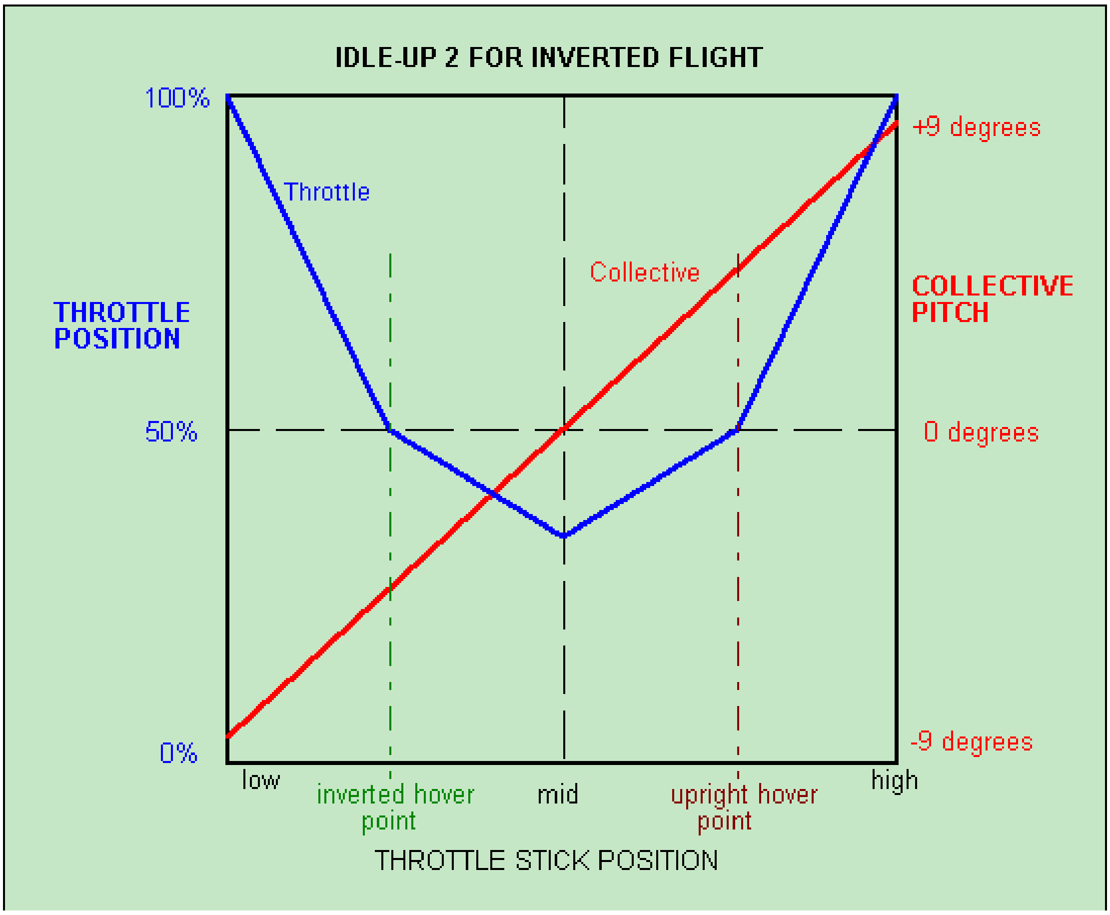


The name comes from the facility on early basic heli transmitters in which a switch on the set allowed the minimum throttle opening (with the throttle stick at the idle position) to be increased - hence the name 'Idle Up'. At certain times (such as the inverted bit of a roll for example) it is necessary to bring the collective pitch down to say -3 degrees but if this is done with our 'normal' pitch/throttle relationship it will also chop most of the power as well. The use of 'Idle up' allows more power to be kept on at these reduced pitch values and the head speed to be maintained. Modern computer radios typically allow for two such switch selectable pitch/throttle curves to be selected. In the basic heli transmitters of the pre-computer era the idle up switch only affected the relationship between the throttle channel and the stick position while leaving the collective-to-stick position relationship unchanged. More recent computer sets allow each idle up to have its own collective-to-stick and throttle-to-stick relationships.



Every pilot has his own set-ups but a typical set of idle up curves would perhaps go like this

IDLE-UP	Bottom Stick	Mid Stick	Top Stick	Comments
'Normal'	-4 degrees 0% throttle	+5 degrees +50% throttle	+9 degrees 100% throttle	set to give substantially constant RPM upright
'Idle up 1'	0 degrees 30% throttle	+5 degrees 50% throttle	+9 degrees 100% throttle	Easy-to-find zero pitch for stall turns etc.
'Idle up 2'	-9 degrees 100% throttle	0 degrees 30% throttle	+9 degrees 100% throttle	Symmetrical about mid stick for inverted and '3D' flying
'Throttle hold'	-5 degrees 0% throttle	+5 degrees 0% throttle	+12 degrees 0% throttle	For aurorotation



I used to use a set of idle-ups something like those tabled above but now (under the influence of Bob Johnston*) I use a much simplified arrangement in which all my pitch ranges (including throttle hold) go from about -9 to +9 degrees with 0 degrees at mid stick. I use 'normal' only for starting and switch to idle up 2 (much like the one above) for all flying except for the use of throttle hold. I don't however think you could classify this as a 'typical' set-up! *(Ed: I don't know, both myself and Jeremy Morcom fly like that too!)* For me, the important aspects of this arrangement are:-

1) I don't get any sudden jumps in the collective pitch as I operate the throttle hold or idle up switches, and

2) the idle up 2 gives me inverted handling that is as near as possible to the upright handling.

Next Time

A topic very closely linked to the pitch/throttle arrangements is that of tail compensation so next time I'll start look at this aspect of the set-up. Oh yes, before I forget, is anyone interested in a 2-door Jaguar XJ6 ? (both doors on the same side - corners best to the right therefore would suit clockwise rotor flyer)

Colin Mill

** For those who have not met Bob Johnston he is easily identified - if you see a heli doing rolling backwards figures of eight, indoors, under a 35 ft ceiling then just take a look in the pilot's ear. If you see a brain on gimbals going round in there you've just found Bob!*

(Parts 3 & 4 Originally published December 1995/January 1996)

Practical Theories

Colin Mill

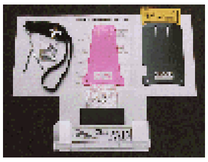
Parts 5 & 6

Transmitter trays

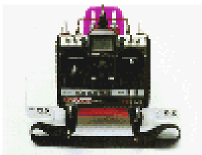
Now, how you hold your transmitter and which stick mode you use can be as controversial as what style of flying you do. Before taking up helis I used to fly fixed wing mode 1 (that's with the throttle on the left stick) and operated the sticks 'thumbs on top' . I decided to swap to mode 2 (throttle right) for helicopters so that none of the undesirable fixed wing reflexes like slamming throttles shut would get in the way. To improve my control over the fine stick movements needed in the hover I started to operate the sticks 'finger and thumb' style. Since this makes it hard to keep a reliable grip on the transmitter I started to use a neck strap. I still was not happy with the security of my grasp on the transmitter as it didn't balance very well about the neck-strap fixing point. (Sweating and trembling hands had a bit to do with the problem too I guess) In desperation I gave a transmitter tray a try.

I got the thing mail-order and when it arrived I was horrified. It weighed in at about two pounds and had a deck area like a young aircraft carrier. It looked as if it normally got used to serve ice-cream and popcorn at the local cinema. I'd got some ribald comments off my flying buddy, Ian, just for suggesting a tray. I was cringing at the prospect of what he'd say when he actually saw the thing. (He dubbed it an '18 hour girdle') However, I had to admit the thing worked. If you have never used a tray before it takes some time to adjust to the thing. However, the transmitter is really well located and I'm convinced that, for me, it gives me better fine control in the hover and better access to idle-up and throttle hold switches than I had before. Having one time recently flown without a tray (I forgot to take it to the field!) I certainly don't plan to switch back.

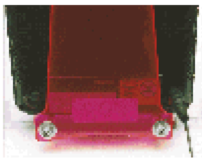
I recently got into a 'conversation' on ModelNet with Peter O'Connor and It transpired that Pete manufactures transmitter trays in the USA under the 'Petal Manufacturing' trade name. I jumped at the opportunity to try a tray designed by a flyer rather than a confectionery vendor so I horse traded a simulator for a tray. I can only hope Pete is as happy with his half of the deal as I am with mine. The 'Petal Elite' tray is light, weighing in at just on a pound (450g) which saves on the neck muscles. It allows use of the buddy socket while the Transmitter is mounted on the tray - useful as it allows me to use the tray with the simulator. I can also charge the transmitter without removing it from the tray (which should save me arriving at the flying field without it!). Most important for me (and a feature not on my previous tray) I can now adjust and optimise the height of the hand rests ('Pro-Pads') relative to the transmitter.



The 'Petal Elite' and 'Sabre 6' trays as they arrive. If you're like me you spend time assembling things like this without reading the instructions and end up with a Dali sculpture...



Sorted! The Elite tray fits the Futaba FF7 like a glove. The 'Pro-Pad' hand rests are adjustable for height



Rear view. Buddy and charging sockets accessible with tranny still on the tray

Straightforward handle clamp holds tranny to the tray

If you would like more details of the Petal range of trays, Email [Peter O'Connor] at 76055.30@compuserve.com. *(Editor's Note February 1998 - We can't guarantee that this still works...)*

Tail rotor set-up.

In the last couple of issues I have looked briefly at the setting up of collective pitch and throttle. The set-up of the tail rotor is closely linked to this so let's look at what we are trying to get from the tail rotor.

The first function of the tail rotor (as anyone who has had a tail drive failure will tell you) is to counteract the torque reaction on the body of the helicopter from the main rotor. It's quite handy to get some idea how much thrust the tail rotor must produce to do this. Let's use the example I gave in December's article with a '30' sized machine hovering with a head speed of 1750 RPM. In this case about 300 watts (0.4 hp) is used in turning the main rotor. At 1750 RPM this takes a torque (turning effort) of about 1.6 Newton Metres (1.2 ft lbs). With the tail rotor some 0.7 metres away from the main shaft it needs to push with a force of about 2.3 Newtons (0.5 lbs force) to give the desired torque.

Main rotor tilt

As an aside, This side thrust would push the heli sideways (to the left for a clockwise rotation machine) unless counteracted by a tilt of the main rotor disk. With a typical '30' machine weighing in at about 2.75 kg the side thrust of the tail is about 8% of the weight of the helicopter and the main rotor will need to be tilted about 5 degrees from the horizontal to counter this. Incidentally, the attitude adopted by the body depends on many factors such as the vertical position of the tail rotor, the lateral and vertical C of G positions, the teeter stiffness of the head etc., but the tilt of the main rotor disk is not affected by these things.

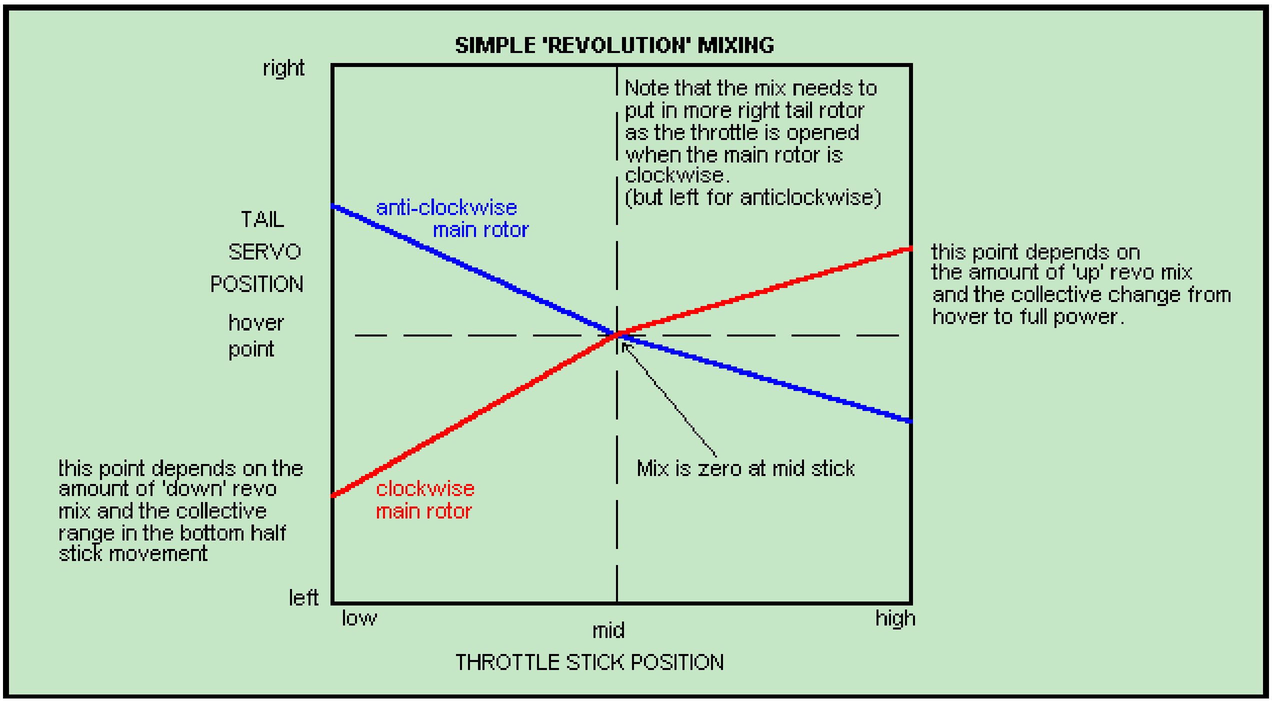
Tail trim in the hover

Coming back to the trimming of the tail, A typical '30' size tail of say 210mm diameter turning at 8750 RPM (5 times the main rotor speed) will generate the required thrust with around 7 degrees of pitch (depending to a degree on how much the fin masks the tail rotor). So this gives us a starting point for the tail trim in the hover. One complication about the hover tail trim is that it is RPM dependant. If the hovering head speed is reduced say by 10% (from 1750 to 1575 rpm) the power being used to drive the main rotor is reduced because of a reduction in the profile drag power (that used simply to push the blades through the air) but the Induced power (used throwing air downwards) stays unchanged. So the torque needed to turn the main rotor falls by about 11% while the fall in the tail rotor speed reduces its thrust by 19% giving about an 8% shortfall. To make this up the tail needs to have a higher pitch angle.

The moral of this is get the collective pitch/throttle set-up right first then start working on the tail rotor trim. One useful aspect of this is the way it can be used to confirm your suspicions about a fall off in engine performance. If, with a previously well set up machine, the motor sounds sick and the nose is trying to swing left (right for an anticlockwise rotor) then its a fair bet the revs are down.

Revolution Mixing

Next let's see what we need as we depart from the hover. At full power let's assume we have our pitch/throttle sorted so the revs are close to those we get in the hover. The extra power is then being transmitted to the main rotor as an increased torque. Let's assume our example '30' has a motor capable of giving 700 watts (0.94 hp) to the main rotor while having enough left over to drive the tail and the gear losses. With this amount of power we will, at 1750 rpm have a torque at the head of 3.8 Newton metres. The tail pitch will need to be increased to about 13 degrees to balance this.



In 'normal' pitch range the tail rotor pitch needs to reduce as the throttle is closed (and the collective pitch is lowered). A fairly obvious point here is that when the throttle is closed to tickover (or at least to the point at which the clutch disengages) the engine will be applying no torque to the main rotor so the tail rotor pitch should be zero.

There are several ways of dealing with these changes of tail trim with throttle position. Even simple heli radios have some form of automatic tail compensation. The simplest just provide mixing between collective pitch and tail rotor pitch (often called Revolution Mixing). Again, even the basic transmitters allow for two rates of mix; one below half stick and the other above half stick. The traditional method of adjusting these mixes is to indulge in meteoric climbs and descents adjusting the 'up' mixing rate to keep the heli straight in the climb and setting the 'down' mixing rate to keep it straight in the descents.

Throttle-Tail rotor mixing

All this sounds very reasonable but there is a fairly fundamental limitation of the collective to tail rotor mixing principle which becomes apparent when we consider inverted flight. If we have a 'V' shaped throttle curve so that upright hovering can be achieved with about +4 degrees collective and 50% throttle when the stick is at about the 3/4 stick position while inverted hovering is achieved with -4 degrees collective and 50% throttle at about the 1/4 stick position. The problem for our revo mix is that for both upright and inverted hovering the tail rotor pitch needs to be the same (or very nearly so). This is something a simple revolution mix can't give. I think there is another problem with revo mixing, at least in the way its implemented on the transmitters I've looked at. They use the mid-stick position as the neutral point for the mix. This causes a lot of flyers to get a fixation about getting the hover point at mid stick. This in turn causes them to set up much bigger collective pitch changes (maybe 10 degrees) for the bottom half of the stick movement than for the top (maybe only 4 degrees).

Another curious result of the mid stick reference point is that changing the collective pitch at the hover point will change the collective throw in the top half of the stick movement. This in turn changes the amount of collective mixed into the tail as you push the stick to the top. So, guess what, you now have a different tail rotor pitch at the full power position, and you get a change in the tail trim at full power when you haven't been playing with that part of the set-up at all! Complex transmitters such as the Futaba 9ZHP, JR PCM10SXH and the like can be programmed to have different revolution mixes for each idle up state, so you can, with effort, engineer what you want.

However I prefer a simpler solution and that is to employ throttle to tail rotor mixing. After all, its the engine that's producing the torque you're trying to cancel out! On a Futaba Field Force 7 for example I inhibit the revo mixing and set up the 'P-MIX' free mixer to mix the throttle channel into the tail rotor channel. As with revo there are separate mixing rates for the upper and lower halves of the throttle movement. Having established the tail rotor trim for the hover I then adjust the mixing rate for 0 to 50% throttle so that the tail pitch is reduced to zero as the throttle is closed to tickover. I then adjust the mix for 50 to 100% throttle openings to maintain acceptable tail trim in full power forward flight (I'm not much given to doing full bore vertical climbs so I don't see the need to trim for them.) Now, since the throttle is in the same position for inverted manoeuvres as it is for the equivalent upright manoeuvre the throttle to tail rotor mix gives the same tail rotor pitch in both cases which is what we need. It may not be right but at least it will be wrong in a way that's consistent between inverted and upright flight!

There is an even simpler solution; the one adopted by Bob Johnston (I know, I'm starting to sound like Bob's publicity manager). He uses no form of tail compensation but instead does it all by pure pilot skill. (Sickening isn't it!)

Editor's Footnote: It's rumoured that Colin is working on the next interface for his simulator, which involves no transmitter at all, simply a phono plug interface directly to his brain. This means he will be able to `think' a manouevre and the model will perform that same manouevre. I understand there are practical difficulties with one's mind wandering during the flight - and it has not yet been decided where the phono socket will be fitted.....

Part 6 *(Originally published March 1996)*

The Tail Rotor Gyro

Last time I was considering the set-up of the tail rotor, and in particular, the various automatic methods for adjusting the tail rotor pitch to compensate for main rotor torque variations that occur between hover and descent and between hover and climb. Perhaps the most important idea to come away with is the impossibility of the 'perfect' tail compensation arrangement and I think its fair to say most set-ups rely fairly heavily on the performance of the tail rotor gyro to iron out the remaining imperfections so its worth looking at the basics of the gyro.

The basics of the tail rotor gyro

Without a gyro, the 'natural' handling characteristics of a helicopter tail rotor is (as anyone who learned in the days before gyros will tell you) rather unpleasant. This is because the natural damping of the helicopter in yaw is small so controlling it without the help of a gyro is a bit like balancing a marble on a sheet of glass. The purpose of the gyro is to provide artificial damping of the yaw motion of the helicopter so its more like balancing a marble on a sheet of glass coated with a thick layer of oil.

To generate this effect the gyro needs to incorporate some method of measuring the rate of yaw of the helicopter. This may now be done by a conventional mechanical gyroscope or by the use of a solid state rotation sensor. It could also be done by an optical method called a 'ring laser' though these are so expensive that I don't think they have ever been applied to a model application.

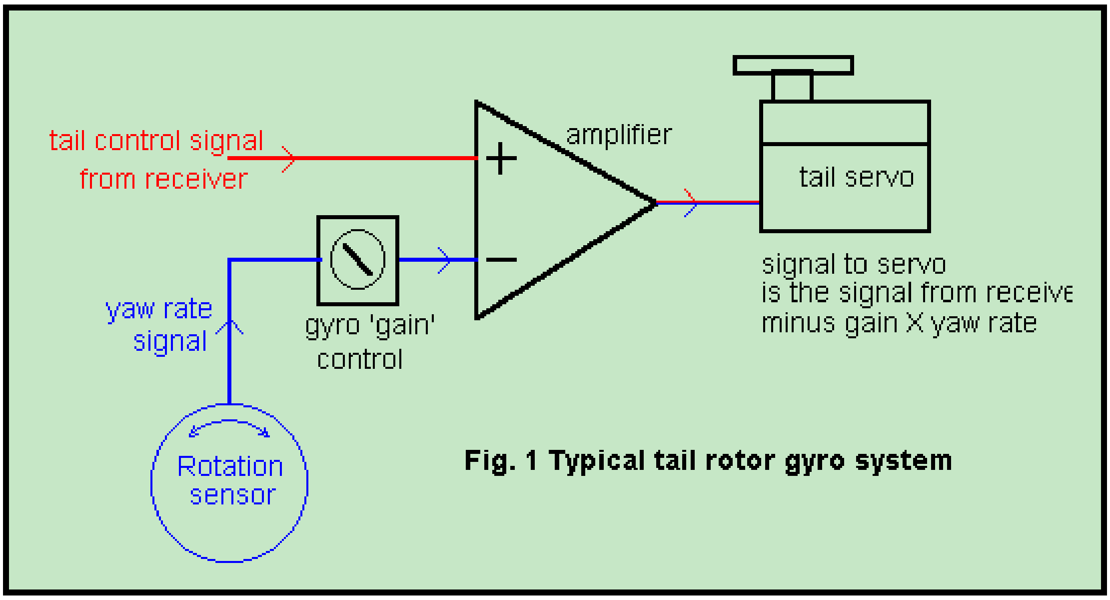


Fig. 1 Typical tail rotor gyro system

From Figure 1 we can see how the gyro system provides the desired damping of the helicopter yaw. Lets assume for a moment that the system in figure 1 is in trim with the tail rotor thrust just balancing the main rotor torque and the yaw rate at zero. If say a gust of wind disturbs this balance and the helicopter begins to yaw. The yaw rate sensor detects the turn and produces an output proportional to the yaw rate. This is passed via the gyro 'gain' control to the amplifier and on to the tail servo. Now the signal from the rotation sensor is in such a direction that this movement of the tail servo causes a change in the tail pitch that opposes the initial turn. So, if the gust initially causes the helicopter to yaw to the left the gyro system will apply some right tail rotor control to oppose the swing.

What if the direction of the rotation sensor signal is wrong? Well, in this case the response of the gyro to a small swing to the left is to put a bit of left tail rotor control in just to help it on its way! This of course increases the yaw rate that in turn increases the sensor signal that in turn puts in yet more tail control, etc. Very quickly the small swing builds up into a full blown pirouette. So, if you do get the gyro sense wrong it will very quickly let you know! A friend of mine went to great lengths to make sure he had the sense of the tail stick control and the gyro right on a new Concept 60 he was putting together. He checked it over at least five times before finally flying the model. He was therefore more than somewhat surprised when, just at the point of lift-off, the machine went round like a blue-bottle on pyrethrum. How did he get it wrong after all that care? Well, simple really; he put the tail blades on back to front and then used the direction the blades were facing when working out the sense of the tail control and gyro!

Unfortunately, getting the sense of the gyro wrong isn't the only way to get things screwed up. Most beginners are looking for as much help as they can from the gyro. Since the higher the gyro 'gain' setting the more the signal from the gyro resists any yaw motion of the helicopter it follows that beginners are going to want to run as much gyro gain as possible so as to buy as much time as possible. However, if the gain of the gyro is wound up to full its more than likely the tail of the helicopter will go into violent oscillation once the machine leaves the ground. Why? Well the answer lies in the delays in the gyro - tail servo - tail rotor system. The first delay in this system comes simply from the yaw inertia of the helicopter itself. Simply, it takes a certain amount of time for the yawing of the body of the helicopter to respond to any change in tail rotor pitch (and hence thrust). Exactly how long depends on many things - how the weight on the helicopter is distributed along the body, the diameter of the tail rotor, the chord of the tail blades, the tail RPM, etc., etc. However the typical response time is of the order half a second (500 milliseconds). Next comes the delay of the rotation sensor in the gyro which may be anything from 20 to 100 milliseconds. Next comes the tail servo which may contribute a delay of between 50 and 200 milliseconds. There may well be other sources of delay - slop in control linkages, radio system frame rates, etc.

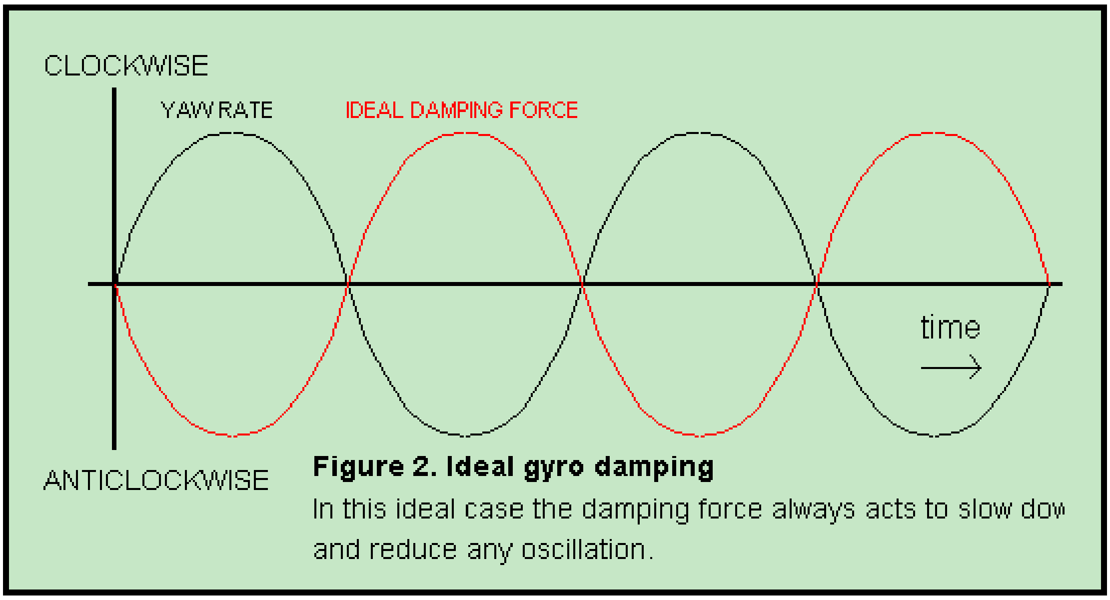


Figure 2. Ideal gyro damping
In this ideal case the damping force always acts to slow dow and reduce any oscillation.

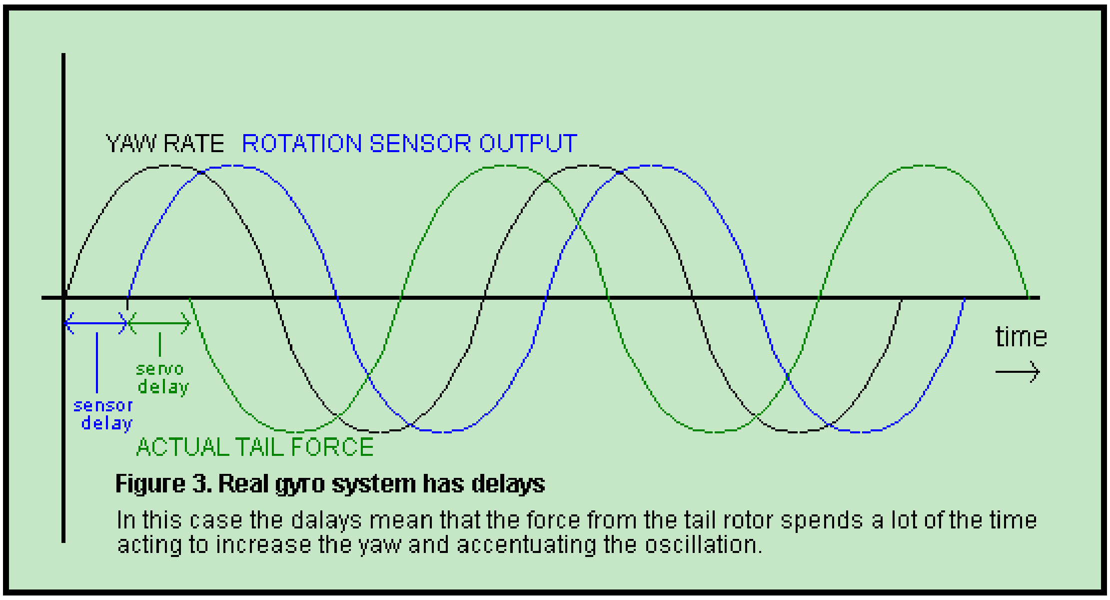


Figure 3. Real gyro system has delays
In this case the dalays mean that the force from the tail rotor spends a lot of the time acting to increase the yaw and accentuating the oscillation.

Figures 2 and 3 show the ideal and real cases for the gyro damping. In the ideal case the tail rotor pitch is arranged so that it always produces a force that directly opposes any oscillation of the tail. In this case oscillations are likely to die out very quickly. In the real case the delays in the gyro and servo mean that the actual tail rotor pitch changes occur later than they should and its possible for the tail to spend some of its time actually increasing the amplitude of the tail oscillation. If the gyro gain is high enough any disturbance can set the tail off into a set of self- sustaining oscillations that can be very violent. The normal solution is to turn down the gyro gain until the oscillations don't occur. However there are a number of things we can do to reduce the tendency to oscillation and allow us to gain a higher degree of damping from the gyro before risking these instabilities.

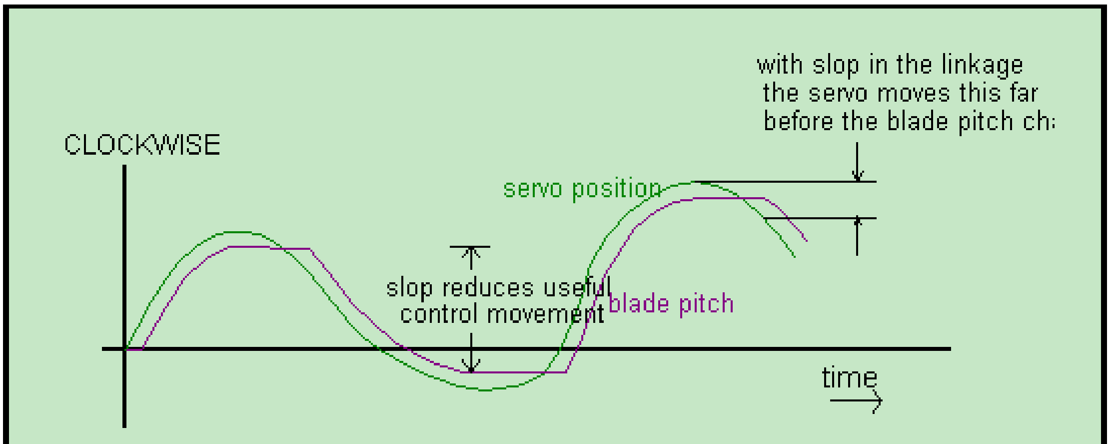


Figure 3. Effect of slop in linkages

slop in the tail pitch linkage reduces the control movement and introduces delays because servo must move significantly before any effect gets through the linkage to the tail pitch.

First in my list would be to eliminate any avoidable delays by getting rid of as much slop and 'give' in the tail pitch control linkage as possible. To my mind, this seems to be an area of helicopter design that usually gets less priority than it should. Often the tail servo is mounted at the front of the radio tray and the long tail control linkage goes through some idler arms, some dog-legs in light gauge piano wire, or some poorly located bell-crank (or sometimes all of these). Add to this some stiffness in pitch sliders and feathering bearings and the servo may have to move quite a bit before anything at all gets through to change the tail blade pitch. There is certainly a healthy market in rear servo mount and push-rod kits that are designed to overcome these shortcomings in the standard designs and one of these may be a worthwhile investment even for the beginner.

Tail servo arm length

Another effective delay reducing measure is simply to use a large radius arm on the tail servo. In fact I set up my tail linkage so that the full travel of the servo cannot be used without the linkage binding. This apparently dangerous arrangement relies on the simple fact that, in flight, the full authority of the tail control is not transmitted through to the servo because, as soon as a tail command from the stick starts to take effect the gyro senses the yaw and opposes the authority of the stick thus reducing the servo movement. The advantage of this arrangement is, for a given speed of servo, the tail pitch can be changed more quickly than with a shorter servo arm so minimising the delay introduced by the servo. Increasing the length of the tail servo arm increases the authority of both the gyro and the stick. As far as the available yaw rate is concerned the two effects are competing so, if nothing else is changed, the two pretty much cancel each other out. Remember that, by increasing the servo arm length you also effectively increase the gyro gain and as a consequence it may at first seem that the longer servo arm has made the tail stability worse. However, if you subsequently have to back the gyro gain control off somewhat to prevent oscillation the overall effect should be an improvement in the tail stability. Next time I'll be looking at some other gyro defects, their consequences and some likely areas for gyro improvement.

Until next month

Colin Mill

(Parts 5 & 6 Originally published February / March 1996)

Practical Theories

Colin Mill

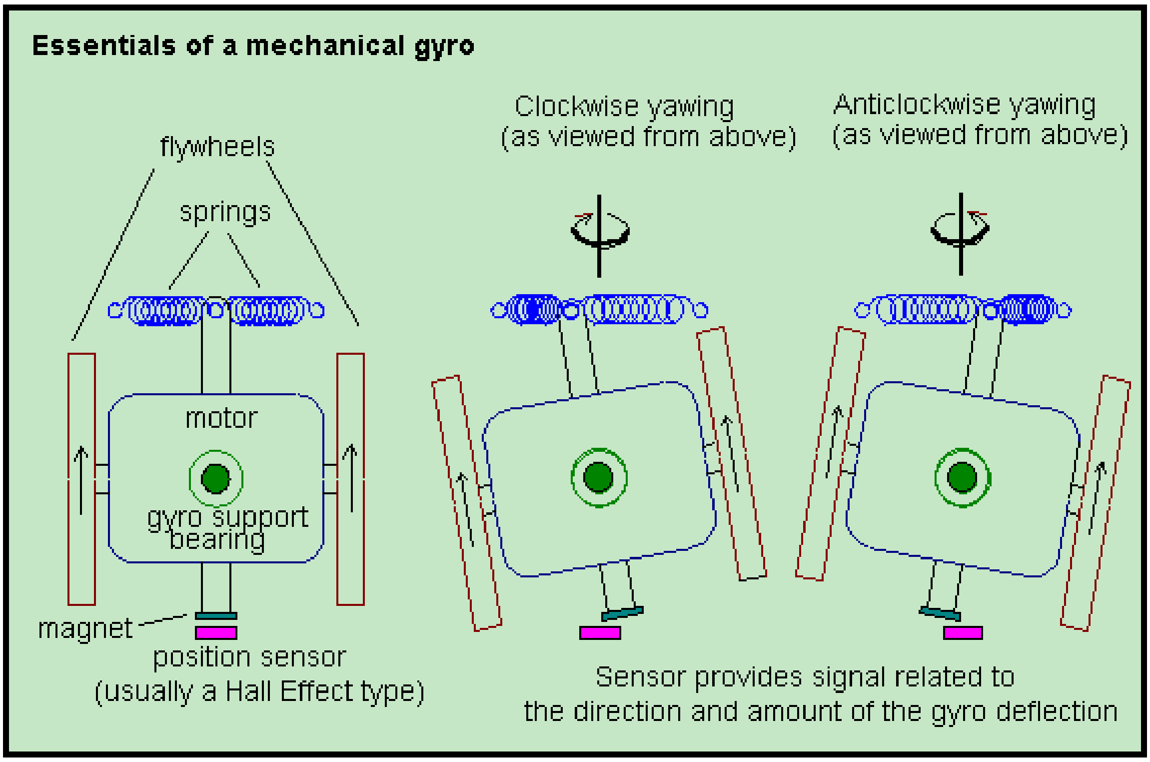
Parts 7 & 8

More on gyros

Having looked last time at delays in gyros I finished by saying that there were other defects in gyros that I would look at this time (what a fool I am!). In order to see how the defects come about we need to look a little at the ways in which gyros work, so here goes.

Mechanical gyros

The heart of a conventional (mechanical) gyro is a motor driven flywheel or, more typically two flywheels, one mounted at each end of the motor.



This whole assembly is suspended, in balance, from a pair of bearings that permit it to rock about a horizontal axis that's at right angles to the motor shaft. Springs apply a centring force so that it normally sits horizontally. As anyone who has played with a kid's gyroscope will know, if you try to change the direction in which the axis of a gyroscope points, the gyro 'fights' this, not with a force directly opposing the change, but rather by attempting to move in a direction at right angles to the one in which you tried to move it (could one perhaps think of gyros as being 'bloody-minded' ?)

For our tail rotor gyro this means that any attempt to turn it about a vertical axis (i.e. yaw it) will cause the gyro to 'want' to tilt about its horizontal axis (i.e. tilt in its support bearings). If it was not for the springs and limit stops the gyro assembly would continue to tilt until its axis was vertical (aligned with the axis about which it is being twisted). With the centring springs the gyro assembly tilts until the force of the springs arrests it. The greater the yaw rate the bigger the spring force needed and so the more the gyro assembly tilts in its bearings. So, if we arrange to measure how far (and in which direction) the assembly has tilted we have a measure of the rate of yaw. The sensing of the gyro tilt is typically done by a solid-state magnetic sensor called a Hall Effect probe who's output depends on the position of a small magnet attached to the gyro assembly. In an ideal situation the output of the Hall probe would be proportional to the yaw rate so the gyro system would provide a true measure of the helicopter's yaw rate.

Yaw rate sensing limitations

Even if this is so there comes a point as the yaw rate increases at which the mechanical end stops prevent any further tilt of the gyro axis. Any increase in yaw rate beyond this will not give any further increase in the gyro signal. As we will see, this gives rise to some curious behaviour of the gyro gain control. To understand this lets look at some data for a particular gyro, the Futaba FP-G154.

Futaba FP-G154 gyro test data

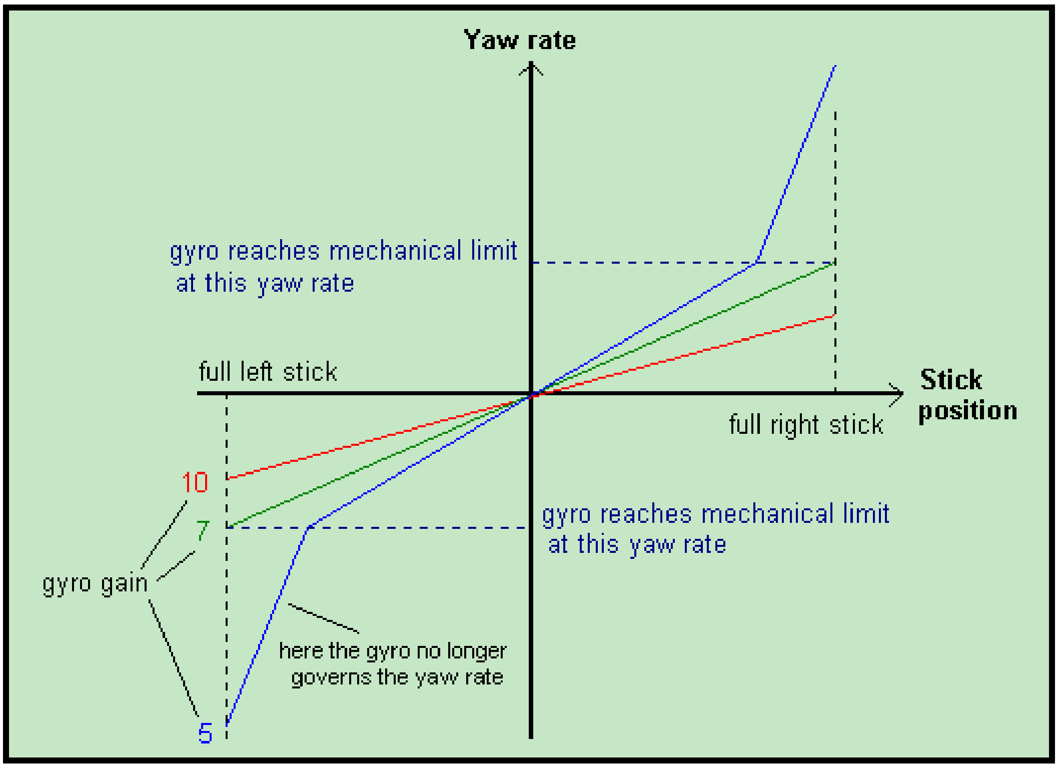
Here are the maximum servo disk movements, at various gyro gain control settings, that the 154 gyro could produce before hitting the mechanical limit stops.

Gyro gain	Max servo disk movement (degrees)
10 (max)	65
8	44
6	30
4	20
2	10
0	0

Notes

- 1) With a Field Force 7 transmitter set to 100% travel volume and rates full stick deflection gave 37 degrees servo output disk travel.
- 2) When run on a 5 volt supply, the full gyro travel (limited by the mechanical stops) was reached at a yaw rate of about 0.29 revs/sec (102 deg./sec). Being a mechanical limit (as opposed to an electrical one) this rate was independent of gyro gain setting.

We can see from these results that, with the gyro gain set to 7 or more the gyro has enough authority to cancel even the full stick deflection from the transmitter. With this much authority the gyro is always in control of the yaw rate. To see this let imagine we have the gain set to 8 and that the servo is at its mid position (call this 0 degrees) with the heli in a steady fixed-heading hover. If we now bang in full tail rotor command on the stick the servo disk moves to 37 degrees (see note 1 in the data) Now as the yaw rate of the helicopter builds up the gyro output acts against the stick input and brings the servo disk back towards the centre position. Since the gyro is capable, with this gain, of moving the servo disk back 44 degrees its possible for the gyro to remove all the 37 degrees stick deflection and actually drive the servo 7 degrees the other way. The yaw rate rise must stop at a rate below that at which the gyro hits the end stop. Notice that the mechanical limits of the gyro are reached at a quite modest rotation of 102 degrees per second. If the gyro gain is reduced to say 6 we see that the gyro authority over the servo (30 degrees) is no longer able to counter the full stick command (37 degrees) and the maximum pirouetting speed may no longer be under gyro control. This causes the maximum yaw rate to change in a rather curious way with gyro gain as can be seen from the graph below.



How the gyro gain affects the yaw rate /stick deflection relationship

Suddenly, as we reduce the gyro gain below a certain value the maximum available yaw rate goes up dramatically with much of the extra rate coming with the last bit of stick travel.

Motor speed dependence

The amount of gyroscopic effect a flywheel has increases with increasing RPM (this is obvious - if it didn't we wouldn't need to turn the thing at all!) It follows that speed variations of the gyro motor due to battery voltage changes etc. will change the effective gyro gain, with a low battery giving a reduced gain.

Zero Error

The position of the 'zero' on the gyro i.e. the way the gyro sits when at rest or at zero yaw rate depends on the balance of the springs. At first sight it might seem unimportant if the gyro does not sit quite in the correct place as any small error can be accommodated by a change in the trim position on the transmitter or in the linkage. However, If a zero error exists in the gyro, the effect of this will go up and down with the gyro gain. All the gyros I have had apart (I wonder why no one lends me radio gear any more!) have a mechanical adjustment to change the mechanical zero, and its worth checking this adjustment by seeing that your tail rotor trim doesn't change as the gyro gain is varied.

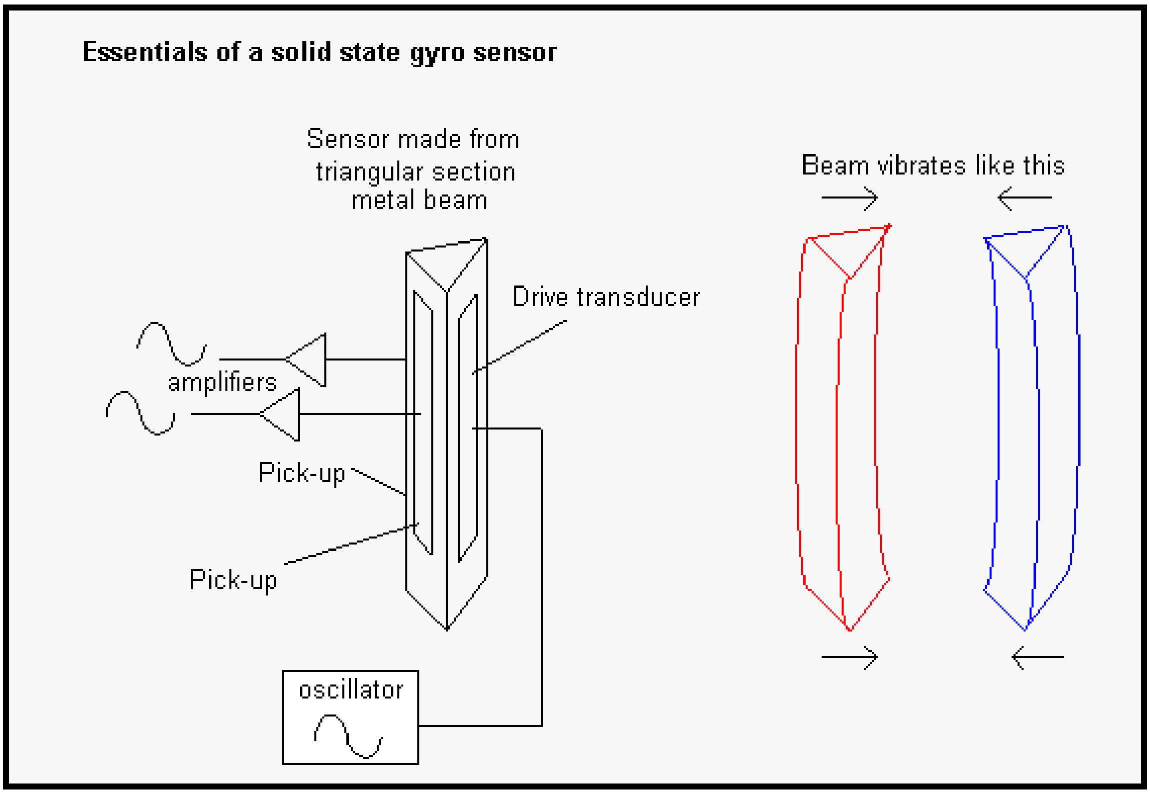
Response time

We touched on the consequences of this last time. The cause in the case of the mechanical gyro comes from the inertia of the gyro motor and flywheel assembly in its support bearings. It simply takes a finite time for the assembly to cant over to the required degree.

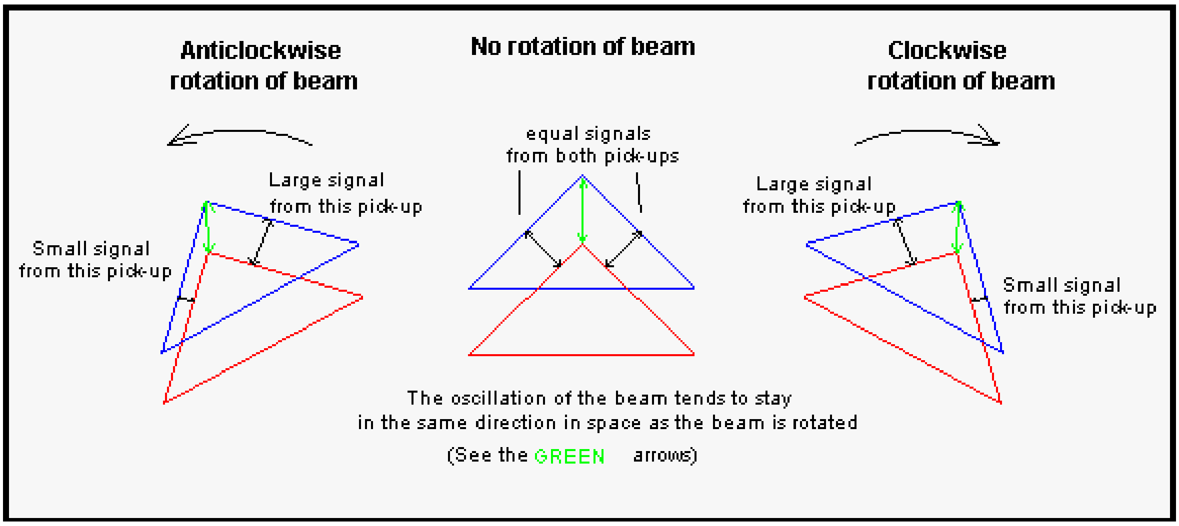
Solid state gyros

In some ways these are a bit of a misnomer. They still depend on motion (in the form of a vibration) for their sensing and, to that extent, they are still 'mechanical'.

As far as I am aware, all the current crop of model helicopter solid state gyros make use of the same type of sensor, indeed I believe they all use units from MuRata's "Gyrostar" ENC series. Though not by any means the only type of vibration based angular velocity sensor these are of a particularly interesting construction based on a triangular cross-section metal bar. To this bar are attached three Piezoelectric transducers that are used both to drive and sense the vibrations of the bar.

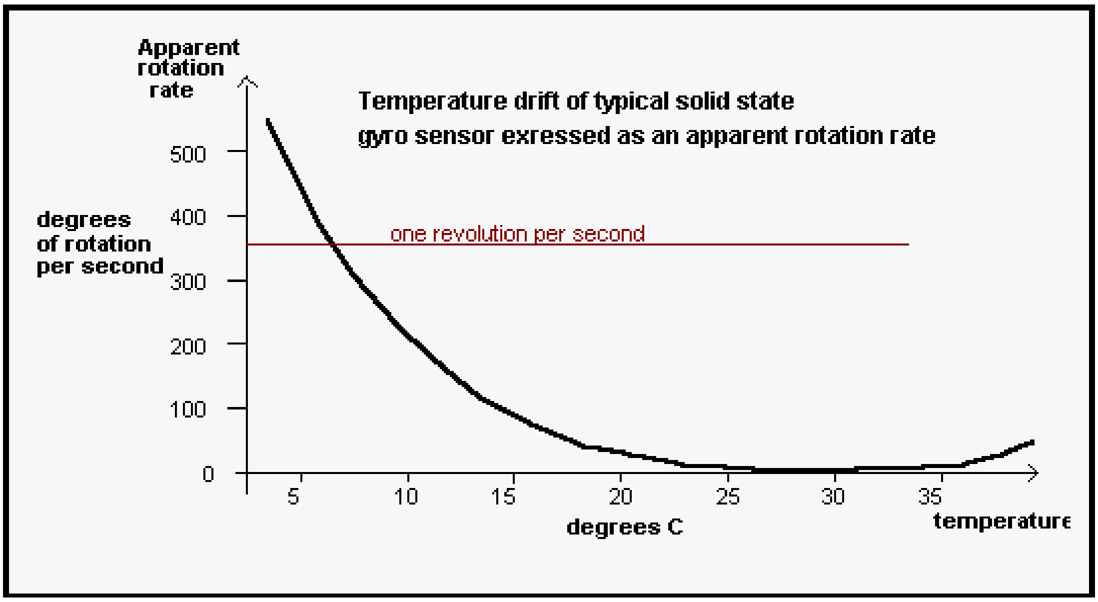


When in operation the bar is set in vibration as shown above. The vibration is such that the degree to which the two faces carrying the vibration pick-up flex is the same (see the middle diagram below) When the beam is not being rotated the signals coming from the two pick-ups are the same size. However, if the bar is rotated about its axis the tendency is for the direction of the vibration to remain the same in space and, as far as the beam is concerned, to be 'left behind'. As a consequence the two pick-ups see different amounts of vibration as one of the pick-up faces bends more than the other (see the left and right diagrams below) Once we stop rotating the sensor the direction of vibration 'catches up' and the vibration seen by the two pick- ups becomes equal again. So, by looking at the relative size of the two pick-up signals we can measure the rotation speed of the sensor. Smart isn't it!



The Pros and Cons

The big thing about these sensors is their rapid response. Roughly speaking, they respond to a change in rotation speed in about 1/50 of a second. This largely eliminates the gyro sensor itself as a factor in the delay-induced tail wagging problems discussed last time (a serious pro!). On the down side we should remember that these devices are vibration sensitive. JR, for example, obviously take this very seriously as they suspend their solid state sensor in a beautifully engineered anti-vibration mounting. However, the most frequently discussed disadvantage of solid state sensors is one of temperature stability or, should I say, the lack of it. There is potentially about a 20% gain drift with temperature over the likely operating range of say 5 degrees C to 35 degrees C. This is much less significant than the temperature drift in the zero. It's interesting that the sensors used in model gyros were developed for anti-shake video cameras, an application where long-term zero stability is not important. Below is a typical zero drift curve drawn so that the drift can be seen in terms of the apparent rotation of the sensor.



At low temperatures especially this drift is severe. If the sensor is zeroed at 10 degrees C and then cools by only 1 degree C its output will change by the equivalent of a rotation rate of about 30 degrees per second. Since the gyro sensor is otherwise 'blind' it can't tell the difference between output changes due to yaw rates and output changes due to temperature changes.

It's all in the software

Ok, I hear you say, how come there are some quite successful solid state gyros about? The answer lies in using software drift compensation. The first 'trick' is for the gyro electronics to zero when the radio is first powered up. To allow this the gyros must be kept still while their electronics take a reading of the output at zero rotation. A 'look-up table' of correction values against temperature for the sensor may be used if the sensor temperature is continuously monitored. The gyro system may also make some assumption about the long-term average rotation of the helicopter being small simply because we spend a lot of the time flying straight and (unless we are un-reformed control-line fliers) make a similar number of turns to left and right. So, if the gyro system 'sees' a significant long-term average yaw rate it's probably due to sensor drift and an appropriate correction can be applied. This is a very good trick to use as it works really well if the temperature drift is checked 'on the bench' or, of course, the model shop counter (a con?). In the interests of a scientific investigation of the methods used by different gyros I think we should see how well they cope when the 'test bench' goes round a bit. I would be grateful if all you solid state gyro owners would try the following simple experiment for me.

- **1.** Cool your nice, expensive gyro in the refrigerator (the wine cooler in the limo would be fine but the freezer is probably a bit over the top!)
- **2.** Set up the gyro on a turntable (you remember, the thirty-three-and-a-third RPM job you used to put black vinyl on in the days before CDs) with receiver, nicad and tail rotor servo.
- **3.** Turn on the radio (including the transmitter) and note the zero position of the servo.
- **4.** Now, with the gyro still running, start the turntable and let it run while the gyro warms up. (Try not to fire the whole lot down the back of the hi-fi or mutilate the tone-arm of the record deck like I did)
- **5.** Now stop the turntable and check where the servo zero is now.
- **6.** Email me with the results please. *(Ed: I think he's serious, so please include details of the make of Gyro! :-))*
- **7.** Try and convince the rest of your household you haven't finally 'tripped out'.
- **8.** Unless failure to do (7) above has landed you in a rubber room, come back next month.

Colin Mill
(Ed: From the rubber room.....)

Part 8

Gyro Drift experiment - the results

Last time you may recall I proposed an experiment that involved refrigerating solid state gyros. Thus far I have had no data come in from this experiment and so I have to make outlandish predictions based purely on the absence of data. I conclude :

All Solid state gyro owners had to pawn their fridges and limos-with-wine-cooler to pay for the gyro. An interesting, little known, but 'scientifically' verified fact.

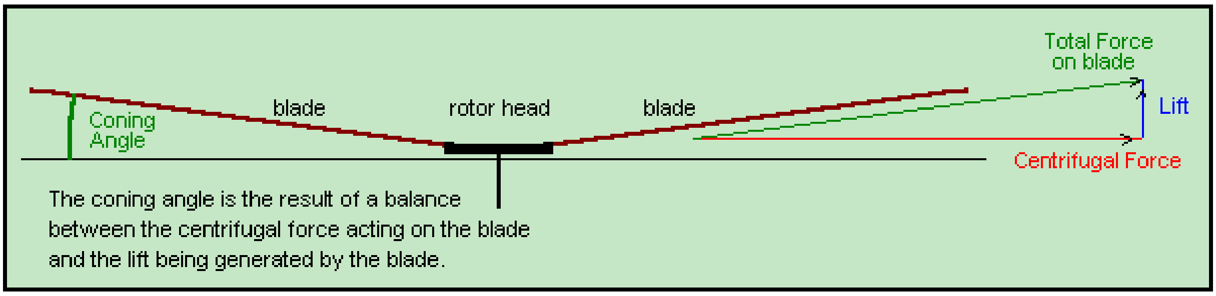
At least for the moment I think I have spent enough time considering the tail of the model and in order to avoid being suspected of an unfortunate tail-obsession I will this time move to the more honourable topic of the main rotor.

The main rotor

I want to start to look at the factors that influence the design of the rotor head. This article will look at the natural behaviour of the blades so that we can better understand what is required of the control system.

Coning Angle

Because the tips of the blades are travelling through the air faster than the inner parts the majority of the lift is produced towards the outer ends of the blades. However, if you try to lift your helicopter by the ends of the blades you will see that the blades bend up in an alarming way long before the skids come off the ground. Indeed the blades might well break at the root if you did lift the helicopter in this way. From this we see that stiffness of the blades does little to support the weight of the machine in flight. It is centrifugal force acting on the blades and throwing them outwards which balances the tendency of lift to fold the blades up.



You can see how the forces balance out when the blades are inclined upwards towards the tips by the coning angle. The greater the centrifugal force the smaller the coning angle while the greater the helicopter weight the larger the coning angle. The centrifugal force depends on the weight of the blades, the rotor diameter, and the rotor RPM. How the weight is distributed in the blade is also important. Weight at the ends of the blades has more effect than weight near the root.

The centrifugal force is surprisingly high. Taking a typical pair of 30 size blades of about 100 grams on a head running at 1700 RPM the centrifugal force trying to pull the blade off the head is over 100 kgf. (220 pounds force), making the rotor head a highly stressed unit. If this rotor is lifting a 3 kg helicopter (1.5kg per blade) the resulting coning angle is only 0.8 degrees. The tendency of the blades to cone up has to be accommodated either by flapping hinges or flexible plates that permit the blade holders to hinge up or (with a through axle head) by the flexing of the blades.

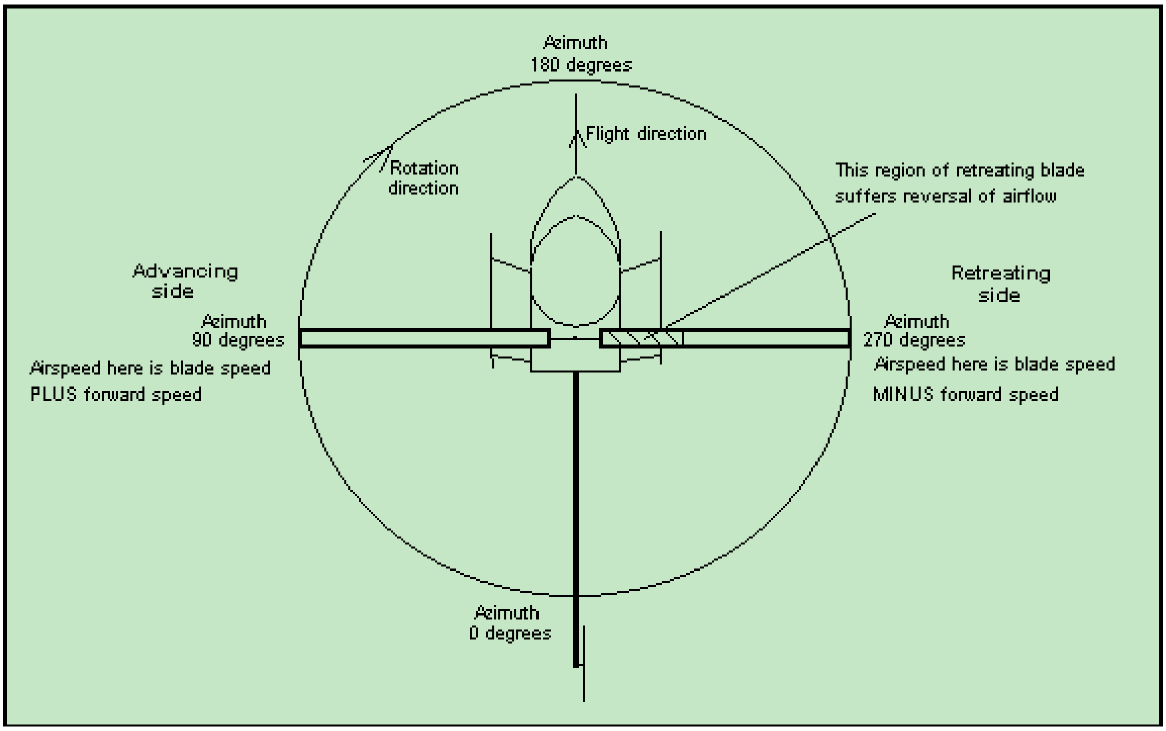
Since coning looks rather like the dihedral on a fixed wing aircraft it is tempting to think that it has a similar effect as an aid to stability but as we will see its effect in forward flight is undesirable.

Forward Flight

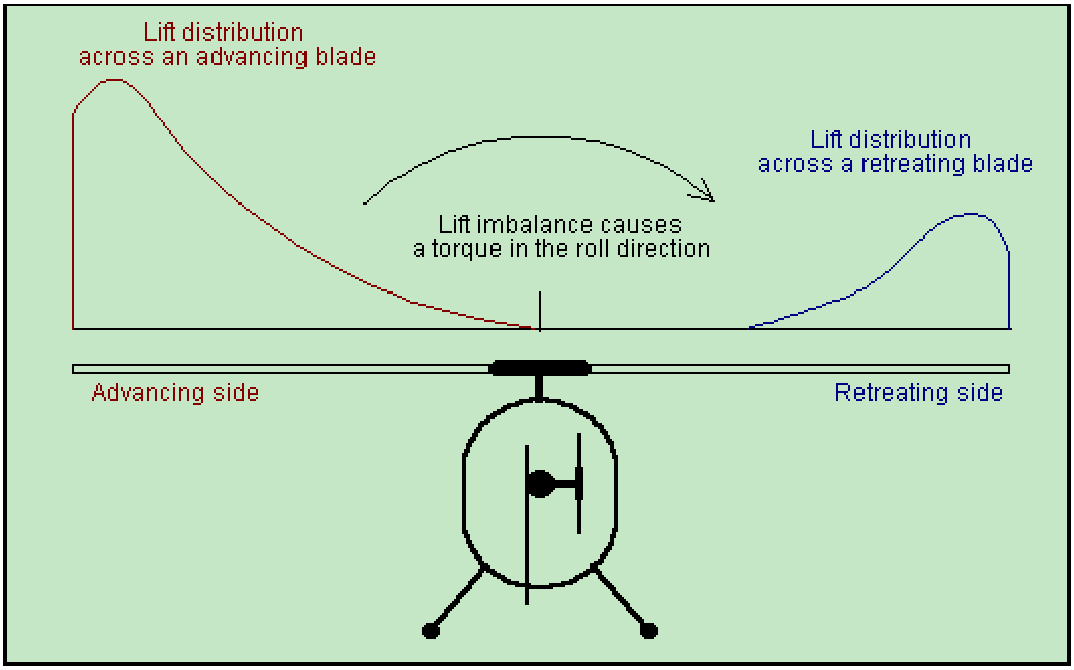
Before we go any further let me explain two terms often used when talking about forward flight.

Advance Ratio
This is the forward speed of the helicopter as a fraction of the tip speed of the blades. Typically this ranges from 0 to about 0.5.

Azimuth Angle
This is used to describe the rotational position of a blade. The zero position is when the blade points down stream (i.e. from the point where it is directly above the boom). The advancing side is from 0 to 180 degrees and the retreating side from 180 to 360 degrees.



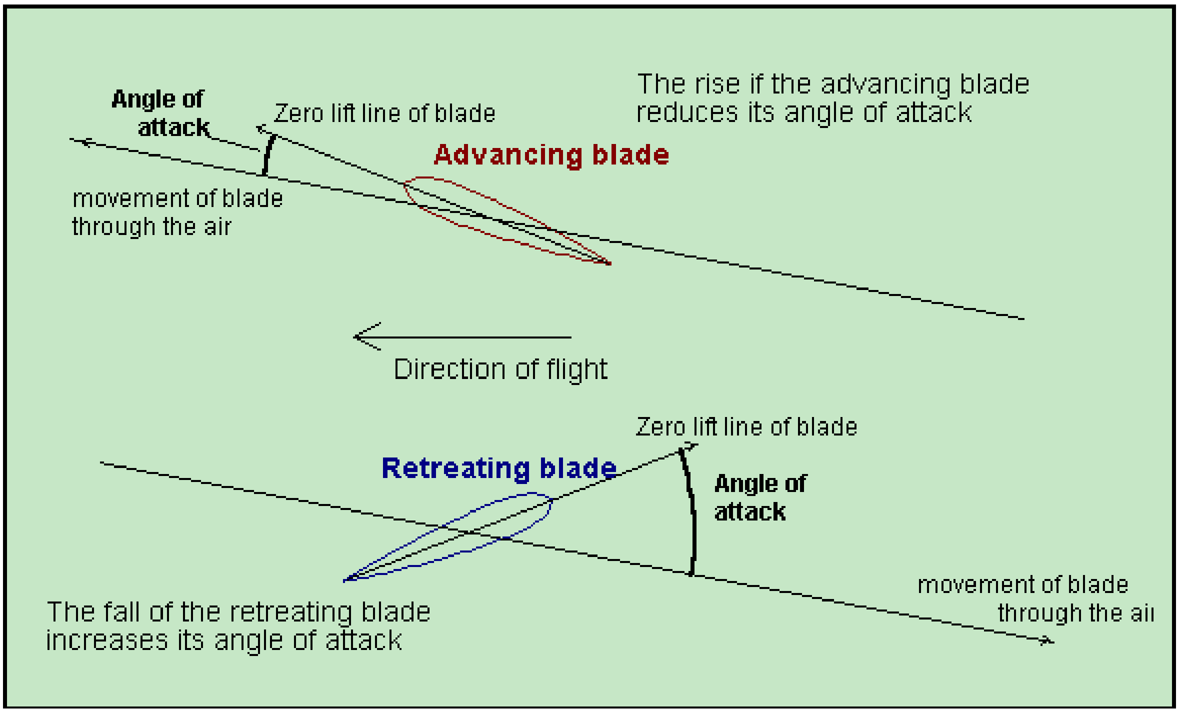
In the hover the blades are subject to the same airspeed at all points of their rotation. However, in forward flight a blade experiences a greater airspeed on the side where it is moving forward (the advancing side) than it does on the side where it is moving backwards (the retreating side). On a helicopter with a clockwise rotor head the left side is the advancing side, the right side the retreating side. On the advancing side the forward speed of the helicopter adds to the blade speed to produce an airspeed greater than in the hover while on the retreating side the forward speed of the helicopter opposes the blade speed and the resulting airspeed is lower than the hover value. Near the root , the blade speed is low and the flow actually becomes reversed at the inboard end of the retreating blade. If nothing is done to prevent it, these airspeed changes will cause a lift increase on the advancing side and a lift decrease on the retreating side. The lift distribution for a rigid, constant pitch rotor would be something like this.



Even at a modest advance ratio of 0.3 about 80% of the lift would be generated on the advancing side of the rotor. This lift imbalance would cause a torque (turning effort) in the roll direction, but because of gyroscopic effects would result mainly in a nose up pitching of the helicopter.

The same freedom of the blades to move up and down that allows for coning also provides a solution to this problem. Interestingly it was work, not on helicopters, but on autogyros, carried out by Juan de la Cierva that provided this breakthrough. It was reasoned that if the blades were hinged at the mast so that they were entirely free to flap up and down then they could not transmit a rolling moment to the body of the helicopter. Instead, as the lift on the blade increases on the advancing side the blade simply rises while on the retreating side, where the lift is least, the blade falls.

The act of flapping has an effect on the angle of attack of the blade as seen below.

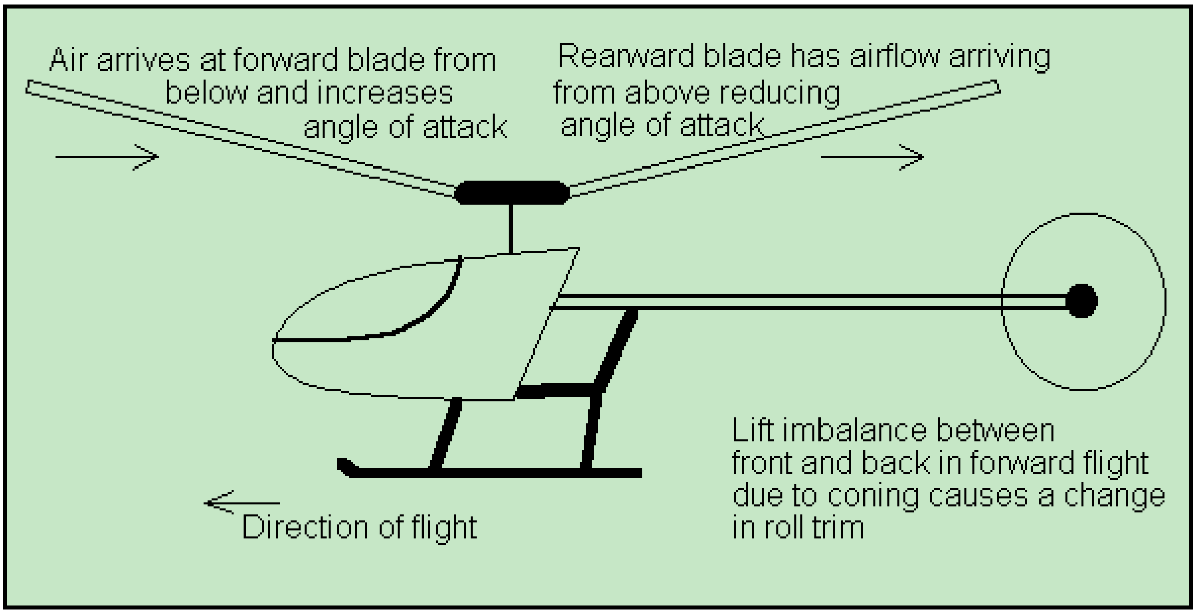


The vertical motion of the blades reduces the angle of attack where the blade is rising (on the advancing side) while increasing it where the blade is falling. When the blades are free to flap these changes in angle of attack occur naturally and need no special geometry of the head. These cyclic attack angle changes result in lift coefficient changes that eliminate the imbalance in lift between the advancing and retreating sides.

The higher the forward speed of the helicopter the more pronounced the flapping becomes. This results in a diminishing angle of attack on the advancing side and an increasing angle of attack on the retreating side. Interesting the limitation to the forward speed of a helicopter (given enough power) is reached when the blades stall on the retreating side as the down flapping on this side increases the angle of attack beyond the point of stall (say about 12 degrees).

Just imagine you are a fly sitting on a rotor head in forward flight and that you are looking out along one of the blades. You would see that on the advancing side the blade rises and reaches its highest point as the blade is pointing forward (azimuth 180 degrees). The blade falls on the retreating side reaching its low point when pointing rearward (azimuth 360 degrees). Seen from outside this flapping action looks like a rearward tilt of the rotor disc relative to the shaft. So by letting the blades flap freely we have traded a violent rolling moment for a rearward tilt of the rotor disc that can easily be opposed by a suitable forward cyclic control input. It is worth noting that the extra lift on the advancing side (at azimuth 90 degrees) raises the front of the rotor (azimuth 180 degrees), indeed the effect of extra lift at any point in the rotation results in an upward movement in the rotor 90 degrees later. This becomes important when later we are thinking about the effect of cyclic controls.

The simple picture of the flapping rotor head is complicated by several factors.



Firstly, the coning angle causes an imbalance in the lift generated by the blade at the forward and rearward positions. The coning causes the angle of attack of a blade to be greater when pointing along the direction of flight than when pointing rearward So the blade continues to rise as it passes over the nose of the helicopter and to fall as it crosses the boom. In other words the high point of the flapping is on the retreating side (say at an azimuth of 200 degrees). Now the tilt of the rotor disc is not simply backwards but has in addition a sideways component. With a clockwise rotor this tilt will be to the left and would need some right cyclic control input to maintain level forward flight if the machine were trimmed for the hover.

Again in our simple picture we have assumed that the blades are free to flap about hinges and that these hinges are coincident with the main shaft. This gives a blade flapping frequency equal to the rotation frequency of the head. However, this is a somewhat impractical arrangement as the body of the helicopter would be free to swing about below the rotor resulting in poor control of the body attitude. In practice the flapping hinges are often set some way out from the shaft and the flapping is restricted by damper rubbers or spring plates. Both these factors affect the flapping action of the blades and raise the natural flapping frequency so that the blade tries to flap at a frequency greater than the rotation frequency. The end result is that the blade flapping reaches its high point earlier in its rotation (i.e. before the blade reaches the forward position), in other words the high point is slightly on the advancing side of the rotor disk (say an azimuth of 160 degrees). This effect is in opposition to that of the coning angle and may swamp it, in which case left cyclic trim may be needed in forward flight (given a clockwise rotor).

Next time

I have been very busy with the preparations for the Sandown Park show and the new release of the simulator so I will be taking a holiday and will be back with you in two months time when I will look at the requirements for cyclic control of the main rotor. In the meantime, good flying!

Colin Mill

(Parts 7 & 8 Originally published April / May1996)

W3MH HOME PAGE

Practical Theories

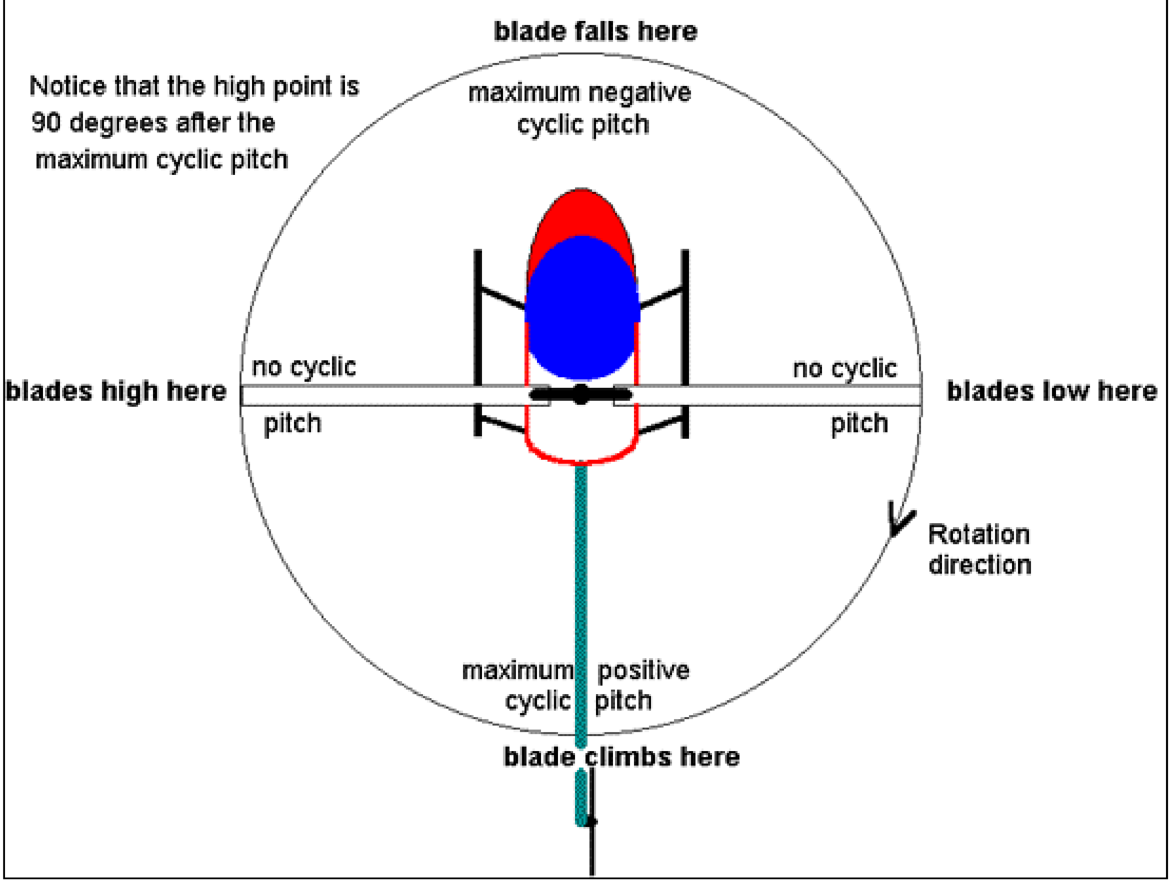
Colin Mill

Parts 9, 10 and 11

In the May issue I looked at the way the main rotor reacts in forward flight. We saw that to cope with the different airspeed seen by the blades on the advancing and retreating sides of the rotor disk it was necessary to allow the blades some freedom to flap up and down as they go round. This time we will look at the way the rotor head allows control of the helicopter in roll and pitch. This is done by changing the angle of attack of the blades. To permit the angle of attack of the blades to be varied they are pivoted around an axis that points approximately along the length of the blades. These pivots are called the feathering hinges or feathering shafts. Rolling and pitching control is provided by changing the angle of attack of the blades in a cyclic manner. The angle of attack is increased as a blade passes through some part of its rotation while being decreased when it is on the other side of the rotor. For obvious reasons this is called cyclic control.

At first sight it can seem as if the roll and pitch cyclic controls are crossed over however the following way of looking at things helps overcome that confusion.

Figure 1. Cyclic pitch control for a right roll



In figure 1 we see what happens when a clockwise rotor has cyclic control applied. In this example the control is arranged to increase the angle of attack of the blades at the back of the rotor and reduce it at the front of the rotor. In response to the increase in attack, the blades (which are more or less free to hinge up and down) respond by climbing as they travel around the rear half of the rotor. Conversely, in response to the reduced angle of attack there the blades fall on going round the front half of the rotor. The result of this is for the rotor to take on a tilt with the 'high point' on the left side of the helicopter and the 'low point' on the right. In other words the effect of this particular cyclic control is for the rotor to roll to the right.

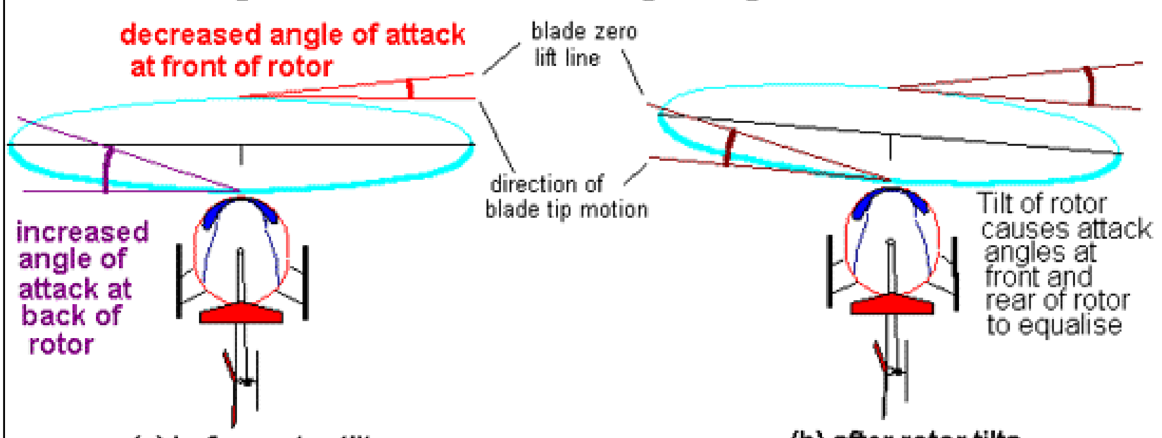


Figure 2. Rotor disc tilt changes angle of attack.

We can get another insight into the way the rotor responds by looking at the same situation as seen from behind the helicopter. To keep things simple let us imagine that the helicopter is strapped down preventing it from following the rolling motion. In Figure 2(a) we catch the rotor the instant the control is applied (but before the rotor has had time to respond). Here the different angles of attack at the rotor disk front and rotor disk back resulting from the cyclic input are seen. In Figure 2(b) we see the situation when the rotor disc has had time to tilt over to the right. Notice how the blades are now at the same angle of attack all the way around the rotor. This happens because the tilt of the rotor disc changes the path of the blades through the air but, because we have fixed the helicopter, the head and swashplate (that are responsible for fixing the direction in which the blades 'point') have not tilted and so the direction of the zero-lift line of the blades has not changed. There is a simple relationship between the cyclic pitch and the limit to which the rotor disc will tilt. If the cyclic control increases the angle of attack at the back of the rotor by 5 degrees and decreases it by 5 degrees at the front, the rotor disc will tilt over by 5 degrees relative to the head and stop.

If the helicopter is not strapped down the tilting of the rotor disc will be followed by the body rolling with it. The force that the rotor imparts to the body when cyclic controls are applied comes from three causes. The first source of torque (turning effort) results from the thrust of the rotor no longer acting straight through the helicopter's centre of gravity (C of G). As can be seen from figure 3 the thrust line now passes to one side of the C of G and the resulting torque is equal to the rotor thrust multiplied by the distance between the thrust line and the C of G.

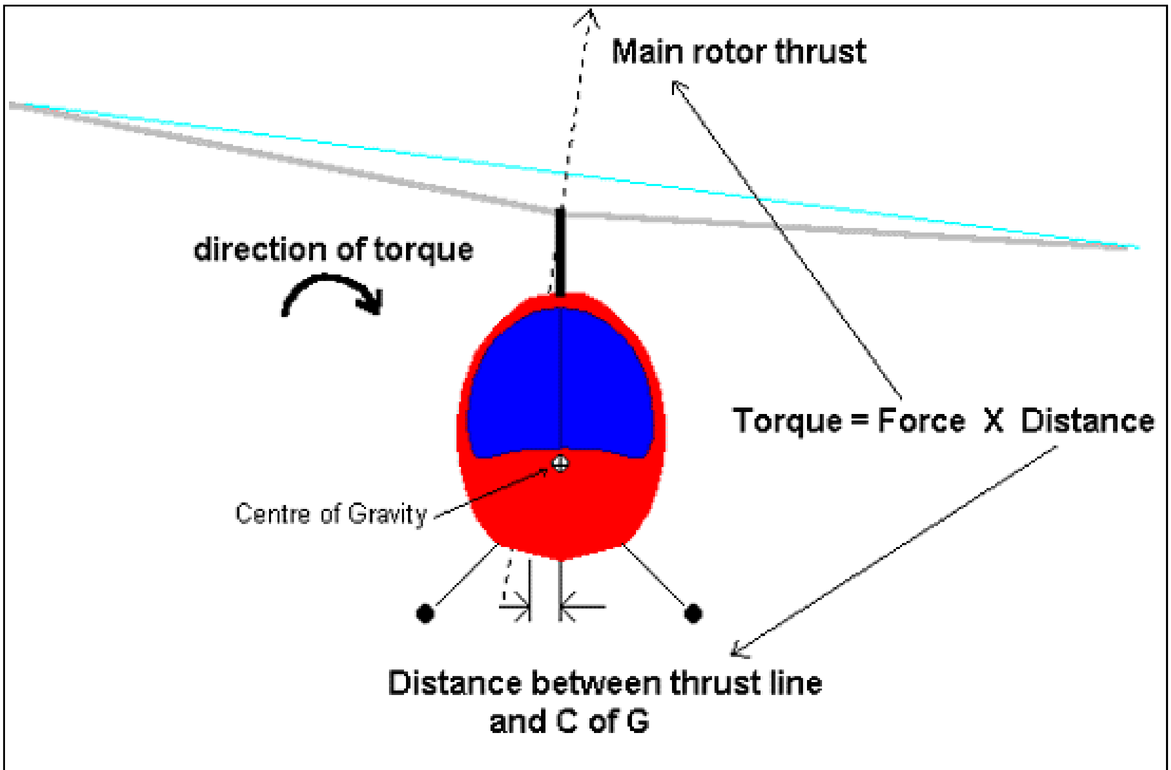


Figure 3. Torque on body due to the main rotor thrust line

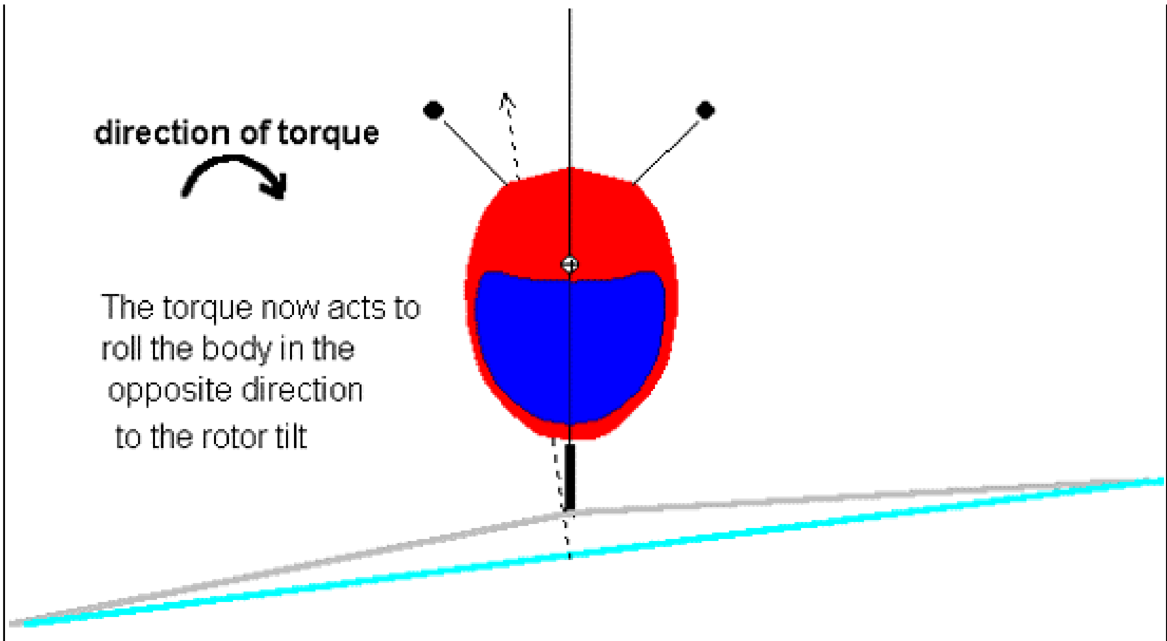


Figure 4 Torque on body due to main rotor thrust when inverted

This torque depends on the size and direction of the rotor thrust. In the hover the thrust will approximately equal the weight of the helicopter and the torque will be acting to make the body follow the rotor. In inverted flight however the direction of the thrust is reversed. This reverses the torque that now acts to tip the helicopter in the wrong direction (see Fig. 4). So this torque is de-stabilising for an inverted helicopter and for reasonable stability in inverted flight it is important that the other torques are big enough to overcome this effect. We can minimise this torque by keeping the distance between the rotor head and the helicopter's C of G to a minimum.

The second source of torque between the rotor and the body comes from the head having some sort of damper rubbers or spring plates that resist the free up and down hinging of the blades. As the plane of the rotor tilts relative to the head these come into play and provide a torque tending to roll (or pitch) the body with the rotor disc. Where the damper rubbers are very hard, flexibility of the blades may also come into play.

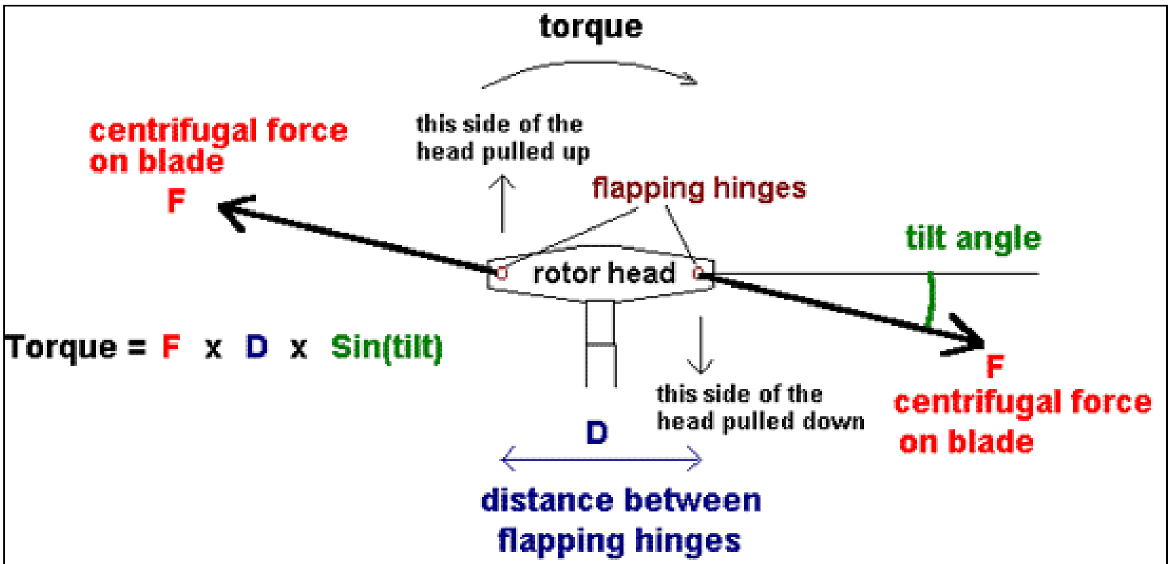


Figure 5. Centrifugal force on blades and flapping hinge offset combine to produce body rolling torque

Finally, if the rotor head has flapping hinges (such as the 'Concept') there is a torque due to the centrifugal force acting on the blades combined with the separation of the hinges. Fig. 5 shows an exaggerated situation where the rotor disc is canted over relative to the head. The uplifted blade on the left is pulling the left hand side of the head up while the blade on the right is pulling the right hand side of the head down. Because the blades are not hinged at the same point but at flapping hinges that are separated the result is a torque that is trying to tilt the head to the right. This force increases with increasing distance between the flapping hinges and with increasing centrifugal force on the blades. The latter means that heavy blades and high rotor head speeds will give an increase in this torque and cause the body to respond faster to rotor disc tilting. Some heads have a single axle and no flapping hinges. In these cases this effect is absent.

Now let us return to the case of our right roll command and see what happens when the helicopter is free to follow the rotor. Because of its inertia the helicopter body initially lags behind the rotor but the torques we have just looked at accelerate the body into the roll and eventually the body 'catches up' with the rotor. If the roll command is held on the cyclic pitch on the blades is maintained because the swashplate moves with the body. Rather than stopping as we had with the helicopter strapped down, the rotor continues to roll and the body goes with it. It is fair to ask how fast the helicopter will roll. However, the answer to this does not rest with the forces we have just been discussing as they do not set the final roll or pitch rate but rather they govern how quickly that rate will be reached.

The speed of response of the rotor to cyclic commands is very important to the controllability of the machine. If the response of the helicopter to cyclic commands is too slow the pilot may, in extreme cases, have insufficient authority to correct for natural disturbances in the helicopter attitude. Conversely, the helicopter may be so quick to respond to cyclic controls that the pilot is unable to react fast enough to maintain proper control. The natural tendency with model helicopters is towards an excessively rapid response. It is generally the requirement that the control system tame this exuberance. So far we have assumed that the cyclic controls are applied directly from the servos to the main blades (well, via the swashplate of course). Without very careful design, this arrangement makes for a helicopter that responds too quickly for a human pilot to control. This is because the main blades respond very quickly to cyclic control inputs. The aerodynamic forces acting on the blades are large (comparable to the weight of the helicopter of course!) On the other hand the blades are relatively light so it is inevitable that the blades will react quickly to any changes in their angle of attack. To get some idea, the two situations shown in figure 2 would typically be separated in time by only a few hundredths of a second. The application of a small, say 5 degree, cyclic control could cause a roll rate of more than 360 degrees per second. This sort of handling characteristic would render the machine almost un-controllable.

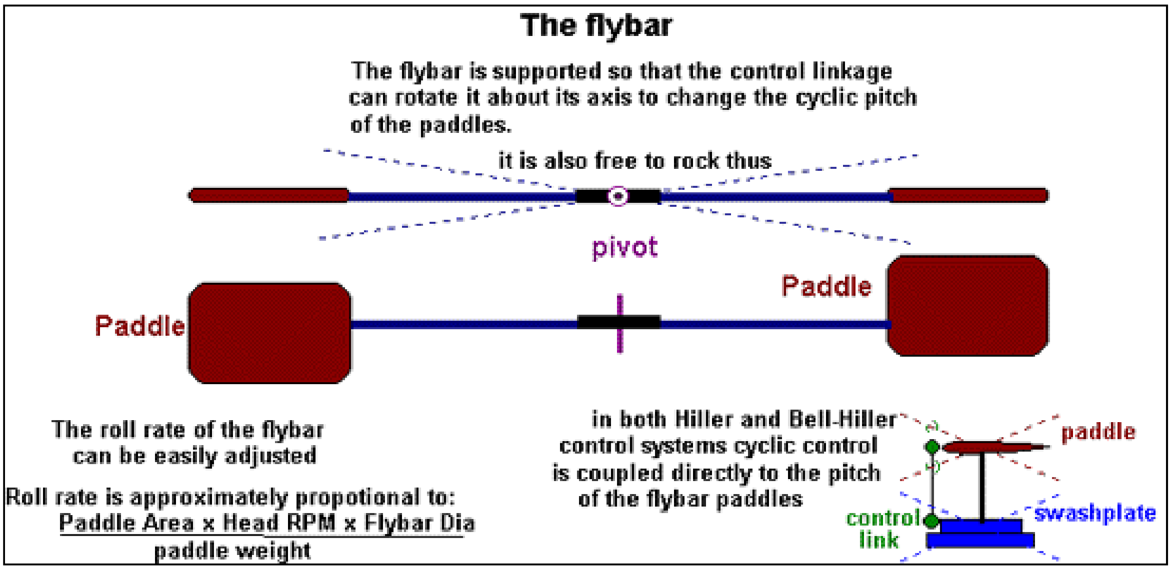
While some so called 'flybarless' model helicopters exist they are by no means common, and with very few exceptions are scale types where the choice has been driven by the need for scale appearance rather than by handling characteristics. The vast majority of model helicopters employ a control system, standing between the servos and the main blades, to regulate the response to cyclic controls. These systems vary in many respects, however they all have one feature in common: the flybar, about which more next time.

Part 10

The flybar and control systems

Last time I touched on the question of the cyclic response of a model helicopter. We saw that the natural tendency is for the main blades to respond too quickly to cyclic commands. This happens because the aerodynamic forces acting on the blades are large compared to the weight of the blades. We can't do much about this because the lift on the blades has to be big enough to support the weight of the helicopter and so we can reduce the forces on the blades only at the expense of not having the helicopter fly at all!

The control systems employed on model helicopters almost without exception employ a flybar to overcome these difficulties.



The flybar as illustrated here consists of a rod carrying small aerofoils (paddles) and is pivoted so that it may rock. The angle of attack of the paddles is set by the cyclic control and they respond in much the way outlined for the main blades last time. Again, to roll the flybar to the right the angle of attack of the paddles is increased on going round the rear half of the rotor and reduced on going round the front half of the rotor. This is simply done by rotating the whole bar around its axis. Because the flybar is not responsible for lifting the helicopter the aerodynamic forces acting on the paddles can be tailored to give the required speed of response. It is best to think of the flybar as a gyroscope that can be steered by the cyclic controls but when not being steered tends to maintain its axis of rotation relative to the ground rather than the helicopter body or the air. The speed of response of the flybar to commands can be adjusted as follows:

- *Increasing the weight of the paddles slows it down.*
- *Increasing the area of the paddles speeds it up*
- *Increasing the rotor RPM speeds it up*
- *Increasing the aspect ratio (span/chord) of the paddles speeds it up.*
- *Increasing the length of the flybar speeds it up.*

This last point was something that Ken Rudd touched on in W3MH some time ago. However its not obvious why this should be the case so let me just give my reasoning for it. If we take one size and weight of paddles and fit them to a flybar that has been lengthened by say 10%. We :-

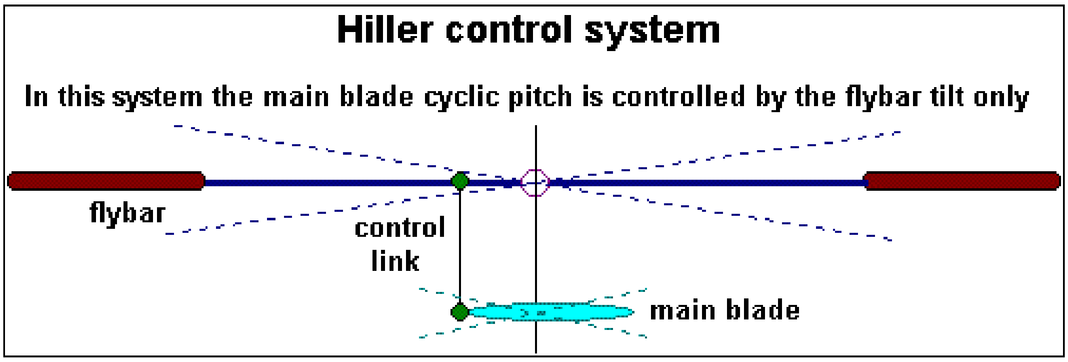
- *1) increase the moment of inertia (the flywheel effect) of the flybar. This means that the flybar will need a greater torque to impose a given rolling or pitching rate on it.*
- *2) However, in putting the paddles further out we have increased the leverage that they have so that, for a given aerodynamic force on the paddles, we have a bigger torque.*
- *3) In addition, by putting the paddles further out we have, for a given head speed, increased the airspeed of the paddles and thus increase the aerodynamic forces they produce.*

Now effect 1) acts to slow down the response of the flybar, and it involves a square law so a 10% increase in flybar length increases the torque needed for a given roll rate by about 20%. However, effect 3) also involves a square law so, with the paddles 10% further out they produce 20% more force for a given cyclic pitch. So effects 1) and 3) cancel one another out. This leaves effect 2) which is linear and so a 10% increase in flybar length speeds the flybar up by 10%.

The Hiller control system

This is the simpler of the two systems seen on models. In this case the cyclic controls are transmitted from the servos to the flybar only. The cyclic pitch variations of the main blades are then controlled entirely by the tilting of the flybar. The sequence of events that follows the application of a cyclic roll control go like this:

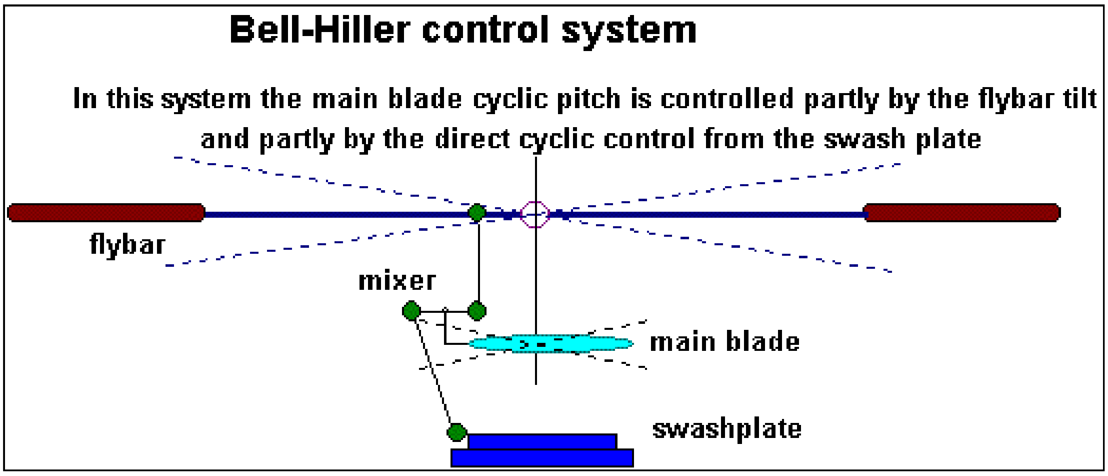
- *1) Cyclic pitch acting on the flybar paddles causes the flybar to start tilting in the desired direction.*
- *2) As the flybar tilts cyclic pitch starts to be applied to the main blades and they start to follow the flybar.*
- *3) Torque from the main blades acting on the body accelerates it into the roll.*
- *4)The rate of roll of the helicopter settles down to that determined by the flybar.*



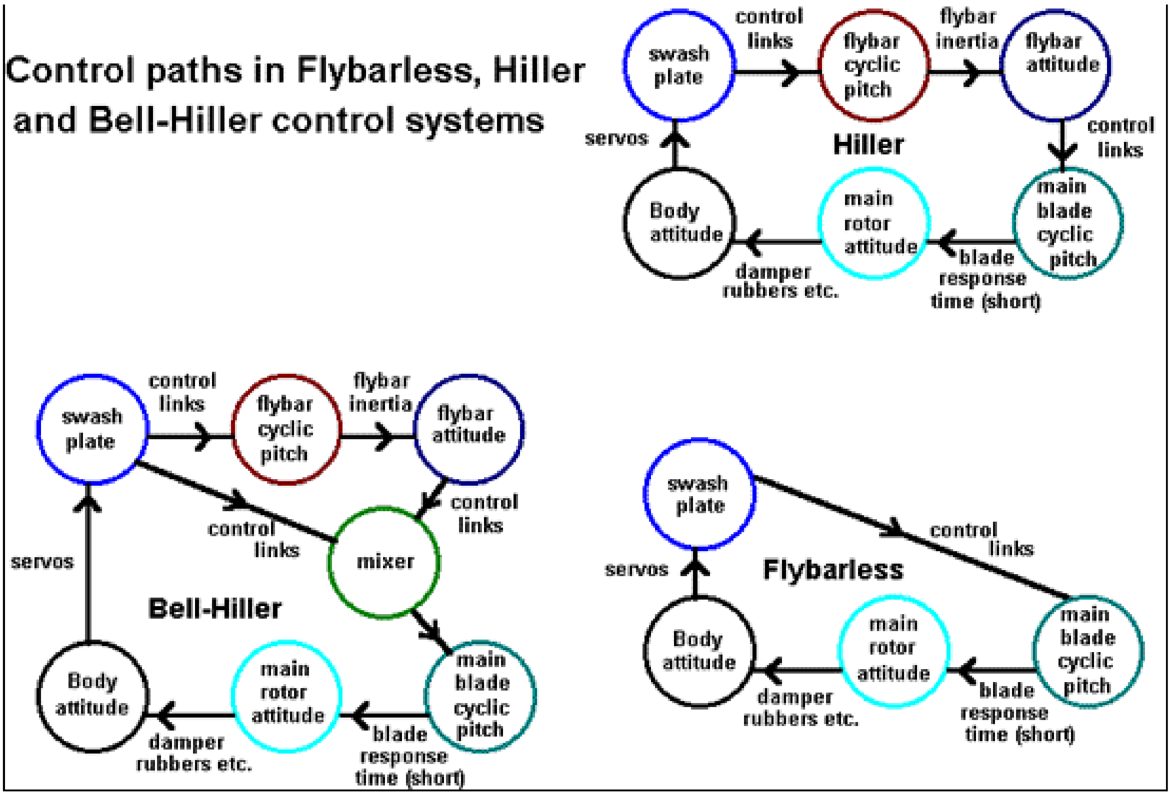
The amount of cyclic control applied to the main blades is automatically adjusted so that the correct roll rate is maintained. The more the main rotor lag behind the flybar the greater the cyclic control applied to the main blades and vice versa.

Bell-Hiller Control

The problem with the basic Hiller control system is the delay it introduces in the response of the helicopter. The pilot must wait for the flybar to respond before his cyclic commands get through to the main rotor. This means that a degree of anticipation is required by the pilot to get the control inputs in slightly ahead of their being required.

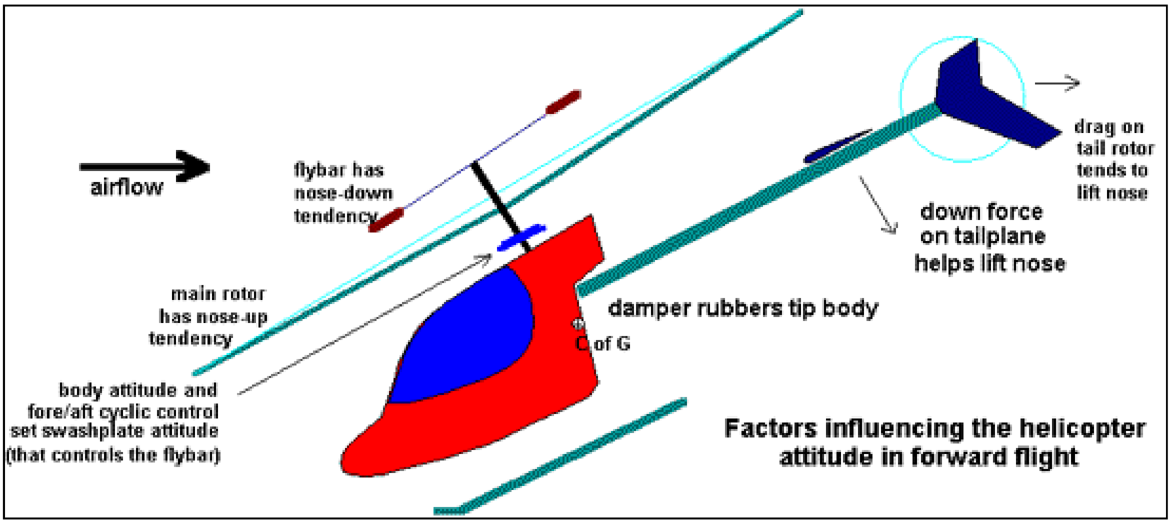


The Bell-Hiller system of control addresses this problem and has become almost universal in modern model helicopter designs. In this system the cyclic controls go to the flybar as before. A proportion of the cyclic control is also taken directly to the main blades and mixed with the cyclic control from the tilt of the flybar. The Bell-Hiller mixing ratio determines the proportion of the main blades cyclic control comes directly from the swashplate and how much comes from the flybar. When a cyclic control input is made the main blades now respond immediately to the command. Any tendency for the main rotor to roll too far or too fast is resisted. If the main rotor overtakes the flybar in the roll the control fed from the flybar to the main blades will reduce the cyclic control on the main blades and slow their progress. The beauty of the Bell-Hiller system is the degree to which the response of the helicopter can be adjusted to suit various requirements. For a beginner, the helicopter can be set up so that the flybar roll rate is very slow by using heavy paddles. The resulting machine can still have a quick response to cyclic commands because of the direct element of the main blade control that allows the main rotor to tilt before the flybar has moved. The slowly responding flybar helps in two ways. It limits the initial rotor tilt and acts to help return the rotor level after the command has been released.



The flybar in forward flight

So far we have only considered the action of the flybar in the hover but it is interesting to see what happens to the flybar in forward flight.

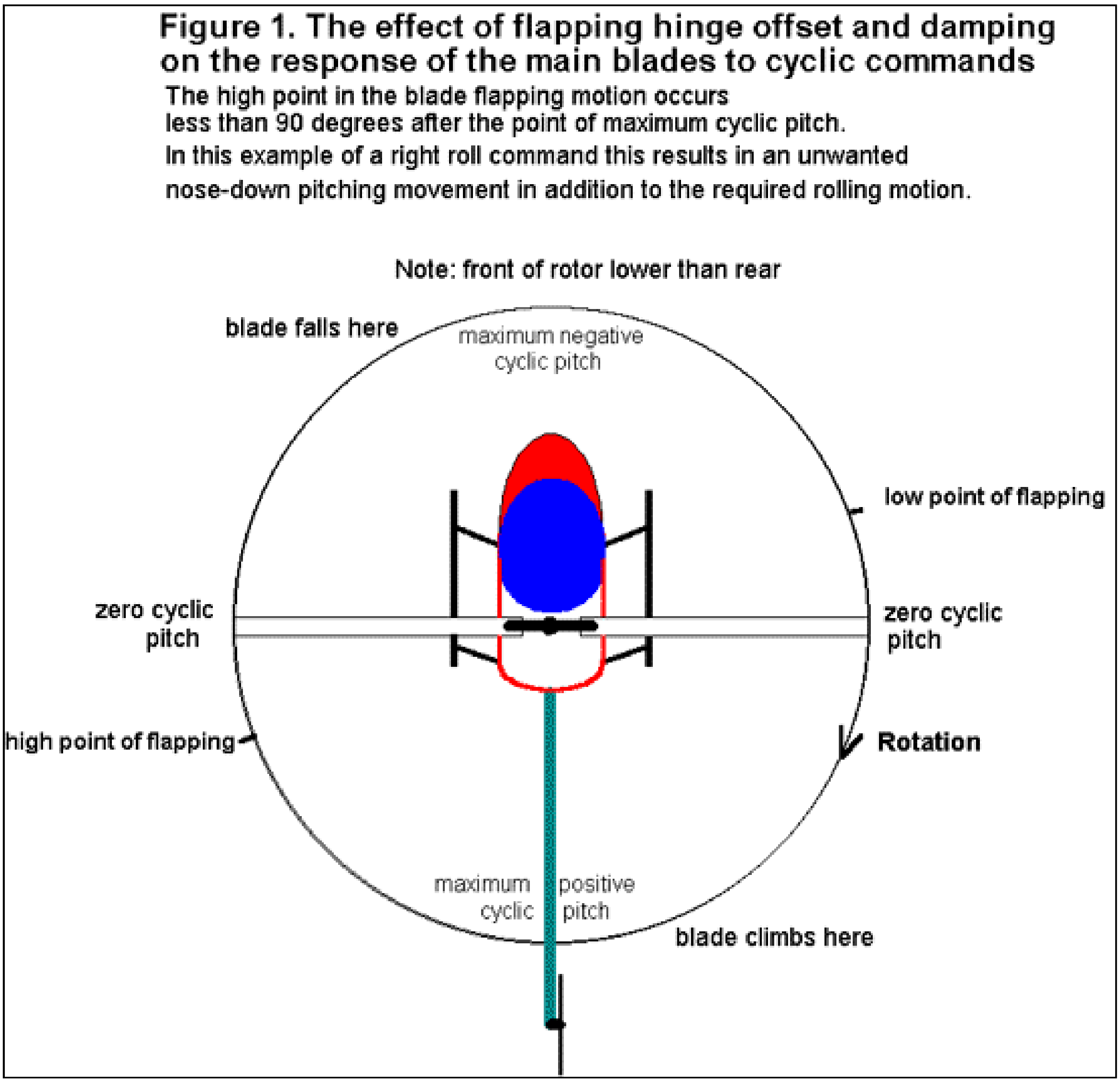


Normally the paddles of the flybar are set with no collective pitch. In forward flight the helicopter is tilted nose down and there is a net downflow through the main rotor. This means that the flybar paddles are at a negative angle of attack. As a consequence the paddles are pushing downwards. However, when the paddles are on the advancing side they have a higher airspeed and the downforce is greater than on the retreating side. The paddles fall on the advancing side and rise on the retreating side resulting in a nose down tilting of the flybar. If this effect was not opposed the helicopter would take on a steadily increasing nose down attitude and dive into the ground. What opposes the nose down tendency? Previously we saw that in forward flight the greater lift of the blades on the advancing side causes the main rotor to have a nose-up tendency and this requires some forward cyclic control to be used if a constant attitude is to be maintained. The natural nose-down tendency of the flybar will go some way to provide this. A correct balance between the two opposing effects depends on many factors: Flybar length influences the advance ratio of the paddles. Bell-Hiller mixing ratio determines how much the main blade cyclic pitch is changed by the nose-down attitude of the flybar. The stiffness of the damper rubbers, etc. determines how closely the body follows the main rotor attitude. The attitude of the body determines the plane of the swashplate that in turn influences the cyclic pitch of the flybar etc, etc. Down force on the tailplane and drag on the tail rotor and the boom all provide a stabilising influence on the nose-up nose-down attitude of the helicopter. Certainly, this seems to be one aspect of the helicopter where almost every component has some influence.

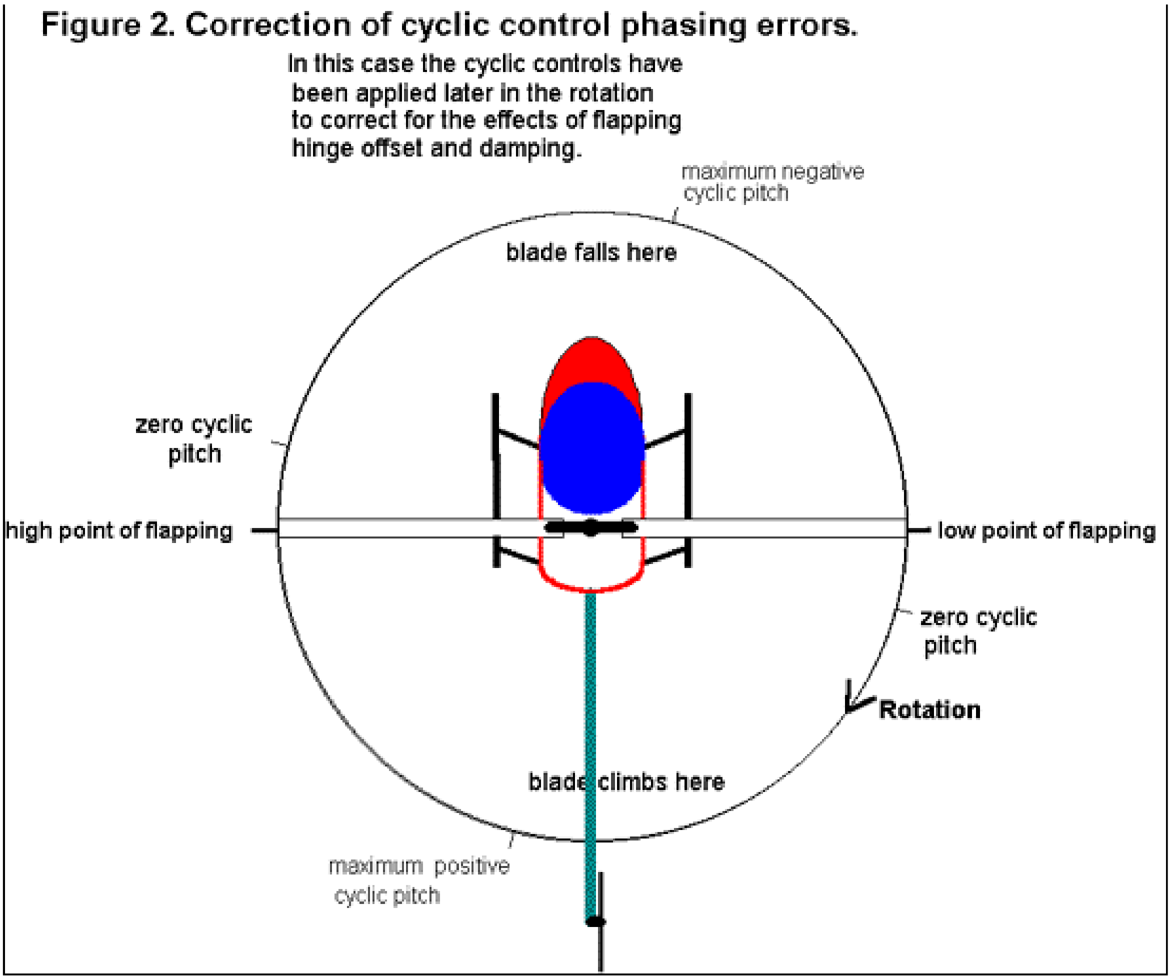
Part 11

In the last few articles we have seen how cyclic control of the pitching and rolling motion of the helicopter is accomplished and how Hiller and Bell-Hiller control systems allow the response of the helicopter to cyclic control to be tailored. We saw that, for freely flapping blades the maximum cyclic pitch must be applied 90 degrees before the required high point of the flapping. In other words, for a clockwise rotor a right roll is caused by having maximum cyclic pitch as the blades cross the boom, and nose-down pitching is caused by having maximum cyclic pitch on the retreating side of the rotor.

In the May issue I mentioned (when considering forward flight) that offset flapping hinges and damper rubber stiffness change the way in which the blades flap, and that they could cause a roll tendency in forward flight. Cyclic control response is also changed by flapping hinge offset and damper stiffness. They cause the high point of the flap to occur earlier, that is, less than 90 degrees after the maximum cyclic pitch.



In this illustration we see what happens if we continue to apply the cyclic controls 90 degrees ahead of the required motion. Notice how the right roll command now additionally causes a nose down pitching motion. To combat this the control system needs to feed the cyclic inputs in later in the rotation. This can be done by rotating the swash plate in the direction of rotation. With the cyclic controls retarded in this way the correct response to cyclic inputs is obtained as seen below.



Phase errors and the control system

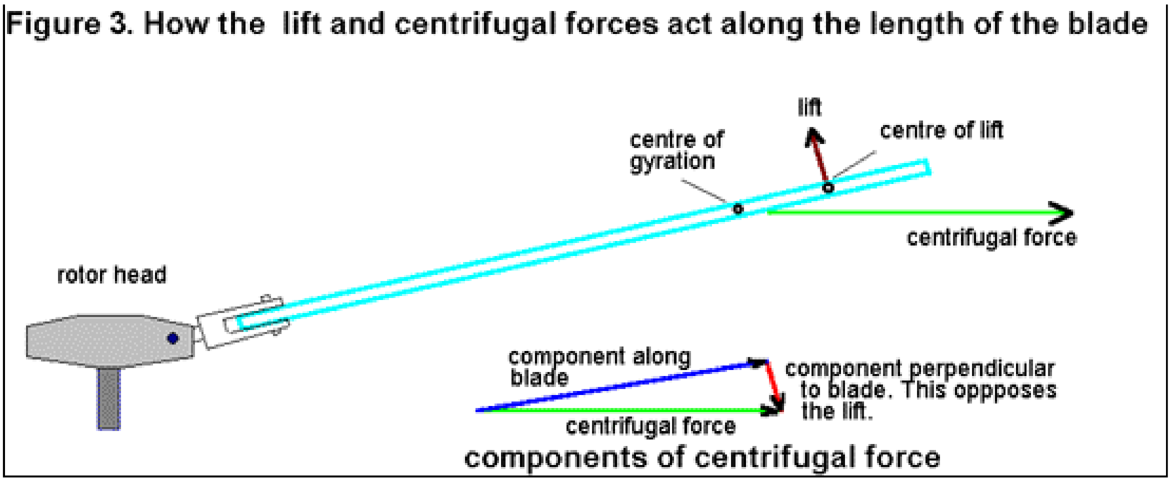
The Hiller and Bell-Hiller control systems have the effect of reducing these cyclic control phase shifts and so many model helicopters make no provision for rotating the swashplate. The flybar in the control system is freely rocking and pivoted on the axis of the main shaft (the equivalent of having zero flapping hinge offset) so it does not suffer the sort of phase errors just described. In the Hiller control system the cyclic control to the main blades comes from the flybar and any tendency for the blades to misbehave (pitch up or down during a roll command for example) is suppressed. This happens because any angle between the plane of the main blades and the flybar causes a correcting cyclic control to be fed to the main blades to make them follow the flybar. If in a roll the main blades start to pitch nose down the nose down attitude of the main blades relative to the flybar will cause some nose up cyclic control to be fed to the main blades opposing further nose down movement. The same happens with the Bell-Hiller system but because a proportion of the cyclic control of the main blades taken directly from the swash plate, the degree of phase error suppression is lower. Where the mechanics provides the facility, residual phase errors can of course be removed by rotating the swashplate as mentioned before.

The effects of blade design

This is a rather involved topic and here I will be looking at just a few aspects such as the position of the Centre of Gravity, or more strictly Centre of Gyration, the position of the Lead-Lag hinge (i.e. the bolt hole) and the stiffness of the blade.

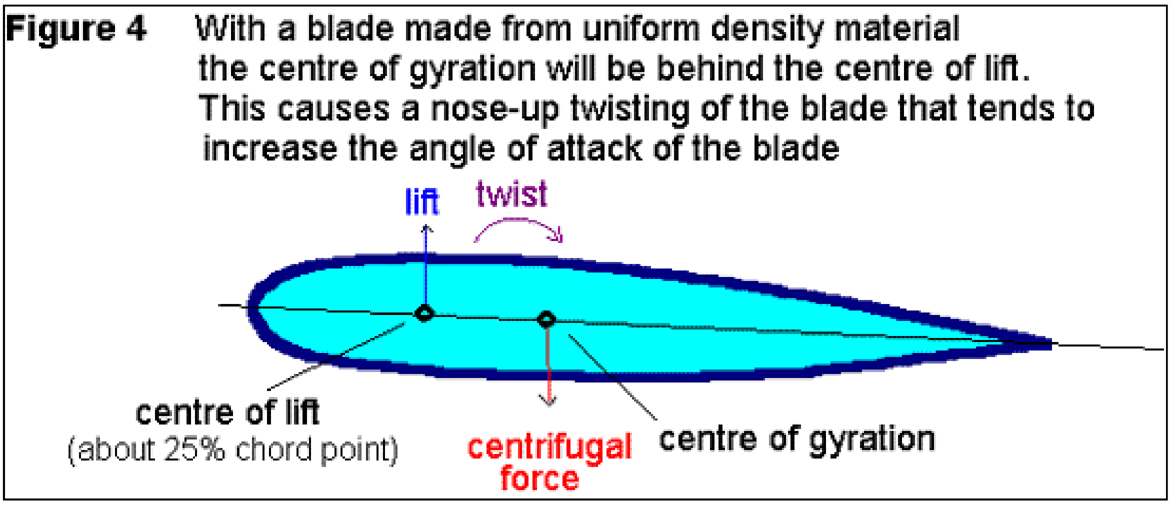
Centre of Gyration

In the May article we touched on the forces that determine the coning angle but at this point it is worth looking on more detail at the forces acting on the blades. Figure 3 shows how the forces are distributed along the length of a blade. Because most of the lift is generated by the fast moving outer part of the blade the lift acts as if centred on a point some 80% of the blade length out from the main shaft. The blade cones up until the lift is balanced by the component of the centrifugal force that is perpendicular to the blade. The centrifugal force does not act at the centre of gravity but at a point called the Centre of Gyration. The Centre of Gyration differs from the Centre of Gravity because, when considering centrifugal forces weight near the centre of rotation (the main shaft) is moving more slowly and is less important than weight further out along the blade. For a blade that is uniform along its length the centre of gyration is 58% out along the blade. The addition of weight at the tip moves the Centre of Gyration further out. Adding 25 grams of lead right at the tip of a 70 gram blade will result in a Centre of Gyration located at about 70% of the blade length. The Centre of Gravity of this blade will, by contrast, be at about 62%.



Looking now at the chord-wise position of the Centre of Gyration, consider the blade is made from a single piece of uniform density material. The centre of gravity of such a blade will be about 35% of the chord back from the leading edge. If the blade is the same along its whole length (i.e. no weights) then the chord-wise position of the centre of gyration coincides with chord-wise position of the centre of gravity. An aerofoil generates more lift near the leading edge than it does near the trailing edge and as a consequence the centre of lift is only about 25% of the chord back from the leading edge.

Chord-wise distribution of forces on blade of uniform density.



This situation as viewed from the end of the blade is shown in Figure 4. Note the centre of gyration lies behind the centre of lift. The lift on the blade, acting at the centre of lift, is balanced by the downward component of the centrifugal force acting through the Centre of Gyration. The distance between the centre of lift and centre of gyration results in a twisting effort or couple that tends to twist the leading edge up and increase the angle of attack. If the blade is flexible to twisting any increase in lift will be accentuated by the increase in lift coefficient resulting from the blade twisting in the nose-up direction. This interaction between lift and twist can set off an oscillation called flutter in which the tip of the blade goes into large torsional vibrations that can make the helicopter uncontrollable or destroy the structure of the blade.

To prevent flutter the Centre of Gyration should be brought forward to a point at, or ahead, of the centre of lift. To this end, wooden blades are made using hardwood at the leading edge and balsa at the trailing edge. Weights added close to the leading edge move the Centre of Gyration even further forward. Weight added near the tip has a greater influence on the Centre of Gyration than weight near the root, so tip weights let into the leading edge of the blade can move the Centre of Gyration significantly ahead of the chord-wise position of the Centre of Gravity.

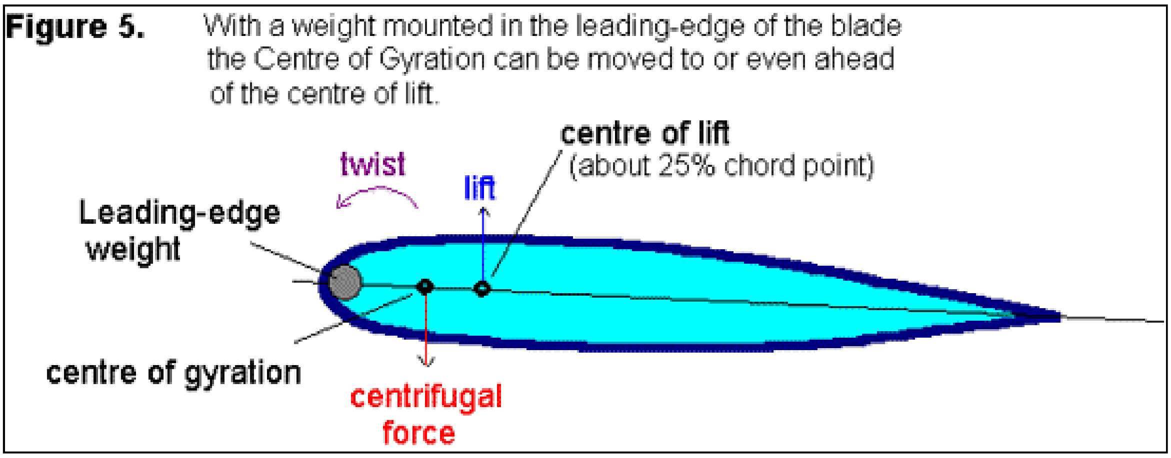


Figure 5 shows the situation when, by the addition of a leading-edge weight, the Centre of Gyration is ahead of the centre of lift. The twist on the blade is now reversed and acts to reduce the angle of attack of the blade. So, any increase in lift will be accompanied by the blade twisting nose-down to reduce the lift coefficient. This tends to damp out any variations in lift and flutter will not occur. In practice flutter will cease with the centre of gyration still some way behind the centre of lift. The stiffer the blade in torsion the further this will be.

Load on control system

It is interesting to look at the torque that the blades cause around the feathering shafts because this torque must be overcome by the control system and ultimately by the servos, especially the collective servo. This is one area where the design of the head has a great influence on how a given set of blades behave. Initially we will ignore the effect of lag angle. First let us look at the situation with unweighted blades.

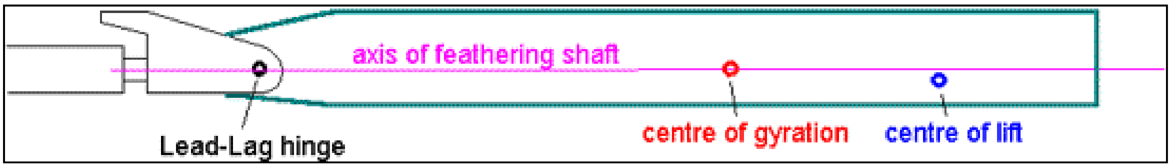


Figure 6. Unweighted blade with bolt hole in line with centre of gyration

Figure 6 shows that with the bolt hole (which serves as the lead/lag hinge) in line with the centre of gyration at about 35% chord the centre of lift lies in front of the axis of the feathering shaft. Lift thus causes a torque about the feathering shaft that tends to increase the angle of attack. If there is any slop or sponginess in the collective linkage this can give a rather sharp response to collective control.

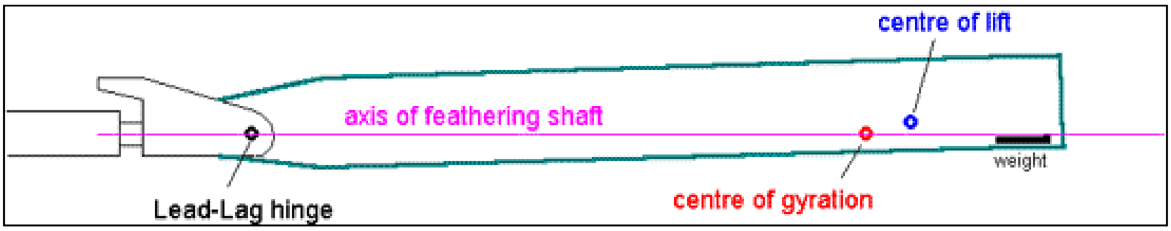


Figure 7. Blade with leading edge weight towards tip

In Figure 7 the Centre of Gyration has been moved out and forward by the addition of a leading- edge weight near the tip. Here the centre of lift is now behind the feathering shaft axis and lift causes a torque around this shaft tending to reduce the angle of attack. This makes for more tolerance of slop and 'give' in the linkages and a softer collective response.

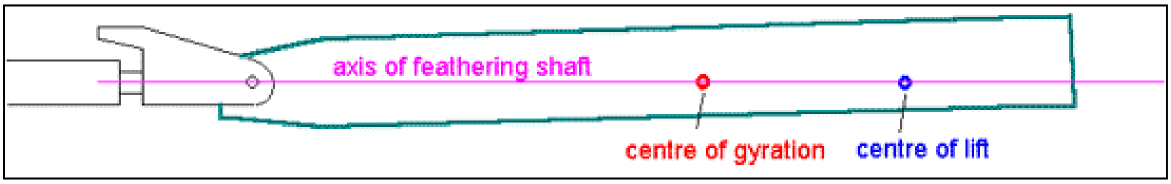


Figure 8. Unweighted blade with bolt hole moved towards trailing edge

In figure 8 we see that the centre of gyration usually lies inside the centre of lift. Moving the bolt hole towards the trailing edge angles the blade backwards at the tip and moves the centre of lift backwards relative to the feathering shaft axis. Notice from Figure 7 that the addition of a tip weight moves the centre of gyration out along the blade and towards the centre of lift. This renders the movement of the bolt hole relatively less effective than on an unweighted blade.

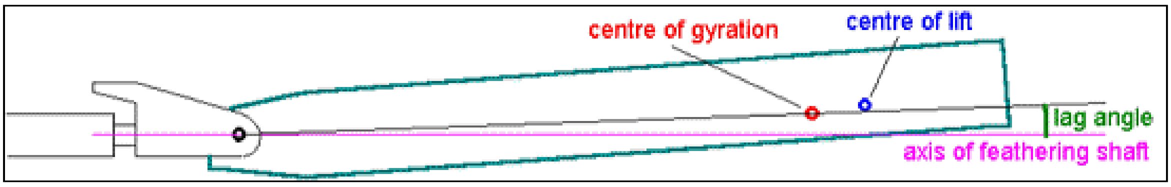
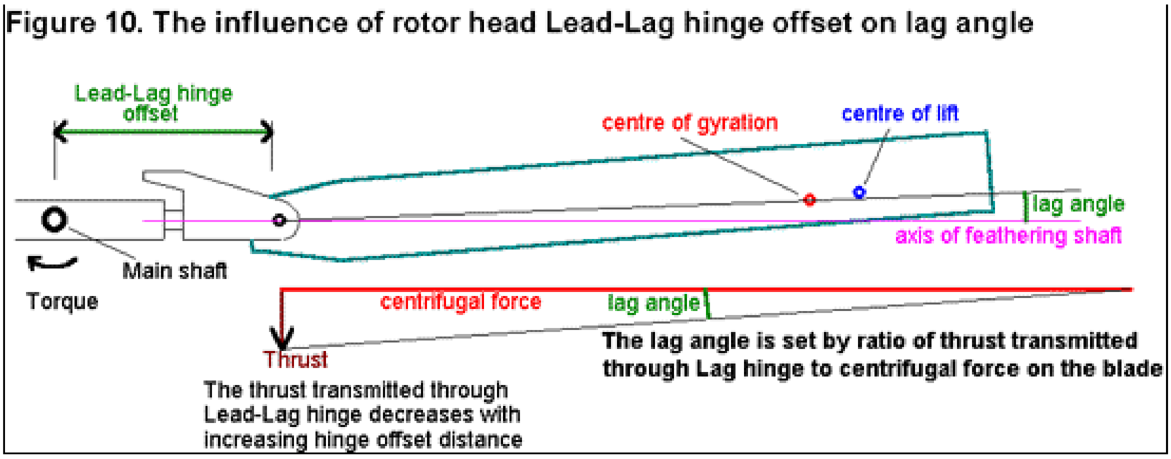


Figure 9. Effect of lag angle on the distance between feathering shaft axis and centre of lift.

We now need to look at the effect of lag angle. The lag angle is caused by the torque transmitted by the head through the lead/lag hinge to the blades. We can see from Figure 9 that the lag angle moves the centre of lift back relative to the feathering shaft axis and so promotes a leading edge down torque about the feathering shaft. The lag angle varies from zero (or slightly negative) during autorotation to its maximum values under high load (high g) situations especially where the head RPM (and thus centrifugal force) are low. Here the design of the rotor head comes in because the lag angle depends on the distance between the lead/lag hinges. The greater the distance between these hinges the smaller the lag angle (see figure 10)



To sum up, the distribution of weight within the blade is important because the combination of a rearward Centre of Gyration and a high degree of torsional flexibility renders the blade susceptible to flutter. However, a very forward Centre of Gyration can cause a high load on the collective servo. This is especially so where a small distance between lead/lag hinges causes large lag angles especially under climb or during high g-load manoeuvres.

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