The history and physical principles of stabilizers (ST101)

Introduction:

Many seem to think that stabilizers are some sort of cutting-edge modern-day invention still being developed and, because they are unaware of the history, feel they and their experimentation are active participants in its current development.

Sorry to disillusion you, but stabilizers didn't just appear by random chance, nor were they the result of some wild backyard experimentation. They are the end product of the application of very sound physical principles and some applied engineering to a problem by some pretty smart cookies (*not by me I hasten to add, I'm just passing this on*) and all the principles were thoroughly investigated and were very well known to these scientists and engineers about fifty years ago.

So what else can I say to current experimenters but ... hey, I'm sorry to tell you this, but - you're just trying to re-invent the wheel!

Stabilizer Development:

Adding Mass

Prior to the introduction of 'long-rod' stabilizers a couple of things were obvious.

Firstly, a bow with small mass was very difficult to hold still while aiming and could easily be thrown to the side during the execution of the shot.

The solution to this problem seems quite simple – just increase the bows inertia by making it heavier (*i.e. adding more mass to it*) to make it more difficult for the archer to move it around, and the heavier the better.

Secondly, some bows were inherently more "forgiving" to a bad shot than others. That is, mistakes such as moving the bow-arm to the side on release when using one bow would result in a shot thrown out into the red whereas if another bow were used the same shot would be thrown out into the blue or black.

The more astute pointed out that while mass played a part, some of this was also due to the "shape" of the bow, that is, the manner in which the mass of the riser was distributed, and the bows that performed worst were those whose centre of mass was further behind the pivot point than the other.

They also pointed out that because the centre of mass is behind the point where the hand is placed, (*which is at the bows 'pivot point'*) any sideward movement of the bow-hand will just cause the bow to rotate about its centre of mass and it will end up pointing further to the side to which it was moved than the 'forgiving' bow whose centre of mass was further forward.

Here's a very simple experiment to demonstrate what is meant by that … Hold something long, such as an arrow shaft, lightly between your thumb and first finger near the tip, let it hang down and then move it quickly to one side. When you do this you'll see the shaft rotates so that its tip starts to point in the direction it's being moved, and we can note that the tip is thus actually moving further and faster than the hand. The centre of mass is "behind" the point where the force is being applied - this is quite analogous with a bow that has the centre of mass behind the pivot point. …

What has happened is that the movement has introduced a *torque* that exaggerates the movement of the hand and leaves the arrow pointing in a completely different direction.

Obviously, if we now hold the shaft **below** the centre of mass the point won't move as far or as fast as the hand does and it will point in the opposite direction - hence the torque is now acting in the opposite direction.

In comparison, if we now hold the shaft right at the centre of mass it just moves as far and as fast as the hand does, it stays upright and is always pointing in a direction parallel with the original direction – there is now no torque acting.

(*There are further simple experiments outlined at the end of this document*).

Positioning The Centre of Mass

It was no secret that bows should be built so that their centre of mass was further forward of what was then the norm, that is, forward and up into the bow-hand itself. Bow manufacturers tried various ways of accomplishing this without adding any unusual external attachments that may possibly be ridiculed and rejected by archers, thereby making them unsaleable. Most took the more conservative approach and focussed on just changing the shape of their risers.

This approach was not very successful because they either had to give the riser some very unusual shapes and/or build so much mass into the front of the riser that it couldn't be lifted very easily - the resulting unusual shapes and the sheer mass of the risers may have meant commercial suicide (*particularly so for the smaller companies).*

Earl Hoyt decided to test the market and in 1961 released the Hoyt Pro Medallist which had two stubby metal stabilizers mounted at the top and bottom of the riser and he is thus credited with inventing what he then called 'torque stabilizers'. While there was some initial hesitation, the market soon responded and externally fitted stabilizers quickly won support

It was not long before arguments began over the most desirable length of stabilizer rods, that is, whether it was better to have a short rod with a heavy mass (*such as that on the Hoyt Pro Medallist bows*) or (*say*) a rod that's twice as long with half the mass.

Some of the clever ones jumped in and said "aha these are 'torque stabilizers' - and a torque implies there is rotation and if that's the case then we'd better consider the *"moment of inertia"* and use the longer rods".

Others said "hang on, the whole idea is to PREVENT the bow rotating in the first place, and the torque is created by the force being applied by the movement of the hand which is at a distance from the centre of mass, so all that's needed to do that is to place the centre of mass in the hand – short stubby stabilizers can do that".

The clever ones responded with "but no matter how loosely you hold the bow there will always be some friction between the bow and grip that will produce a small torque on the grip as your hand moves to the side – longer rods are best".

The others replied "as you say, it **is** only a small torque and all that needs to be done to overcome the friction is to just move the centre of mass a millimetre or two forward of the pivot point so the angular inertia of the bow creates another small torque that compensates for the torque being applied via the hand, the two opposing torques then cancel each other out. Long stabilizers would move the moment of inertia further out and that can only lead to an increase in the angular momentum of the bow when it's moved and the resultant torque then becomes much greater than any opposing torque that can possibly be supplied via friction between hand and bow – this only make matters worse, so shorter rods are best"… STALEMATE!

Interestingly, this last argument is completely correct. It is best to place the bows centre of mass in the hand so that a torque can not be applied to it in the first place. Once the string has been released it really does **not** matter whether long or short rods are used, the only thing that **is** really important during this phase of the shot is that the centre of mass is in the centre of the hand so as to maximise the inertia slowing down any unwanted movement of the bow-hand while minimising any tendency for a torque due to arm movement to be applied via the grip. (*However, please note that I personally would in no way advocate using short rods, longer rods **are** best – but for a more subtle reason*).

We should note now that if an archer has a consistently good form and doesn't make unwanted movements of the bow hand on release, even the requirement to place the centre of mass in the centre of the hand can be discarded – that is, if you don't make an action that creates a torque then you don't need to consider torque.

From this we can only conclude that:

- for an archer with perfect form, the stabilizer set-up has virtually no effect on the shot once the string has been released.

- On the other hand, an archer that often, or even only sometimes, makes such mistakes during this phase of the shot can benefit from having the centre of mass in the centre of the hand.

The above thus always needs to be considered relative to the skill and experience of a given archer - those with consistently good skills can choose to ignore 'rules' that are of most benefit to those of lesser skills.

Development of Stabilizer Set-ups

Many and varied stabilizer set-ups soon appeared, and while almost all archers using short rods got better scores than they got when using an unstabilized bow (*others found them to be of little or no benefit*) the archers using longer rods consistently got better scores and benefited most.

This led to the use of longer and longer stabilizers with even more mass being added to them until the centre of mass was well and truly in front of the bow, at which point some noticed their scores had started to go down again. They added counter-weights to the back (*'belly'*) of the bow to try to prevent the centre of mass from moving too far forward, but it took a lot of weight do this so they resorted to stubby backward mounted stabilizers – stubby simply because they couldn't be made too long or the string would hit them.

At some time during the 70s V-bar stabilizers came onto the market and they were snapped up because they were a much better idea for a much better counter-balance – but there was a problem….

During this whole period there were FITA rules regarding the number of stabilizers allowed on a bow and this went from two, to three, etc. and was only around about 1980 that those restrictions were dropped altogether.

The problem was that V-bars added two stabilizers so there was no use for them in the period when the rules restricted archers to a maximum of two stabilizers - it was better to have the two stabilizers at the front of the bow (*generally these were mounted top and bottom*).

When the rules were changed to allow three stabilizers this allowed the use of V-bar stabilizers in a centrally mounted Y configuration and this setup prevailed for quite some time. Archers wanting a better stabilizer set-up grumbled at this constraint and eventually FITA caved in and changed the rules so that any number of stabilizers could be used.

Now all this took place in the days when statistical proof was not accepted as a valid proof. And it is difficult to conclusively "prove" that the reason for the improved scores after stabilizers were introduced was due entirely to stabilizers (*and was not due to the psychological benefit of having the latest shiny gadget*) - leading some to hypothesise that improvement in scores over time were due entirely to improved skills and techniques, and the only benefit stabilizers gave was simply psychological.

On the other hand, there was almost unanimously agreement that there was various degrees of improvement in the stability of the bow while aiming, and it could also be easily proved that bow noise and vibration could also be reduced somewhat by using stabilizers.

Naturally enough, all of this led to some confusion as to the exact purpose of 'stabilizers' as they were now called and how they should be set up …

A few understood the underlying physics and advocated their use, pointing to the statistical proof as evidence, while some listened to the first few, looked at the evidence, and continued using them.

Some others (*usually those that found them to be of little benefit to their scores*) thought of them as simply a means of reducing noise and vibration and concentrated their efforts on further improvements in that direction and as a result, 'Torque Flight Compensators' were introduced in 1966 to satisfy (*or take advantage of*) that end of the market.

As a result of all this, new-comers to the sport were often left with feelings of confusion and "no-one really knows what they're talking about".

Aiming Stabilization

After some time a general consensus arose among archers that longer stabilizers really were the best option - the reasons for this are somewhat complex…

During the aiming phase of the shot the string is under tension, and like any string under tension there is always a vibration period and frequency associated with it. This vibration period becomes obvious when you move your bow quickly to a new point of aim, there is then a small delay from the point in time when the bow is moved to this position, and the point in time when the whole bow has swung around to actually 'line up' with this new aiming point, and it is during the intervening 'delay' period while the bow is swinging around to the new position that the moment of inertia (*located at the radius of gyration*) becomes important.

This delay is generally greater when longer stabilizer rods are used and is shorter with shorter rods - remove the rods altogether and the bow lines up with the new position almost immediately. The use of the shorter rods would thus be better if you do wish to change your aim quickly, and the use of longer rods better if you do **not** wish to change your aim quickly. So the question arises - when is **not** wishing to change your aim quickly to be considered more desirable?

The answer to this question is: When you're aiming of course…

It's virtually impossible to hold a drawn bow completely still, there is generally some degree of muscular tremor or left/right 'wobbling' of the bow arm about an arc that can be drawn with the shoulder as the principal axis of rotation (*the bow itself also rotates about another axis located at the bows centre of mass in the horizontal plane*).

When a muscular tremor or wobble starts, because of the vibration period of the drawn string the stabilizers moment of inertia causes the movement of the end of the stabilizer to lag behind the movement of the bow-hand. As a result of this, the bow will rotate in the hand and a forward mounted sight on an extension bar will also lag behind the hand movement – but not by as much as the stabilizer mass.

The period of these tremors are generally much smaller than the vibration period of the drawn string, so by the time the movement in one direction stops and starts to move back in the other direction the sight pin has not moved as far as the hand has, with the result that when there is a fast back and forth 'tremor' type movement the sight moves much less than the hand does and the sight pin stays relatively still. When there is a longer 'wobble' type motion the sight moves further - but still not as far as the hand. It is only after a much longer period when the movement has been halted at a new position that the bow swings across to eventually line up with the new aiming position.

This reduction in sight movement during involuntary movements thus gives a more stable sight-pin while aiming, that is - it gives 'aiming stabilization' that allows for better eye/hand coordination by the archer.

Apart from the benefit of being able to aim better, there is also a psychological benefit that gives the archer more confidence and this added confidence may feed back to actually provide a more stable hold that doesn't move their bow-hand as far in the first place.

Increasing Aiming Stabilization

For a given amount of sideward motion, the vibration period can be increased and stability improved in two fundamental ways i) by using a bow that has a light holding force and/or ii) by increasing the moments of inertia of all the stabilizer rods.

For a bow with a given draw force the only option is to increase the moment of inertia about the bows centre of mass. This can be increased either by increasing the length of the stabilizer rods and/or by increasing the amount of mass on the rods. All of which means juggling stabilizer weights around to keep the centre of mass in the hand where it provides the greatest inertial resistance to any sidewards movement.

When an archer is using the longest practical rods and has the greatest mass that they can handle there seems little else we can do to increase inertia and improve aiming stabilization any further. But this is not entirely correct, aiming stabilization can be further improved if the archer has the skills that enables them to do some trade-offs.

Going to Extremes

For an archer that has consistently good form there is one further option for them to increase aiming stabilization, and that option is to increase the moment of inertia by moving the centre of mass out of the hand and to place it in front of the bow.

However, by doing this we now have a new lever arm[addendum] that extends from the bows 'pivot point' (*the grip*) to the bows centre of mass, and the hand pushing on the end of this lever arm creates another torque that acts through the bows true pivot point (*the centre of mass*) to resist the first torque which was created by the drawn string and the archer moving the bow to the side (*which then causes the sight-pin to follow a little later*).

Because of conservation laws, for a given force applied by the archer, there is an increase in angular momentum at the expense of a decrease in translational inertia. In other words, the archer (*who is focussing their whole attention on the sight-pin*) sees the sight pin moving less, but a careful independent observer could note that there is actually a small increase in the distance that the bow-hand is moving and the actual tremor or wobble really becomes larger…

While archers have always argued about the various merits of different stabilizer set-ups (*and probably always will*) the underlying physics behind all these setups is really quite unequivocal, so if they actually know exactly what they want and need to achieve with their own stabilizer setup, it can only help them to know and understand a little of the physics that govern all the various setups.

Note 1: the primary benefit to be obtained from stabilizers is the simple concept of increasing inertia by adding mass so as to reduce movement of the bow by the archer. Of course there are strength limitations here, add mass and the bow becomes heavier, add too much mass so there can be no movement and the archer wouldn't be able to lift it. So within the archers physical limitations there can only be relatively small gains.

Note 2: The points being made about maximising these gains does not mean that there will be absolutely no benefit if there's no maximization, it merely means that one relatively small benefit can be made even smaller and this does not mean that there is no benefit at all if it's not maximised. In other words, it's true to say that "in general, regardless of how "bad" it may be, SOME stabilization is better that NO stabilization, but it's very often possible to make it just that little bit better".

<u>EXPERIMENTS:</u>

PRELIMINARY EXPERIMENT:

Here is another very simple experiment for all to try just to establish a fundamental principle.

1) Hold a full beer stein (*or anything similar - pan of water, whatever*) by its handle loosely in your hand (*with your arm outstretched*) and 'point' it so that the handle is in line with your arm.

Q. Can you agree that the centre of mass of this object is now 'in front' of your hand?

2) Now move your arm quickly to one side.

Q. Did this *movement* induce a torque such that the beer stein handle pivoted **very** easily in your hand, and the stein itself pivoted about a secondary axis (*at the COM*) and ended up pointing in a totally different direction or did it not?

Supplemenary Question:

Q. Do you think the beer stein handle (*the part(s) between where it's being held and where it's attached to the stein*) is somehow acting as a 'lever' or (*more accurately*) a lever arm that facilitates rotating the beer stein about its centre of mass?

3) Now try this again while holding **the beer stein itself** loosely (*bit harder to do with a large diameter object of course*).

Q. Can you agree that the centre of mass is now closer to the hand?

4) Now move your arm quickly to one side.

Q. Did this movement induce a torque such as to cause the stein to pivot easily in your hand (*as before*) or did it not?

Q. Was it, or was it not, more difficult to initiate any movement in this second case?

Any aiming 'tremors' and 'wobbles' are simply analogous movements to those made above.

MAIN EXPERIMENT(S):

For this next set of experiments I have an old recurve that I use to demonstrate all this (*live*) with.

These experiments are still relatively simple but far too lengthy to post as a video anywhere so I will simply describe the experiments so that anyone can try them for themselves (*note: These experiments should be readily observable just by 'feel' and simple observation, but if you still have any doubts and have access to the necessary precision measuring equipment then by all means use it*).

Equipment:

1) Any old bow (*but preferably a recurve*),
2) a long stabilizer rod,
3) a V-bar and V-bar stabilizer rods,
4) a fairly large assortment of stabilizer weights,
5) an exceedingly long string (*a compound cable will suffice*).

Preliminary Setup:

First tie a loop in the long string at one end so that the bow can be strung at its normal brace height (*we are not going to loose arrows from this bow by the way*).

Now tie a number of loops in the string at this same end so the bow can be strung at successively lower brace heights.

Add even more loops at distances on the string much greater than the length of the bow such that the bow can be 'drawn' using this (*now very loose and floppy*) string and held with a zero draw-force at full draw when using the last loop – and so that it can also be held with a hold-force anywhere in between zero and the bows normal draw-force when using the other loops.

Part 1

Start with a long stabilizer rod with a lot of weight on the end so that the centre of mass is well in front of the bow and the bow is strung on the last loop and held with a zero holding force.

Repeat the previous 'beer-stein experiment' using the 'zero-force' bow.

Q. Is there, or is there not, a very similar effect noticed?

Part 2

Now use another loop so that there is a very low (2, *3 or 4 lb*) holding force at full draw and repeat the experiment again.

Q. Was the same effect there this time or not?

Q. Was the effect lessened because of the small hold-force now acting?

Q. Was it noticeable that after ceasing this motion the bow swung round in the hand slowly and only became 'lined-up' some time after the motion had ceased?

Now remember the direction the bow was pointing at the time your motion had ceased and try to visualize what is happening **during** the motion, then try to visualize making a similar movement just before, on, or just after release.

Challenge question:
Q. Do you, or do you not, think the arrow would go in the general direction of where the bow was pointing at the time the nock left the string if this same movement had taken place just before, on, or just after release?

Part 3

Now use other loops so the draw/hold force is gradually increased.

Q. Was the same effect there each time the hold-force increased?

Q. Was this effect lessened a bit more as the hold-force became larger?

Q. Was it noticeable that after ceasing this motion the bow swung round in the hand a little quicker as the hold-force increases but still only 'lined-up' after the motion had actually ceased?

Part 4

Now try all this with ever-increasing draw forces near the bows normal draw-force and then answer this challenge question.

Challenge question:
Q. If these effects do indeed become smaller and smaller as the holding force increases, do they ever actually go to zero, or, do they just become smaller and less noticeable to a casual observer but noticeable to a careful observer?

Part 5

Repeat all the above but with a V-bar and V-bar stabilizers attached so that the centre of mass is now 'in the hand' and compare all this with the other experiments.

Again, we can note that any aiming 'tremors' and 'wobbles' are simply analogous movements to those made above.

By now you should have enough data and information to ask your own questions and to draw your own conclusions...

Addendum:

It appears that some people appear to be quite unfamiliar with the concept of a "lever Arm", this concept is inextricably linked with another intimately related concept, that of "torque". Specifically, a torque is simply the product of the applied force and the length of the lever arm on which the force is being applied, where 'the length of the lever arm' refers to the "effective length" of the lever under consideration. In vector notation this is usually written as the vector cross-product $\boldsymbol{r} \times \boldsymbol{F}$.

Lever arms and torque are both discussed here http://hyperphysics.phy-astr.gsu.edu/Hbase/torq2.html (*from where the illustrations regarding torque and lever arms - shown below - have been copied from*) and I would recommend that you follow the above link if you have any further doubts or queries.

Illustration 1: (Lever Arm = *rsinθ*, torque = *rFsinθ*)

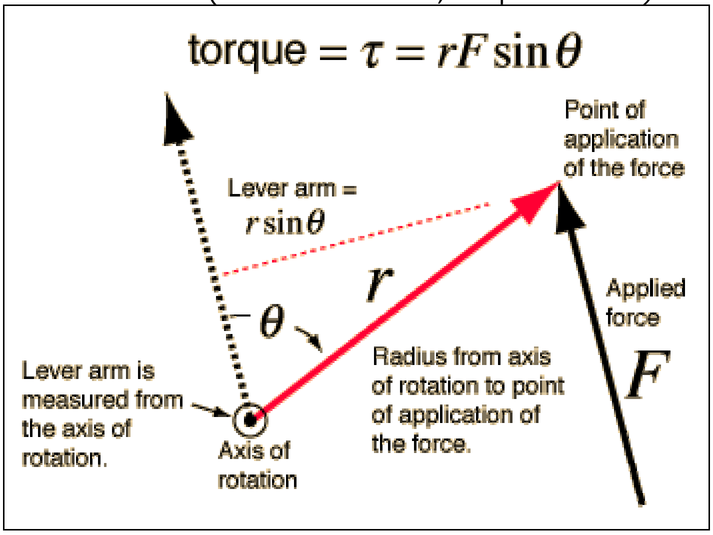

Illustration 2: Practical example of a force acting on a lever arm