MAIN ROTOR TRACKING AND BALANCING

If your helicopter is completed to this point, you will be off the ground very soon! The following procedures will guide you in the main rotor static and dynamic (running) balance and tracking of the main rotor head. Due to the differences in balancing equipment and tracking methods available, this guide should be used along with the appropriate procedures associated with your balancer analyzer and whatever tracking method you choose to employ.

All balancing equipment utilizes long cables to attach the sensors to various points on the helicopter to measure vibration. Make sure the wiring is routed so that it will not interfere with the flight controls, the main transmission shaft rotation, or the output shaft rotation.

There are several brands of balancing equipment available. We still use the old Chadwick equipment, which is obsolete and supported by only a few repair shops. We also have a Microvibe balancer, which works well and is still supported.

Several builders have purchased Dynavibe balancers. We have been very impressed with the factory's involvement in helping them learn to use their new equipment with their Safari. If you have access to balancing equipment, it is not necessary that you own it. Once balanced, you helicopter will not need continual attention. The most likely event will be changes in the tracking or lead/lag after transporting your helicopter on a trailer. Those adjustments can be made the same way they were performed the first time.

The Safari main rotor system has four basic adjustments:

- Pitch Links – Adjust blade track and autorotation rotor speed. Lengthening a pitch link by one turn will lower the blade tip 2 inches. Lengthening both pitch links equally will increase autorotation RPM. Adjusting blade track will move lateral vibrations along the 1:30 to 7:30 axis.

- Grip Weights – Weight should only be installed on one blade and should be installed on the most outboard bolt of the plate on the blade. Do not place weight under the existing nut, but on top of it using a second nut to secure it. If you need to add weight to a blade for dynamic balancing and there is weight installed on the other blade, remove the appropriate amount from the blade that already has weight installed. If enough weights cannot be removed, add the remainder to the blade that initially had none. Adjusting grip weight will move lateral vibrations along the 4:50 – 10:50 axis.

- Head Shift – Adjusted with the head jacking bolts. .002” adjustment nulls approximately .1 IPS on the head. Any adjustment should be made in very small increments (.002”-.004”). If head shift exceeds .003” from initial center adjustment, blade sweep and head box centering should be checked. Head shift adjustments are for fine tuning ONLY and should be kept to a minimum. Adjustments to head shift will move lateral vibrations along the 2:10 – 8:10 axis. If excessive amounts of head shift are indicated by the readings from the balancing equipment, changes to the lead/lag settings of the blades will be made to compensate. The head will be returned to its center position when the blades have been set.

- Lead/Lag (Blade Sweep) – Adjusted by loosening the six grip plate bolts and moving the blade fore/aft. (See Section 26) This aligns the Center of Gravity of both blades so that it runs through the center of rotation of the head box. It is preferred to have the blade’s CG lag slightly and SAFARI blades have this engineered into them. When the blades were installed, they were aligned parallel to the spindle. See “Adjustment of Rotational Center” diagram at the end of this Section and the Lead/Lag Adjustment instructions later in this Section.

MAIN ROTOR TRACKING (STROBE / TIP LIGHT METHOD)

- ☞ Verify that your aircraft is ready for flight and that the area is free from hazards and loose debris which might get blown into the rotors. It is amazing what a plastic shopping bag will cause when caught by a spinning rotor.

- ☞ Review procedures with all crew members and ensure any non-essential personnel remain clear of the aircraft.

- ☞ There must be a qualified pilot at the controls of the helicopter at all times during operation.

- ☞ The operator must maintain visual contact with all ground crew members during operations.

- ☞ Tip targets (red reflective tape on the tab on the end of the target blade, white on non-target) or lights should be installed. Having the sun close to the aircraft’s six o’clock position is helpful.

- ☞ Bring rotor RPM to 500 if possible at flat pitch and light on the skids (17 inches of manifold pressure).

- ☞ Draw an imaginary line from the rotor pickup to the blade tip through the Main Rotor shaft.

- ☞ Point the strobe at about mid-blade along that line. It may be necessary to hunt left or right a bit. Once the blade is acquired, move the strobe along the blade toward the edge of the rotor arc until the targets can be seen. If using tip lights, observe lights at aircraft's 12:00 position (straight off the nose).
- ☞ Record the lowest blade and estimate the distance to the higher blade.
- ☞ Shut down the helicopter.
- ☞ If needed, adjust track by lengthening the pitch link of the higher blade. One full turn on the pitch link translates to 2 inches of blade tip travel.
- ☞ If adjustments are made, ensure the rod end jam nuts are still tight.
- ☞ Repeat these steps until you are satisfied that the blades are flying level to each other.

MAIN ROTOR BALANCE

Install balancer/analyzer equipment as follows:

- ☞ The lateral vibration transducer is mounted directly to the main rotor pylon on the forward right corner.

- ☞ The vertical vibration transducer is mounted below the instrument pod between the vertical and angled support rods.

- ☞ Attach a 2” square reflective target of reflective tape on the underside of one blade where it meets the grip plates at the center of the plates. This blade becomes the “target” blade. This target will remain on the helicopter and should never be painted or clear coated to prevent loss of reflective properties.
- ☞ The optical pickup (photo cell) gets mounted on the front of the tail boom to the port side of the tail rotor output shaft, aiming upwards at the reflective target.

- ☞ Check to be sure that cables and pickups will not interfere with flight control movement or operation.

When making hover balance runs, the aircraft Center of Gravity (CG) should be as close to center as possible. If needed, place shot bags in the cabin to obtain center CG.

We have found that using tracking and grip weight adjustments as the primary method of balancing achieves the best results. Also, utilizing both lateral and vertical measurements

gives a better indication of aircraft dynamic conditions. Measurements for lateral and vertical vibrations should remain on the same side of the chart in that a tracking adjustment to lower lateral vibrations should not increase vertical vibrations. If this is not the case, it may indicate worn bushings in the swashplate, loose flight controls in the cabin or worn rod ends and should be addressed.

Adjustments made to head shift should ONLY be made to determine the need for lead/lag adjustments. When balancing is complete, the head should be returned to the center position as described in the Lead/Lag Adjustment instructions later in this Section. Head shift should be measured by zeroing a dial indicator to the head box and measuring the amount shifted by adjusting the jacking bolts. (see Section 28) No more than 0.002” - 0.004” per run and no more than 0.002” in one direction total. It is recommended that you record head shift as positive (+) when adjusting toward the target pitch arm and negative (-) when adjusting away from the target pitch arm. Always record actual amount moved if it is different from intended amount moved. The adjustments should be added and a running total kept to determine if blade sweep is required.

CAUTION

At approximately 400 RPM (Rotor speed) there is a resonance range during clutch engagement in which the helicopter will vibrate excessively. DO NOT PAUSE in this range. The vibration is greatly exaggerated when the main rotor head has not been dynamically balanced. Pulling a slight amount of collective upon reaching it will ease the transition through the range. To minimize the effects of this resonant range, it is recommended that initial balancing be done on soft ground (grass) as a hard surface will amplify the vibration.
If vibration feels excessive enough to prevent safe operation at 500 RPM, start measurements at 450 RPM and work your way up to 500 RPM as the helicopter’s vibrations are adjusted out.

CAUTION

Balancing a helicopter rotor head tends to attract a crowd of onlookers. Be certain to clear the area of the tail rotor of crew members or bystanders. While injury can occur from the rotating main rotor blades, they are fairly high off the ground. The tail rotor is not, and is extremely dangerous when rotating. Unless marked with striping, it is almost invisible when turning at full rpm. Be certain that the tail rotor area remains clear of persons while the helicopter is running.

- ☞ Ensure your aircraft is ready for flight and that the area is free from hazards and loose debris which might get blown into the rotors.
- ☞ Review procedures with all crew members and ensure any non-essential personnel remain clear of the aircraft.
- ☞ Only allow a qualified pilot at the controls of the helicopter during operation.
- ☞ Ensure the operator maintains visual contact with all ground crew members during operations whenever possible.
- ☞ Run the helicopter to 500 RPM (or max safe speed) flat pitch. If this is the first run, verify calibration of aircraft tachometer with analyzer reading
- ☞ Lift the aircraft gently into a stable hover 3-5 feet AGL.
- ☞ Initiate balance run on analyzer for lateral vibrations
- ☞ Initiate balance run on analyzer for vertical vibrations
- ☞ Return the aircraft to the ground and return to idle. After the cylinders have cooled sufficiently and the battery has charged, shut down the aircraft.
- ☞ Record IPS readings and clock (phase) angle on charts with run number. If your polar chart does not have the adjustment clock angles marked on it, you may wish to use them to alleviate confusion when determining where adjustments should be made.

    - Grip Weight – 4:50 – 10:50
    - Tracking – 1:30 – 7:30
    - Head Shift – 2:15 – 8:15

- ☞ Vibrations recorded in between these clock angles indicate that multiple factors are affecting rotational CG and should be eliminated one at a time starting with the one closest to the above angles.
- ☞ Vibrations that indicate an out-of-track condition require rechecking of main rotor tracking. (see previous section) If track is good, a combination of grip weight and head shift, followed by lead/lag adjustments will most likely be required.
- ☞ Plot readings on polar chart and label with run number.
- ☞ Using the above guidelines, determine what adjustment needs to be made and annotate the proposed change on the chart for the next run. Make only one change per run.

- ☞ For vibrations on the right side of the chart. (12:00 – 6:00)
    - Grip Weight – add to non-target blade
    - Tracking – lengthen target blade pitch link
    - Head Shift – back off bolt nearest target blade pitch link and tighten the other
- ☞ For vibrations on the left side of the chart (6:00 – 12:00)
    - Grip Weight – add to target blade.
    - Tracking – lengthen non-target blade pitch link.
    - Head Shift – back off bolt nearest non-target blade pitch link and tighten the other.
- ☞ Make changes as required. Check to be sure all hardware is tightened and the helicopter is ready for flight.
- ☞ Repeat steps until IPS (inches per second) reading is at least less than .2 IPS. A reading of less than .1 IPS vertical and lateral will give the best results.
- ☞ Safety wire head jacking bolts.
- ☞ Remove balancer/analyzer sensors and cables from aircraft.

ADJUSTING LEAD/LAG

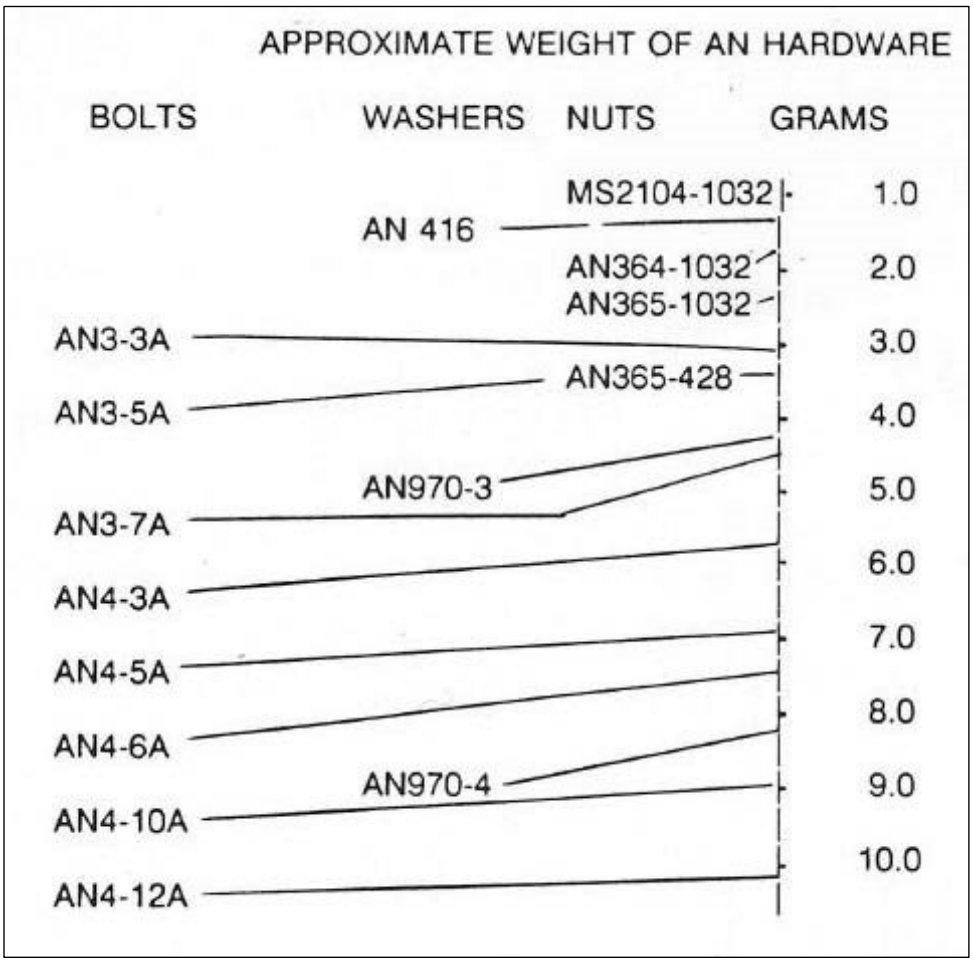
If the readings from the balancing equipment indicate that an excessive amount of head shift is needed, that is an indication that the lead/lag needs to be adjusted. Lead/lag position should be verified. If the blades are in alignment, adjustments to the lead/lag settings on the blades should be made.

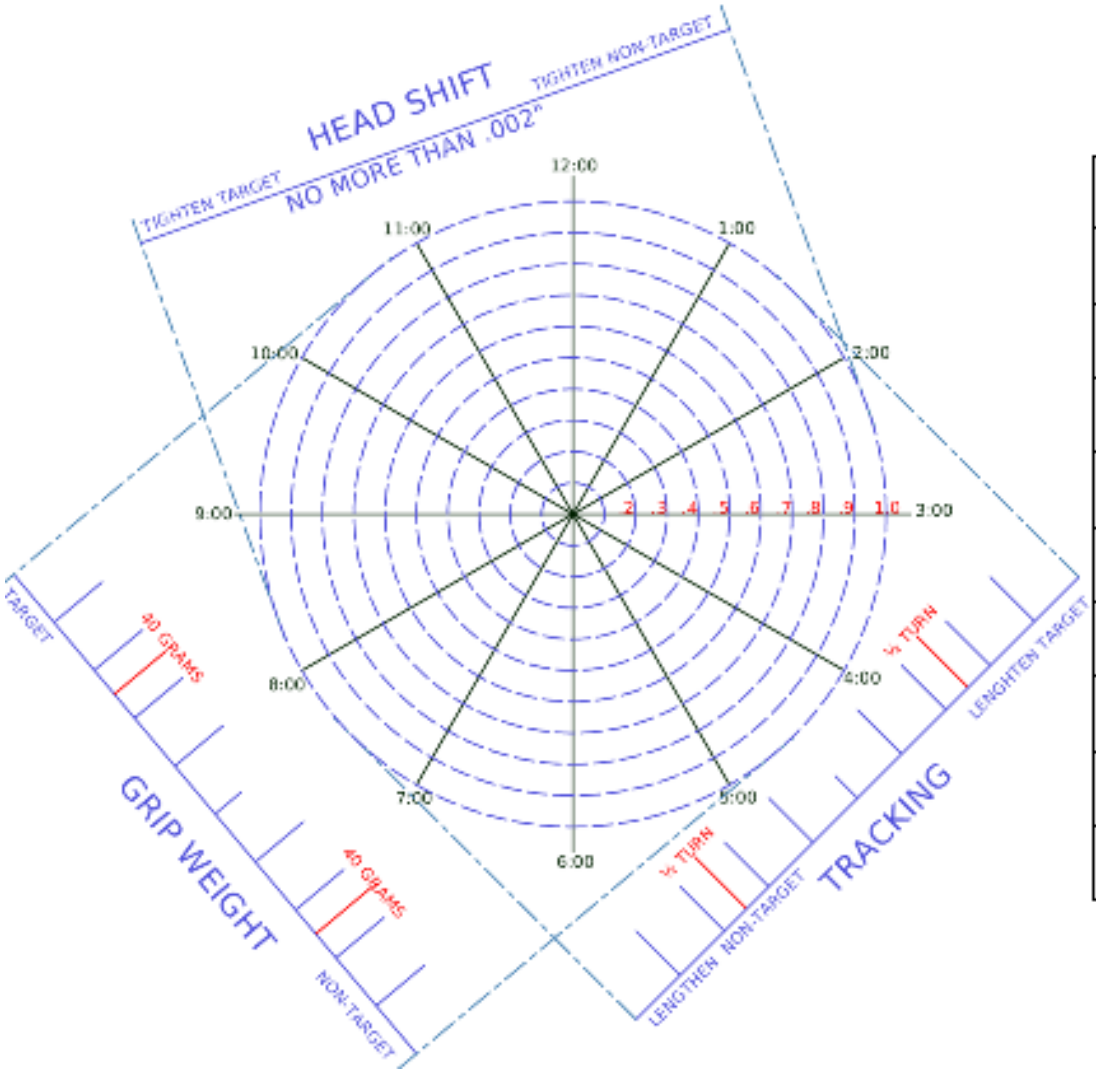
- ☞ Position the blades nose to tail in line with the tail boom.
- ☞ Remove pitch rod bolt on the side the head is offset from center.

  For POSITIVE shift remove TARGET pitch rod

  For NEGATIVE shift remove NON-TARGET pitch rod.
- ☞ Pivot the pitch rod down to rest on the fuel tank.
- ☞ Loosen the six grip bolts on that blade. Rotate the grip trailing edge down. With blade chord vertical, torque grip bolts according to the Maintenance Notice that applies to the bolts you are using. The weight of the blade pulls down on the grip and moves it an immeasurable amount.

- ☞ Reinstall pitch rod. Tighten and cotter pin the nut.
- ☞ Remove cumulative total of changes made to shift head box during balance runs. This should effectively re-center the box.
- ☞ Repeat Main Rotor Balance





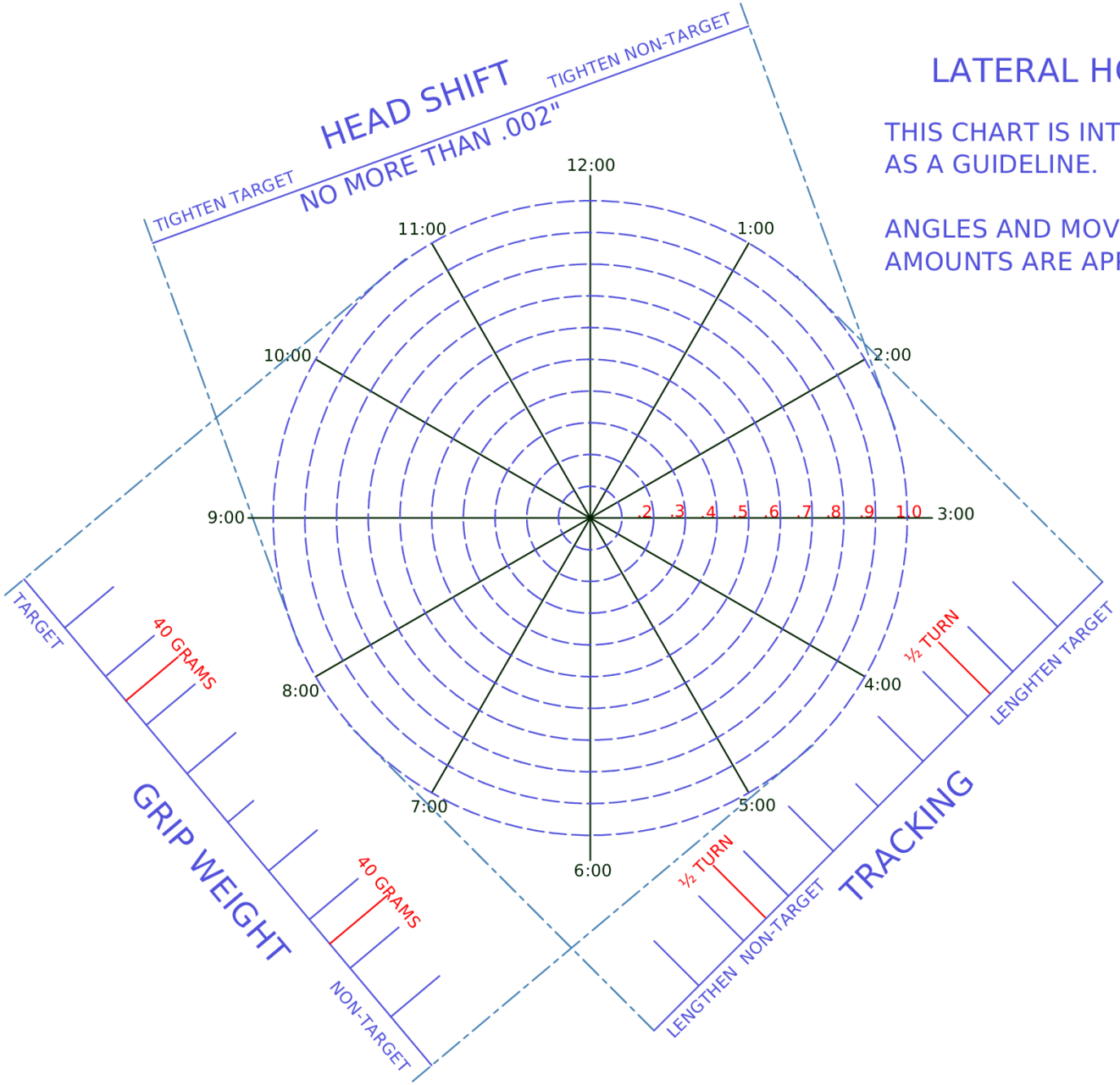
LATERAL HOVER

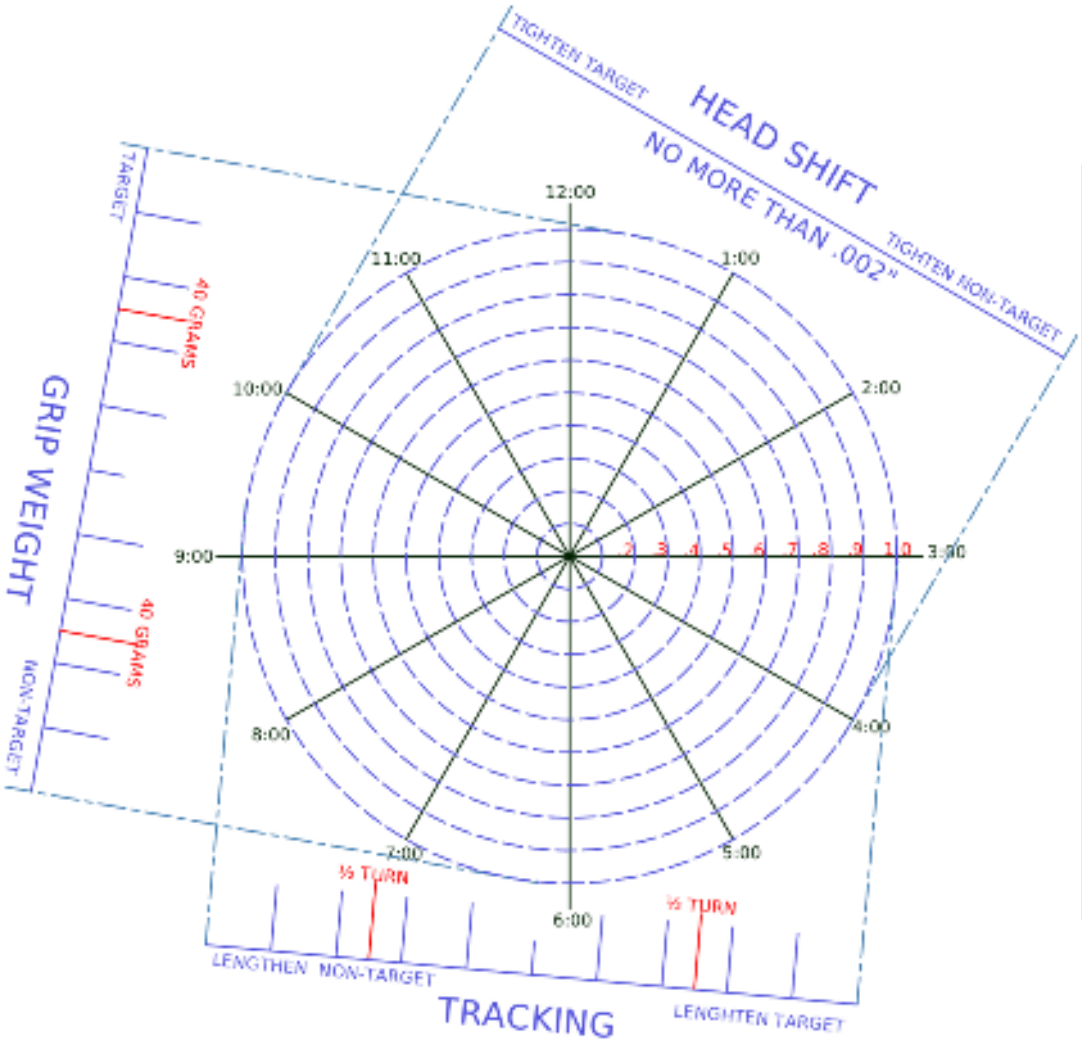
RUN #	CHANGES	IPS	ANGLE
1			
2			
3			
4			
5			
6			
7			
8			
9			

LATERAL HOVER

THIS CHART IS INTENDED AS A GUIDELINE.

ANGLES AND MOVEMENT AMOUNTS ARE APPROXIMATE.

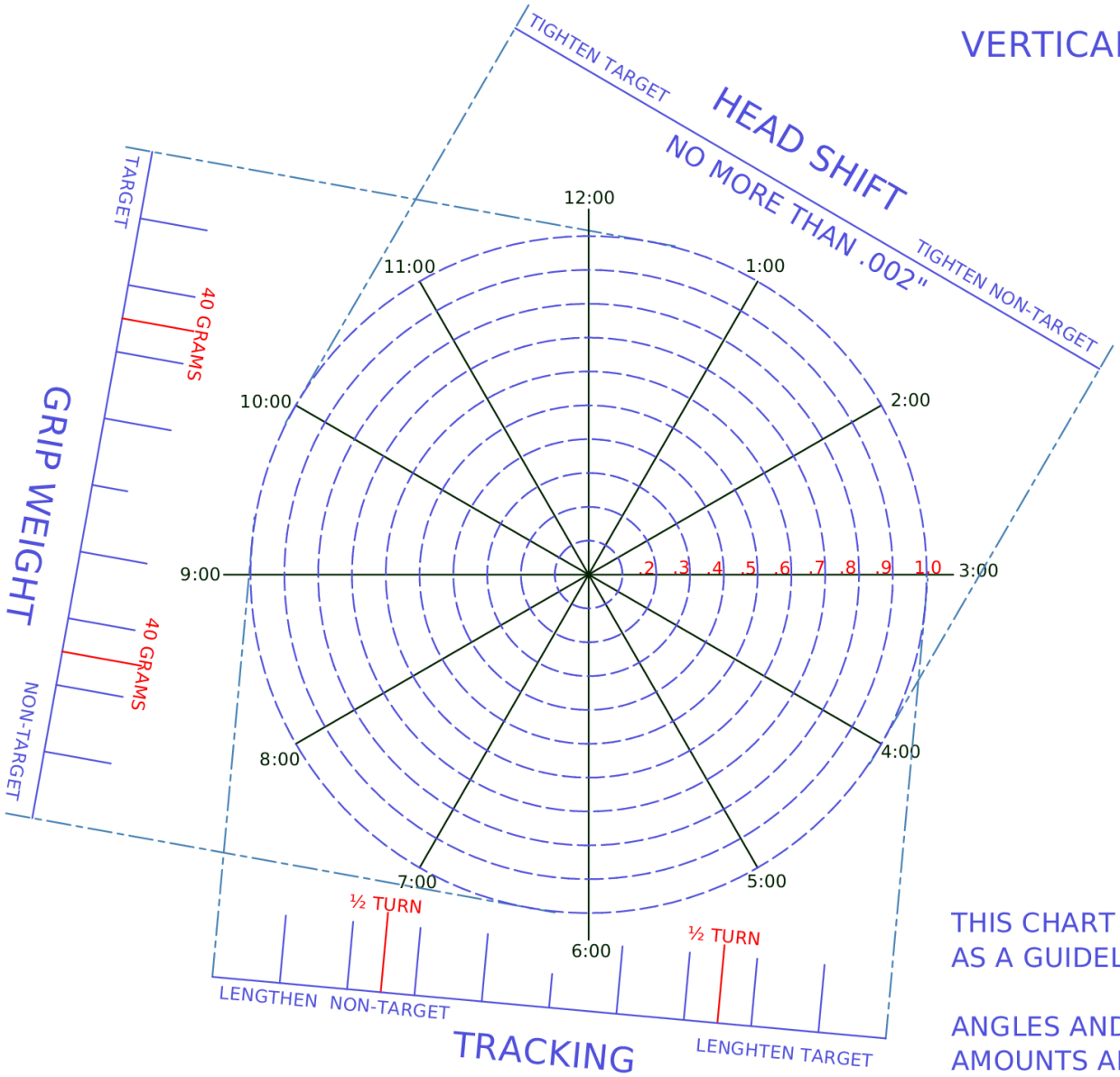




VERTICAL HOVER

RUN #	CHANGES	IPS	ANGLE
1			
2			
3			
4			
5			
6			
7			
8			
9			

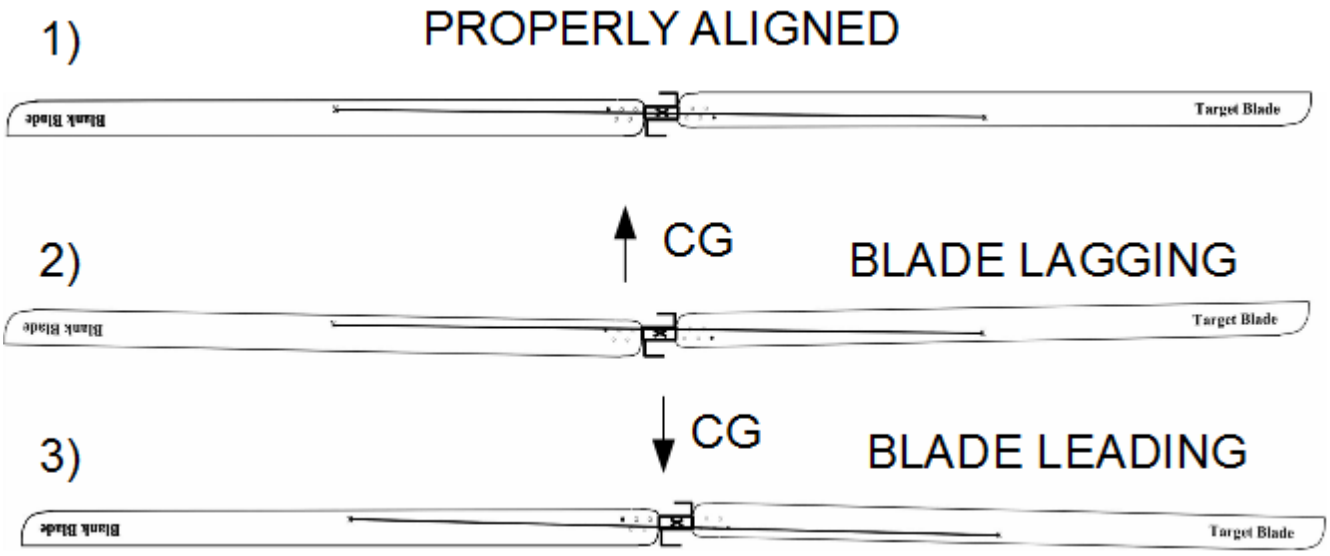
VERTICAL HOVER



THIS CHART IS INTENDED AS A GUIDELINE.

ANGLES AND MOVEMENT AMOUNTS ARE APPROXIMATE.

ADJUSTMENT OF ROTATIONAL CENTER



IN EXAMPLE 1) THE BLADES ARE PROPERLY ALIGNED AND CG INTERSECTS THE CENTER OF ROTATION.

IN EXAMPLE 2) THE TARGET BLADE IS LAGGING AND CG IS OFF CENTER. EITHER TIGHTENING THE BOLT CLOSEST TO THE TARGET PITCH ARM OR LAGGING THE OTHER BLADE EQUALLY WILL CORRECT IT.

IN EXAMPLE 3) THE TARGET BLADE IS LEADING AND CG IS OFF CENTER. THIS BLADE SHOULD BE LAGGED TO CORRECT IT.

The following information is copied from one of the oldest rotor balancing manuals issued by Safari. While a lot of the methods have been improved over the years, there is a lot of useful information here.

ROTOR BLADES AND THEIR DYNAMICS

FORCES ACTING ON THE ROTOR BLADE

Your final balancing of the main rotor blades has a very important influence on the smoothness of your rotor system. To understand the interdependence of the dynamic forces acting on the rotor system, and be able to sort out problems,we need to separate the different forces produced by the rotor blades. We will be discussing forces on the blades and from the air.

A STATIC FORCES
B DYNAMIC FORCES
C AERODYNAMIC FORCES

STATIC FORCES are produced when the rotor system is stationary: they are easily measured and balanced out.

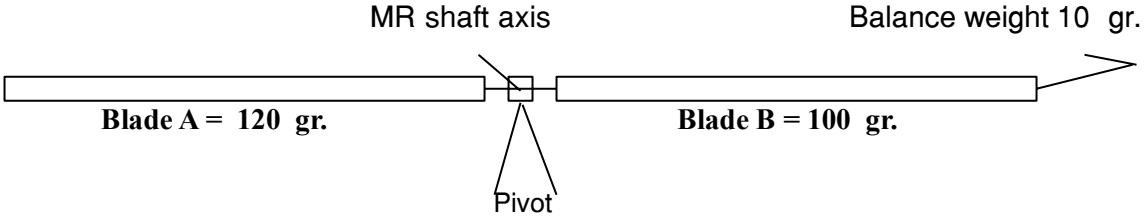
DYNAMIC FORCES are from the rotation of the rotor system and the most important components can be corrected when checking the static forces.

AERODYNAMIC FORCES are a result of the influence of the air on the rotor blades while rotating.

The resultant aerodynamic forces cannot really be measured by homebuilders and can only be estimated by a combination of calculation and comparative experimenting.

THE STATIC FORCES

The term covers all the forces which arise without the influence of rotation. It basically involves balancing the rotor blades and achieving static balance as explained below.

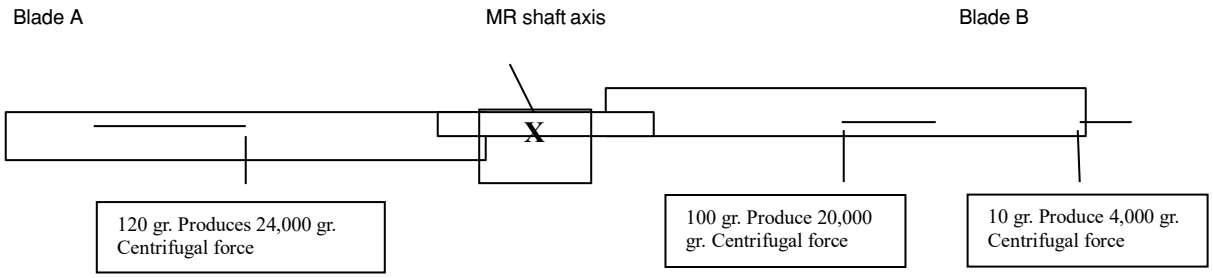


We will assume zero friction at the pivot; the blades are fixed to the main rotor head and set perfectly straight to the feathering axis of the main rotor grip. The only difference; blade A, at 120 gr., is heavier than blade B at 100 gr.
Blade A will pull the whole rotor down. The logical solution is to ballast blade B but where to attach the weight? Statically speaking, i.e. disregarding the forces arising later during rotation, you can make blade B heavier by 10 gr. at its tip as shown. Your rotor system will now balance horizontally being in static balance.
BUT; blade B still only weighs 110 gr. and not equal in weight to blade A although in static balance.

Note: The previous information refers to the “swept tip” blades no longer in use on Safari helicopters. The currently provided blades are statically balanced when manufactured and crated as a set. Current manufacturing processes produce blades which are almost identical in weight when first fabricated. Any small differences are equalized before shipment to the builder.

THE DYNAMIC FORCES

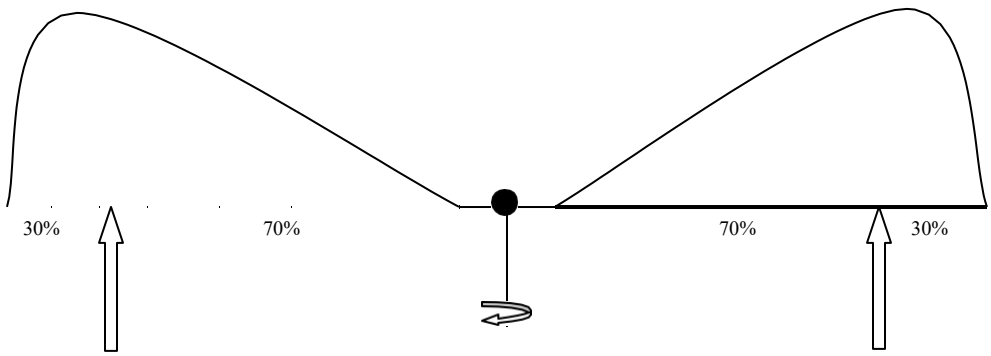
In the example, calculations show that blade A at 120 gr. Produces the same centrifugal forces as blade B weighing only 110 gr. The basic reason for this balance is simply that the 10 gr. weight on blade B travels much faster or rotates much faster around the rotor axis, than the remainder of the blade and therefore the greater flywheel effect of blade B counteracts its lower total weight.



It is clear then that blade A (120 gr.) is dynamically exactly balanced by blade B (110 gr.) when rotated around the main rotor shaft axis. This is only true if the blades are exactly in line, i.e. the radial forces arising from the centrifugal force are acting directly through the shaft axis BUT is not the case because of aerodynamic forces are also acting on the rotor system.

THE AERODYNAMIC FORCES

The main rotor is to provide lift for the helicopter and the lifting force on the rotor blade is not equal at all points along the blade's length being weakest at the hub and increasing towards the tip. In theory, the lift would reach a maximum at the tip, where the speed of airflow is greatest but this is not so. Towards the tip, the airflow breaks down into various vortices, which reduce the lift produced. If all the individual lift forces are imagined as a single force, then this force acts through a point 70% along the length of the blade, or 70% of the rotor blade span.



Sum of forces

Sum of forces

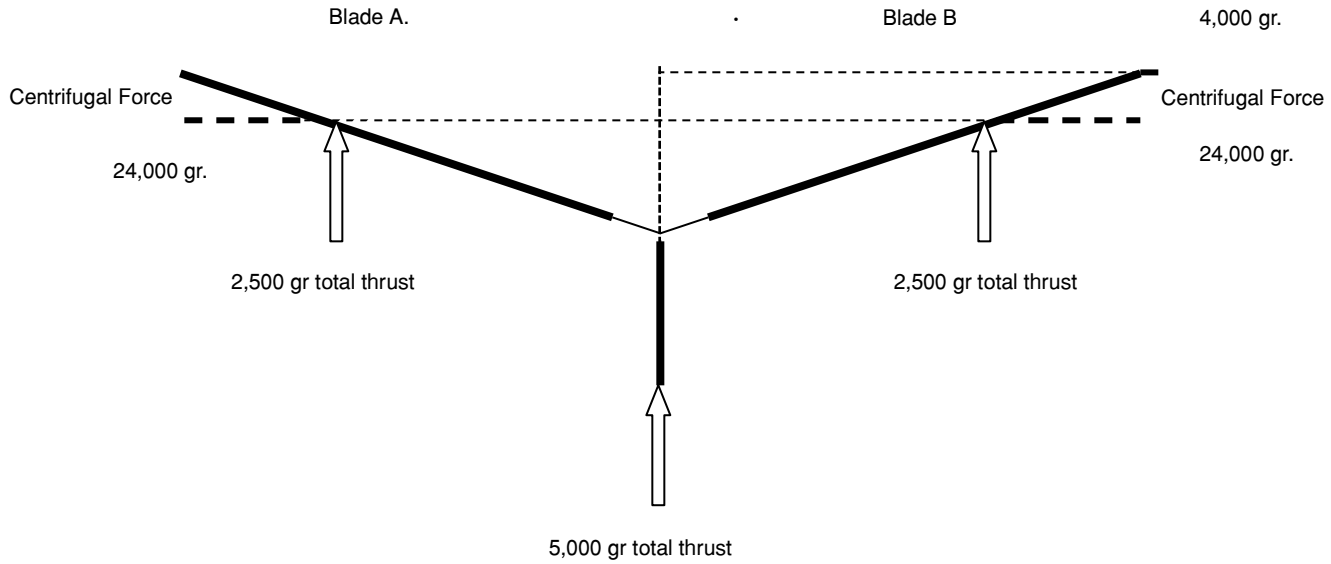
Your result is a battle between two forces on the rotor blade: centrifugal forces try to hold the rotor blades horizontal and the aerodynamic lifting forces attempt to raise the blades above horizontal. The result is a certain "dihedral" effect on the rotor blades, known as the coning angle. You have a 2 degree coning angle machined into your main rotor head spindle.

As your rotor system spins, lift is produced by the blades. The example shows each blade producing 2,500 gr. of lift. This thrust raises the blade at a point about 70% along its length (exaggerated in the diagram). The centrifugal forces (shown dotted) try to pull the blades out

horizontally, concentrating the lift and certain equilibrium is achieved: “the coning angle”.

BUT

As can been seen in the following picture, a dynamic imbalance becomes present caused by the aerodynamic forces.



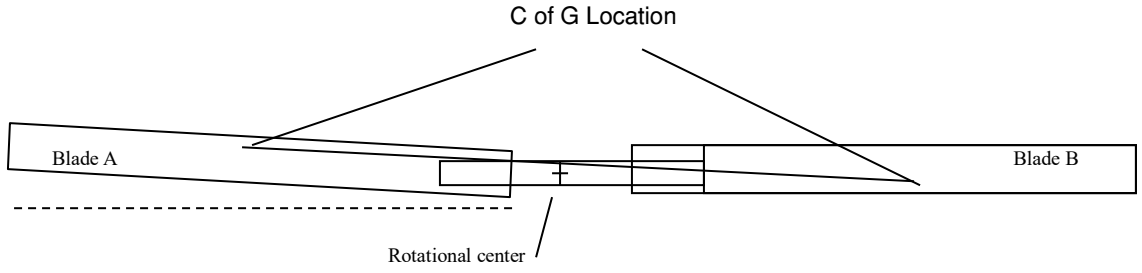
Note that blade A develops 24,000 gr. of centrifugal force acting in one plane above the rotor shaft connection (Teeter pin).
This is not true for blade B, which is being raised by the same amount as blade A by the thrust. There are virtually two centrifugal forces acting: 20,000 gr. from the blades weight and 4,000 gr. from the ballast weight fixed to the tip for static balancing. The fact that the blade is now raised means that these two centrifugal forces are no longer acting in one plane, but in two, one above the other. The 20,000 gr. is pulling to the right, opposite the 24,000 gr. load of blade A but you have 4,000 gr. also pulling to the right which is higher than the common line. The total is again 24,000 gr. but the two forces are acting in different planes and that means that the main rotor shaft is unequally loaded. The result is an oscillating force and severe imbalance. The problem gets worse at higher thrust levels with their attendant greater blade pitch as the tip weight becomes further above the teeter pin.

BLADE FORCE SUMMARY

- The position of each rotor blade is determined by two factors; one is the thrust which is trying to move the blade upwards and the other is the centrifugal force trying to hold the blade horizontal. These factors determine the coning angle.
- The weight of the rotor blades must be equal and distributed equally along the blade length to ensure that the centrifugal forces are equal as they are based on the sum of the blades weights. This will ensure that the forces act in the same plane even when the blades are raised and that they act through the same point in the imaginary extension above the main rotor shaft.
- The airfoil of each rotor blade must be identical so that the lift is distributed equally along both blades.

IMBALANCE DUE TO MIS-ALIGNMENT

If the main rotor blades are not fixed exactly symmetrically, further damaging forces will result most notably as an overspeed vibration. The goal is to have the blades attached perfectly in line with the feathering axis or lagged behind equally. Running a string from blade C of G to opposite blade C of G should put your string going right through the center of rotation of the teeter pin head box.



The example shows blade A lead too far forward of the feathering axis to blade B. This puts the C of G of both blades in front of the center of rotation for the main rotor shaft thus causing an imbalance at higher rpms.
Blade A being forward of the feathering axis also causes the blade wanting to flutter at high rpms or high forward speeds.

TRACKING WITH A TRACKING STICK

This is the most accurate without the use of a strobe light.

The tracking stick shown can be made from a short length of 3/4" oil hose pressed securely over the end of a broom stick. It would be a good idea to use a hose clamp to keep the hose attached to the end of the stick.

Put a smear of grease or better yet, Prussian Bluing onto the tip of the hose point (back side).

During your initial ground runs, check the track of the blades with the tracking stick shown

Always have someone at the controls of the helicopter during operation.

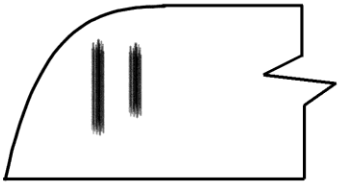
Hint: Always request the person using the tracking stick to gently touch each time and again about 6 inches in from the first marks. This will give you assurance of the results you are seeing in the markings on the bottom of the lower blade. If the low blade is marked the same on each location, it is safe to assume that this is the low blade.

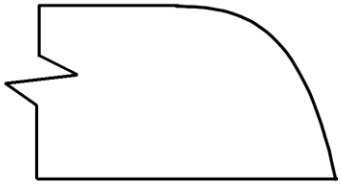
Try to get to a full 500 RPM, light on the skids (17 inches of manifold pressure). Have someone carefully use the tracking stick on the blades. Be sure to have this person working with you in front and full view while you are operating the helicopter.

Raise the lower blade until you get two small tick marks of equal size on the blades when doing the tracking. When this is accomplished, do another tracking measurement by holding the collective position but rolling the throttle off until you are showing 400 main rotor rpm. Now do your tracking ticks and a second one 6 inches in from the first. (you should see 4 ticks on one blade and only 2 outside ticks on the other blade thus showing the climbing blade has the 4 ticks). This will show you the ticked blade will be your climbing blade to a hover and can be considered to continue climbing in forward flight.

Tracking Mark Definitions:

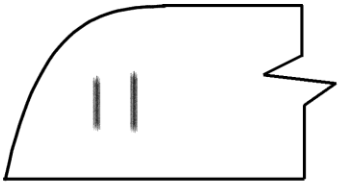
Dual marks/readings shows consistency in tracking stick use.

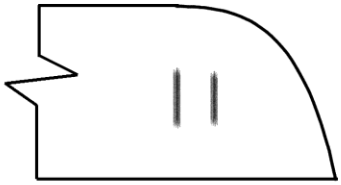




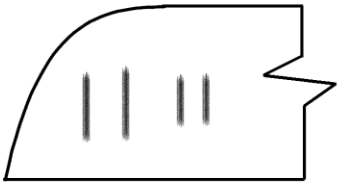
Tracking stick is used too abruptly (thick marks).
Shows blade is low at flight speed.

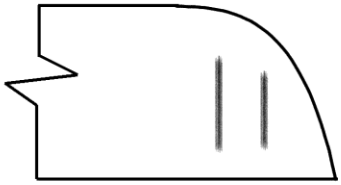
Proves blade is high at flight speed.



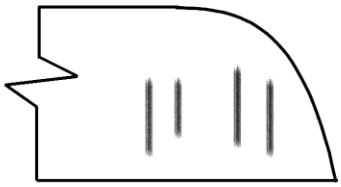


Gentle use of tracking stick gives light marks.
Equal marks at flight speed shows proper track on both blades.





Tracking is set for flight speed.
Blade is low for the same pitch at 400 RPM (climbing blade).



Tracking perfect for flight speed and 400 RPM.

Once tracking is close, it would be advisable to rent, borrow or buy a Chadwick or similar electronic balancer to go further. If not available, trial and error method is very difficult, but not impossible. You must have patience; document each move, and the result, to save time.

NOTE: You will find that a large tracking adjustment may require having to repeat the sweep adjustment or double checking if nothing else. This step may not be required (with a 1/8 turn) as your blade alignment is perfect to the feathering axis of the main rotor grip.