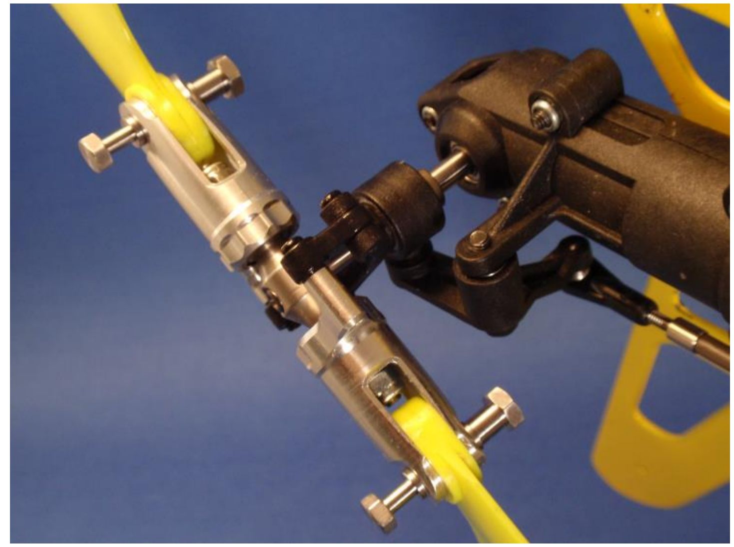
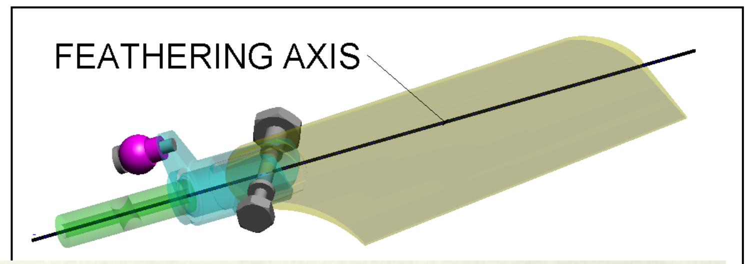
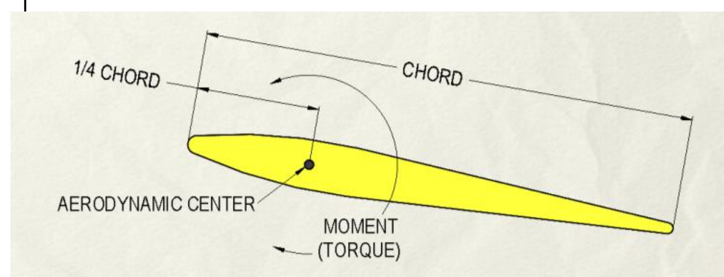
CHINESE WEIGHT MOD (CWM)

By HEIM JOINT I hope to explain the physics of Tennis racquet effect and the Chinese weight mod in more detail, and why the Chinese weight mod is worthwhile. These concepts apply to any Chinese weight system, weighted blade grips, home made CWM, or purchased Chinese weight sets. Kudos to all the great people on this forum who provided my initial CWM education. Before I get started I need to define some terminology.







- **Pushrod force** is the force required to move the tail rotor pushrod away from zero pitch in either direction. It is the total force seen by your tail servo.
- **Tennis racquet effect** describes a tennis racquet's desire to twist (torque) 90 degrees in your hand to a hatchet-like orientation instead of the initial desired paddle orientation when swung in a large arc like a serve. This also applies to a helicopter tail rotor system where the blades will want to forcibly rotate to zero pitch when the tail rotor system is spinning. Centrifugal pitch coupling is another name for the same effect.
- **Chinese weights** are weights strategically added to a tail rotor system to produce a tennis racquet effect (torque) that is opposite to the tennis racquet effect (torque) of the whole tail rotor system before the Chinese weights. The opposite forces cancel each other and produce a tail rotor system that has no preferred pitch angle. (Free to move and stay at any angle)
- **Feathering Axis** is the axis the tail blade grips and blades rotate about when changing pitch and the axis that tennis racquet effect torque is generated about.
- **Aerodynamic center** is the location on the airfoil located ¼ of the chord back from the leading edge. If this airfoil is symmetrical and pivoted on the aerodynamic center it takes no torque to move or hold the airfoil at any angle of attack. Go to http://www.grc.nasa.gov/WWW/K12/airplane/ac.html for more detail on aerodynamic center.
- **Play** is the slop in your tail pitch control system. To quantify play, remove the ball link from the tail servo and fold the tail blades until they touch each other and hold them together. This is just to hold the blade grips still. Now gently push and pull the pushrod and note how much distance it moves. This is the play in the tail pitch control system. This play shows up every time it crosses zero pitch but is minimized on either side of zero pitch by tennis racquet effect loading the pitch control system.

What causes the tennis racquet effect?
Centripetal force combined with an uneven distribution of mass around the feathering axis produces a torque about the feathering axis that is zero at zero pitch but increases on either side of zero up to 45° (actually drops back to zero at 90 degrees). Centripetal force constrains a revolving object to a circular orbit. Tennis racquet effect is purely inertial. It is not caused by any aerodynamic forces.

Do aerodynamic forces on the tail blades play a part in pushrod force?
Most tail blades have the feathering axis close to the aerodynamic center. If a symmetrical airfoil is pivoted on the aerodynamic center it takes no torque to move or hold the airfoil at any reasonable pitch. My answer is very little, if any, of the pushrod force is generated by aerodynamic forces on the tail blades. Testing done without the blades shows the vast majority of the pushrod force is still there. The slight increase in pushrod force when adding the blades is caused by the mass of the blades being aligned with the pitch arm. Don't confuse the power to *drive* the tail rotor assembly with the torque needed to change or hold the pitch of the tail blades.

How are my Chinese weights designed and tuned?
The heli tail system is run at actual operating speed either on the actual heli or on a test stand with tail blades. A digital force gauge is attached to a short pushrod to the pitch control bell crank. Pushrod force is measured at 10, 20, and 30 degrees pitch in both directions using the stock blade bolt and nut. A trial design (heavier than necessary) Chinese bolt and nut are installed and tested for pushrod force. (Note: when the weights are too heavy the tail will want to flop to either extreme of pitch.) Then the nut and bolt heads are reduced in thickness (lightened) a small amount and tested again. This is repeated until the desired pushrod force is achieved.

What is a perfectly tuned Chinese weight?
A perfectly tuned Chinese weight is a compromise of greatly reducing the pushrod force but still leaving enough to keep a small load on the tail rotor pitch linkage system to minimize play on either side of zero pitch (all weights I make now are tuned this way). The play will always be there when crossing zero pitch because there is no load on the pushrod at zero pitch.
If you had a mechanically perfect tail rotor system with absolutely no play (which does not exist), a perfectly tuned Chinese weight would have as close to zero pushrod force as possible. (The first weights I made were designed this way.)

Do weighted grips have the same effect as Chinese weights?
The weighted grips I have tested do not have enough weight to significantly reduce pushrod force. Check out my video of T250 weighted grips versus Chinese weights at http://www.youtube.com/watch?v=wVhit93JrWE.

Why use the Chinese weight mod?
Your servo has to work extra hard to overcome these large forces as it moves away from zero pitch in either direction. I have seen pushrod forces as high as 40 oz. (that's 2.5 pounds!) at 40 degrees pitch. Forces that high are bound to accelerate wear and failure. Digital servos are happy to provide the force but will run hotter, move slower, and draw more current in the process. A well known factory pilot had this comment "I haven't been able to tell a difference in flight performance. However, there is absolutely no doubt in the fact that this is a must do mod in order to extend the life of a servo. While testing this with a Futaba 3154, I noticed the servo temps around 120 or so after a 4 minute flight and with the weights, the temp dropped to below 100 degrees!" Many pilots notice a significant improvement in tail performance and pirouette consistency. Most people have to decrease their gain after installing Chinese weights. All these factors can translate into slightly more flight time on an electric heli and longer servo life. Check out my video of pushrod force and servo current on a Trex 500 with align metal blade grips at http://www.youtube.com/watch?v=iiW7McBiN5s.

THE PHYSICS OF TENNIS RACQUET EFFECT (TRE) .

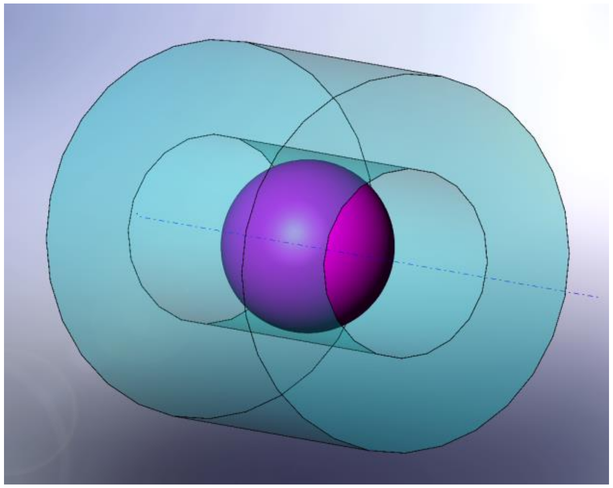
This is how I broke down tennis racquet effect to get my head wrapped around it. Hopefully this will give you a light bulb moment if you are struggling with TRE.
We first have to establish some key concepts.

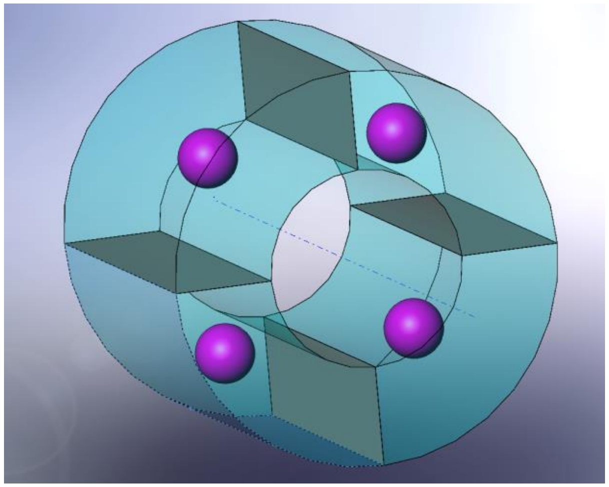
Centripetal force
When you swing a rock on a string in a circle above your head, the tension (pull) in that string is the centripetal force.

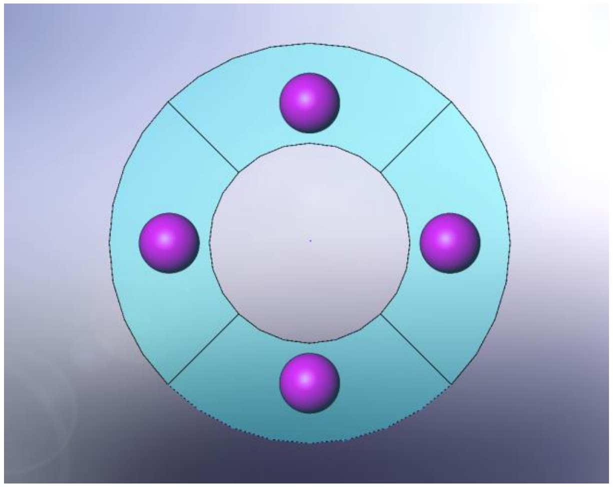
- Centripetal force varies in proportion to the change in mass (mass of rock) 2 times your original mass = 2 times your original centripetal force.
- Centripetal force varies in proportion to the change in radius (length of string) 2 times your original radius = 2 times your original centripetal force.
- Centripetal force varies as the square of the change in rpm. 2 times your original rpm (2 squared = 4) = 4 times your original centripetal force.
  1.5 times your original rpm (1.5 squared = 2.25) = 2.25 times your original centripetal force

Side note: This means that going from 1000 rpm head speed to 1414 rpm head speed just **doubled** the load on your blade grip bearings.

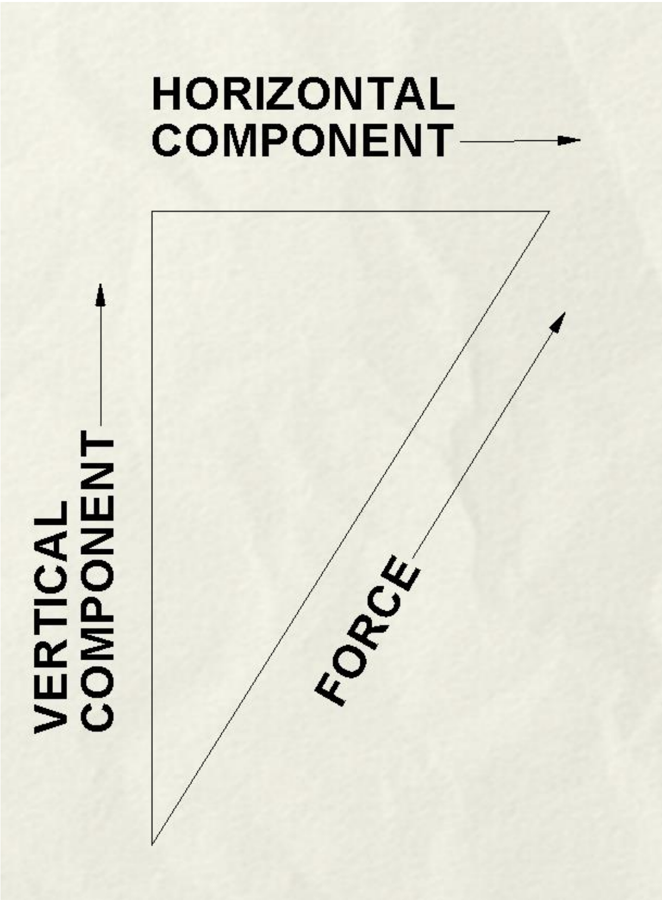
Point mass equivalent
For any 3 dimensional shape we can picture all its mass concentrated to a point located at its center of gravity. We can also split the part into segments with each segment having a point mass at the center of gravity of each segment. These 3 views of a hollow cylinder are shown whole, and then cut into 4 equal segments with the magenta balls representing the point masses of each segment







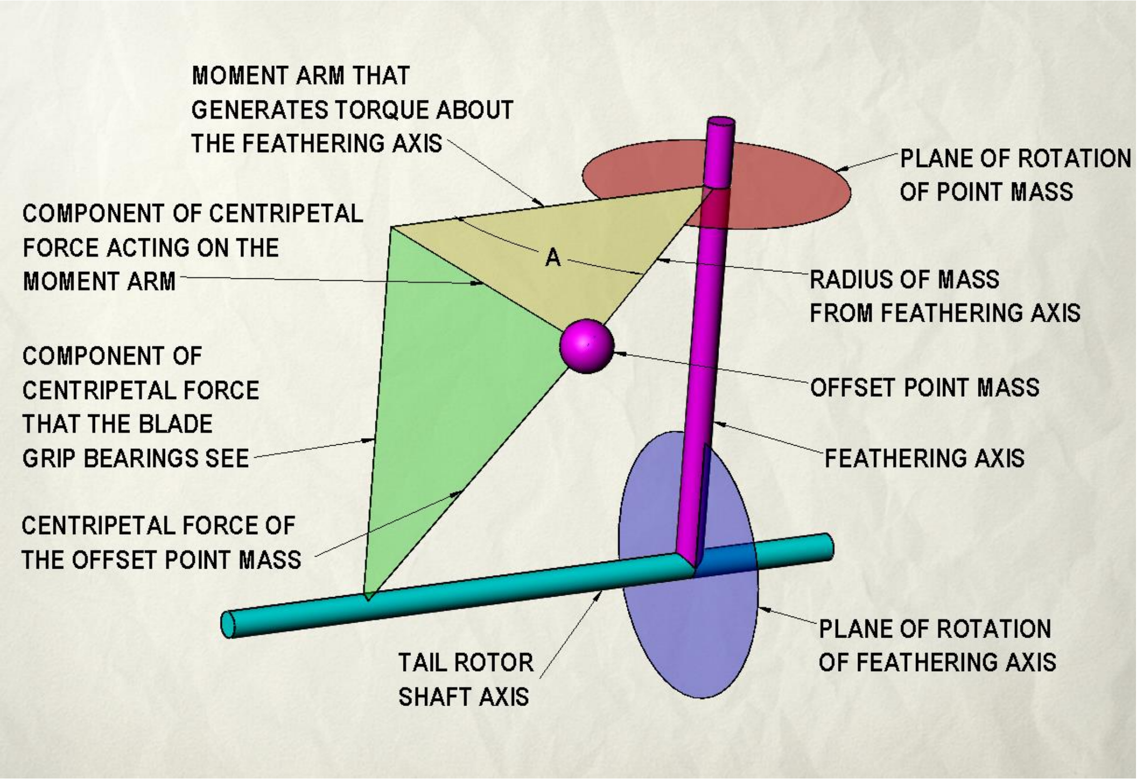
Components of a force
A force with a direction (Vector) can be broken into two other orthogonal components that yield the same effect.



Torque generated by an offset mass

(Tennis racquet effect torque)

Picture this diagram as a stop action photo of half of the tail rotor spinning at full speed. There is no blade grip or blade, just the feathering axis with an offset mass held at a fixed radius from the feathering axis. The plane of rotation of the offset mass is held a fixed distance from the tail rotor axis. There is centripetal force acting on the offset mass. We are not concerned with the tail pitch control system for this example. The offset mass is free to turn on the feathering axis. The centripetal force acting on the offset point mass can be broken down into two components as shown in the diagram. Only the component that can act in the plane of rotation of the point mass can work on the moment arm and generate torque. The other component is restrained by the feathering axis bearings. Let's picture this in three different positions (values of angle A). In each case visualize how the two triangles change shape as the value of angle A changes.



Angle A=0°

With angle A=0 both triangles no longer exist. The moment arm will be the longest possible but the component of centripetal force acting in the plane of rotation of the point mass drops to zero. So zero force on a long moment arm still equals zero torque. All of the centripetal force is seen by the feathering axis bearings. This angle yields the shortest radius the point mass gets from the tail rotor shaft axis. This position is not stable because as soon as angle A is not zero a torque will be generated and the point mass will want to move either direction towards the plane of rotation of the feathering axis. Picture this situation as a ball sitting on the on the top of a cylinder (not stable).

Angle A=45°

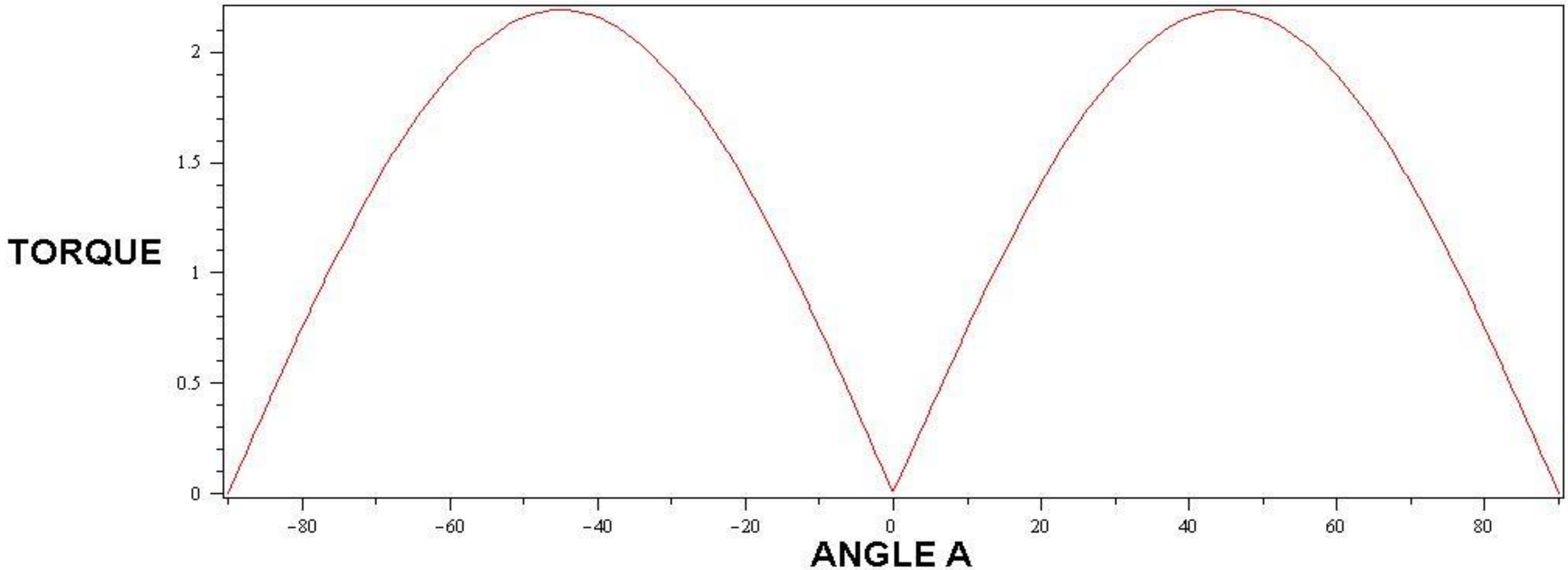
With angle A=45 (as pictured) the moment arm is a little shorter and the component of centripetal force acting in the plane of rotation of the point mass is now a significant portion of the centripetal force. This force acting on this moment arm equals a torque. It turns out that this is the angle that generates the highest torque. Now only a portion of the centripetal force is seen by the feathering axis bearings with the remainder generating torque. The point mass is larger radius from the tail rotor shaft axis and generates more centripetal force. This position is not stable because a torque exists driving the point mass to move to the plane of rotation of the feathering axis.

Angle A=90°

With angle A=90 the tan colored triangle no longer exists. The moment arm drops to zero and the component of centripetal force acting in the plane of rotation of the point mass is now an even greater portion of the centripetal force. Even greater force acting on a moment arm of zero length equals zero torque. Now an even smaller portion of the centripetal force is seen by the feathering axis bearings with the remainder generating torque. The point mass is at the largest radius from the tail rotor shaft axis and generates even more centripetal force. This position is stable because if it moves to either side of this position a torque will be generated driving the point mass to move to the plane of rotation of the feathering axis. Picture this situation as a ball sitting on the inside of a cylinder. The ball will seek the bottom even when pushed to either side (stable).

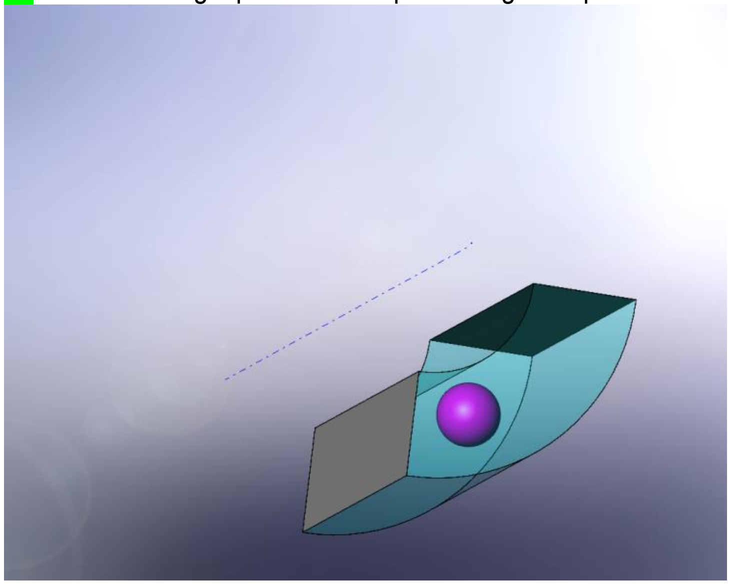
Graph of tennis racquet effect torque

Notice the peak torque is at 45° and drops to zero at 0° and 90°

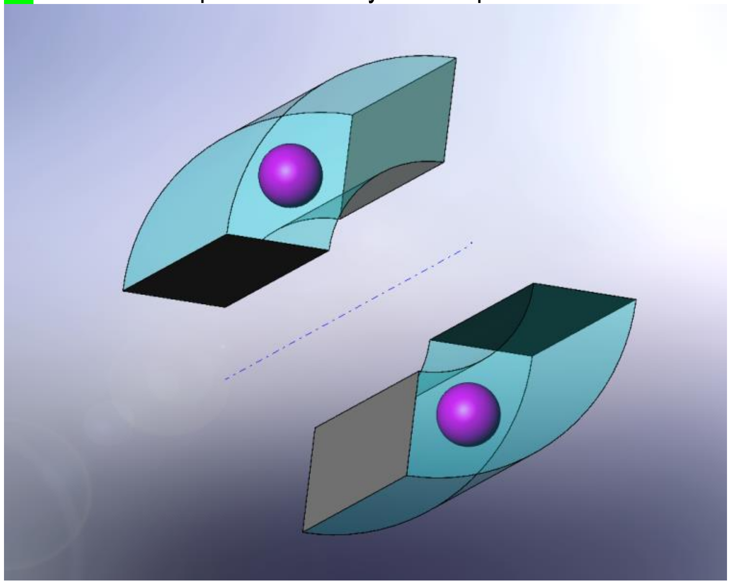


So how does this offset mass example relate to our heli tail?

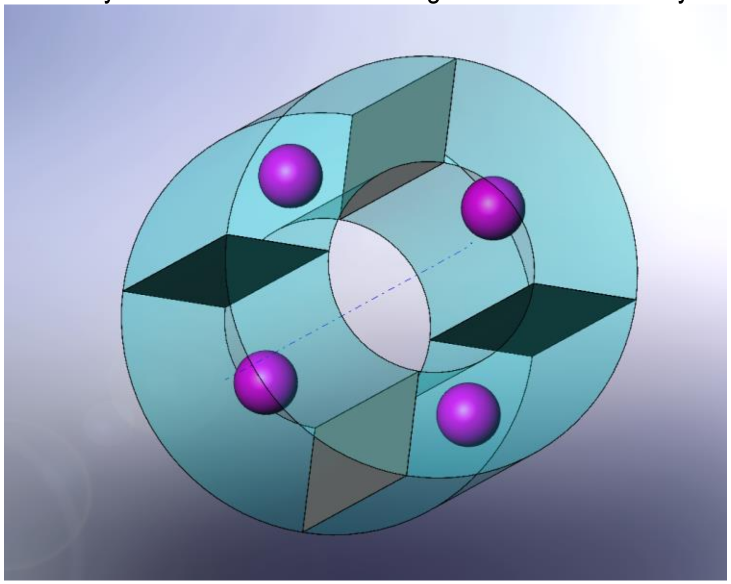
1. Here is a single point mass representing one quarter of the cylindrical portion of our tail blade grip. It would generate a torque just like our example above.



2. Add another quarter of the cylindrical portion of the tail blade grip opposite the original. That will double the torque in the same direction.

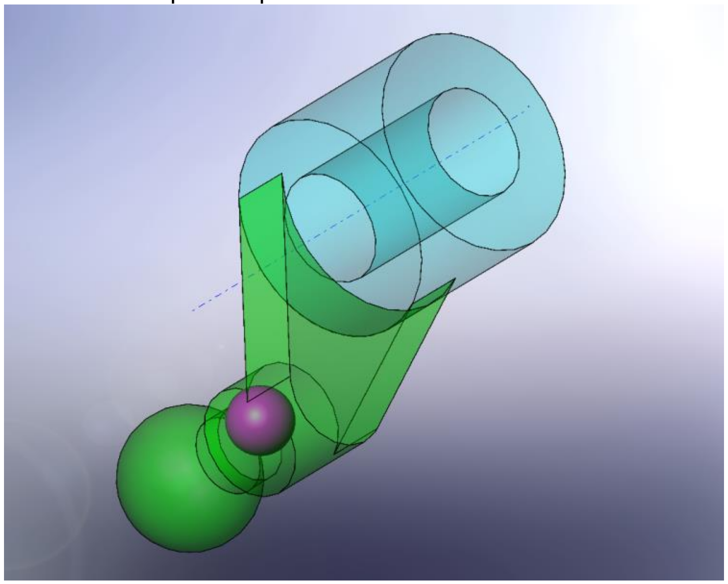


3. Add the last 2 quarters to complete the cylindrical portion of the tail blade grip. The point masses of the last two quarters added are at 90 degrees to the original two. The torque generated by the last 2 quarters is equal to the first two but the direction of the torque is opposite so the torques cancel each other. This is why any cylindrical body centered on the feathering axis does not generate any torque or tennis racquet effect. This is the key concept of the Chinese weight. Picture the view in #2 as your tail before Chinese weights and this view as your tail after Chinese weights are added.

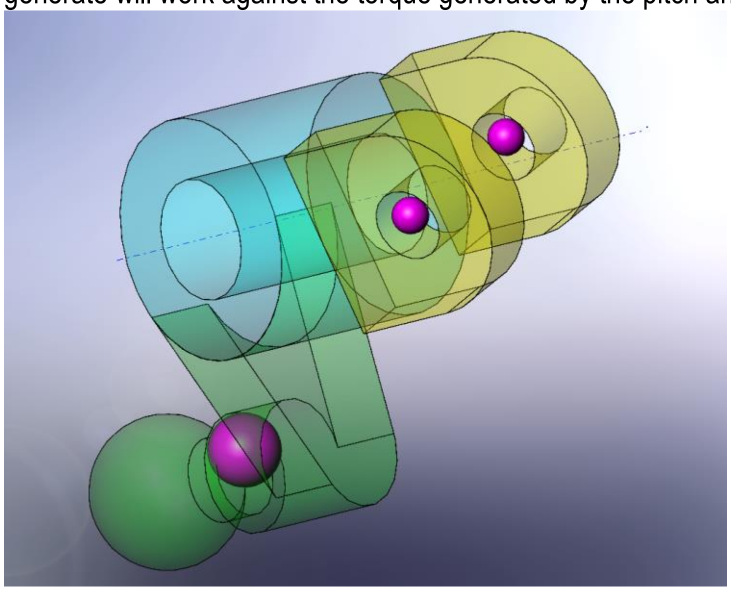


Note: In the above three examples the singe point mass per quarter of the cylinder representation is exact. In the following examples I have only shown the predominant point masses of each added part, so the concepts can be grasped without getting too technical and having the graphics get to hard to follow.

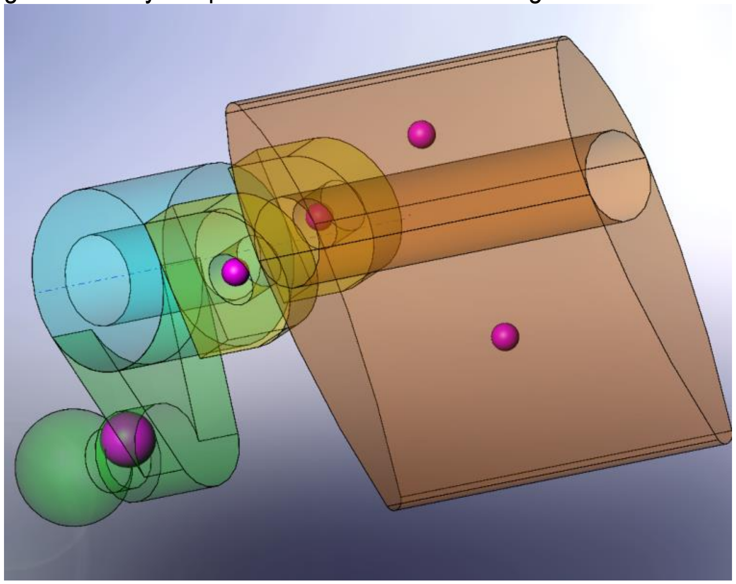
4. Add a pitch arm and ball to the cylindrical portion of the tail blade grip. We just learned that we can now ignore the cylindrical portion of the tail blade grip since it generates no torque. But now we see a single point mass of the pitch arm and ball offset from the feathering axis. We now know that point mass is going to generate a torque until it reaches the plane of rotation of the feathering axis (zero pitch). The pitch arm and ball or bushing and screw are the largest contributors to the tennis racquet torque we see on heli tails.



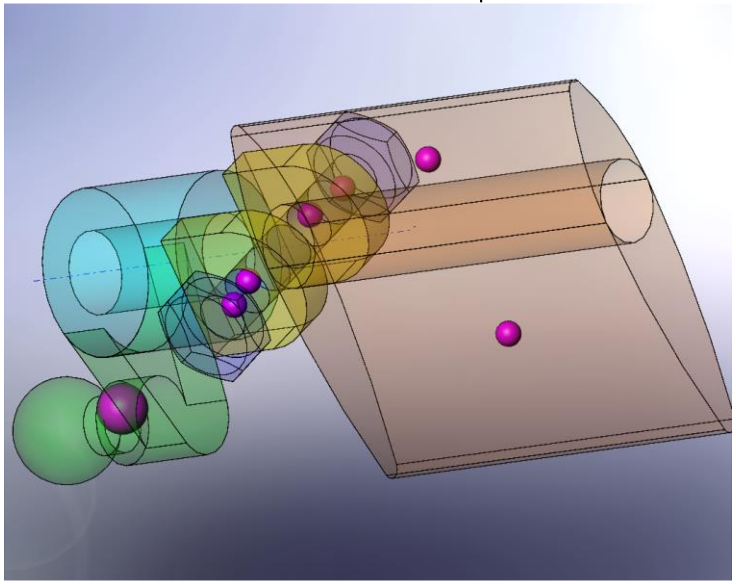
5. Add the blade grip ears to the hub. The point masses of the blade grip ears added are at 90 degrees to the pitch arm and ball. That means whatever torque they generate will work against the torque generated by the pitch arm and ball reducing the overall tennis racquet torque.



6. Add the tail blade. The point masses of the blade are in line with the pitch arm and ball. That means whatever torque they generate will add to the torque generated by the pitch arm and ball increasing the overall tennis racquet torque.



7. Add the blade bolt and nut. The point masses of the blade bolt and nut added are at 90 degrees to the pitch arm, ball and blade. That means whatever torque they generate will work against the torque generated by the pitch arm, ball and blade reducing the overall tennis racquet torque. This shows why adding mass to the blade bolt and nut decreases tennis racquet effect.



Conclusion

All these parts added together will end up with a final torque value. This torque becomes a force at the end of the pitch arm that pushes or pulls the pitch slider through the pitch links. That force is passed through the tail rotor control arm to the tail pushrod becoming the pushrod force. Friction in the Blade grip bearings and the tail pitch control system also contribute to the total pushrod force.

Here are some key points we now know

- With no Chinese weights the pushrod force can be excessively high making your servo and tail pitch control system work very hard to do its job.
- With Chinese weights that are neutral there is only minimal pushrod force caused by friction and any minor aerodynamic effects. This will cause the tail pitch control system play to be seen throughout the entire pitch range. In this condition the gyro and servo have to take the play out every time they reverse direction. (can you say tail wag?)
- With Chinese weights that are too heavy the tail will want to flop to 90° pitch on either side of 0° pitch (opposite of normal). This will aggravate the effects of play when crossing 0° pitch.
- With Chinese weights that are just right, pushrod force is significantly reduced while leaving just enough to minimize the effects of tail pitch control system play. The reduced pushrod force allows your tail servo to do its job more effectively, drawing much less current and running cooler.

Now you should be able to look at your heli tail and see how each individual part contributes to increasing or decreasing your pushrod force and why some blade grip/tail designs have more pushrod force than others.