12.4.2 Dynamic Properties Combined

Graphics to Show it All

First let's go through the basic parameters that determine your swords *dynamical* properties:

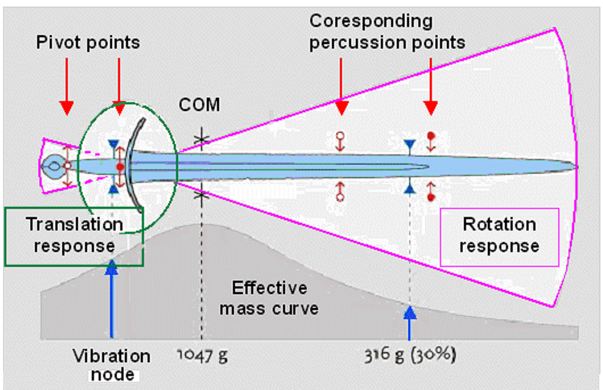
1. Its *mass* ***m***. This is a *single number*, easy to obtain and typically between 1 kg - 2 kg. Mass is a clear thing that does not need more words.
2. The *center of mass*. (**COM**). Once more a *single number* that gives the distance (in cm or mm) to some reference point. It is also a sufficiently clear entity by now. Typically we want it on the blade but not too far from the hilt.
3. The *moment of inertiea* ***I***. This is a measure of the distribution of the mass. It is *not* a single unambiguous number and it is not all that easy to calculate. Its value (given in kgm^2) is always relative to a rotation axis. It is usually given with respect to a rotation axis through the COM at right angles to the blade and then designated I_{COM}. If I_{COM} is known, it is then easy to calculate values for other axes perpendicular to the blade at some arbitrary distance from the COM.
   Generally we want a small moment of inertia since this makes it easier to swing the sword.
4. The *effective mass*. This is *not* a number but a *curve* with a shape that is determined by the mass and the moment of inertia of the sword. It gives values (in kg) that decrease from a maximum at the COM (with a value equal to the total mass) to lower values at both ends of the sword.
   The value of the effective mass at some point relates to the impact felt at that point.
5. *Percussion points*. There are always *two* points! One point is usually chosen as the *pivot point* on the hilt close to the cross guard. The corresponding percussion point then is somewhere down on the blade (or even outside; off the tip). Its distance from the center of mass depends on the mass ***m***, the moment of inertia I_{COM} relative to the COM, and the distance of the pivot point from the COM. We want the percussion point to be found in the tip region because hits on the percussion point do not transmit forces to the hand at the pivot point.
6. *Vibration node points*. Typically swordsmen are concerned about the location of the two nodes of the (low frequency) second order side-to-side vibrations. They are easy to excite and to see. The two nodes of the (high frequency) second order edge-to-edge vibration might be more important, however. Luckily, they coincide more or less with the first variant. Ideally, we want the lower vibration node to coincide with the percussion point.
   Vibration node positions are *not* easily calculated. It is also not easy to change their position substantially. They tend to be - very roughly - around the hilt and about 3/4 down the blade.
7. *Point of maximum impact*. I have not discussed that yet but it is clear that whenever you hit something you transfer some energy from your sword to the hittee. There must be a point somewhere on the blade that delivers the most energy and that is the point of maximum impact. I'll discuss that later in detail.

- In essence, all these parameters result from the distribution of the materials defining your sword. In other words: It is the shape or geometry that counts - and details matter! Change something there and all the parameters above will change. Some more than others.

What that means is simple. You cannot sit down, consider what you want with respect to the parameters given above, make a list with the resulting numbers and curves, and order your sword maker to produce a sword that meets your wishes. All these parameters are simply not independent.

- You must compromise. There is no "ideal" sword for you, only compromises. Swords may give you satisfaction with regard to some parameters while leaving something to be desired with respect to others.

Peter Johnsson has come up with a very attractive way to illustrate the sword properties that result from **Vincen Le Chevalier** calculations [1]. His pictures are mostly published in "The Sword - Form and Thought" [2] and I use some of them here with the kind permission of Peter, Vincent and the Solingen museum.
Here is what it looks like with some explanations added by me:



Sword dynamics graphically

The text insets are from me and I used my nomenclature that on occasion is somewhat different from that of Le Chevalier. Pictures like that are generated by a computer program that is available for everybody in the Net [1)]. You must supply the basic data, of course, and that involves some precise measurements. Le Chevalier has explained most of the math behind the calculations and, as far as I'm concerned, it is sound.
There is a lot of information in these pictures. Let me go through the pertinent points:

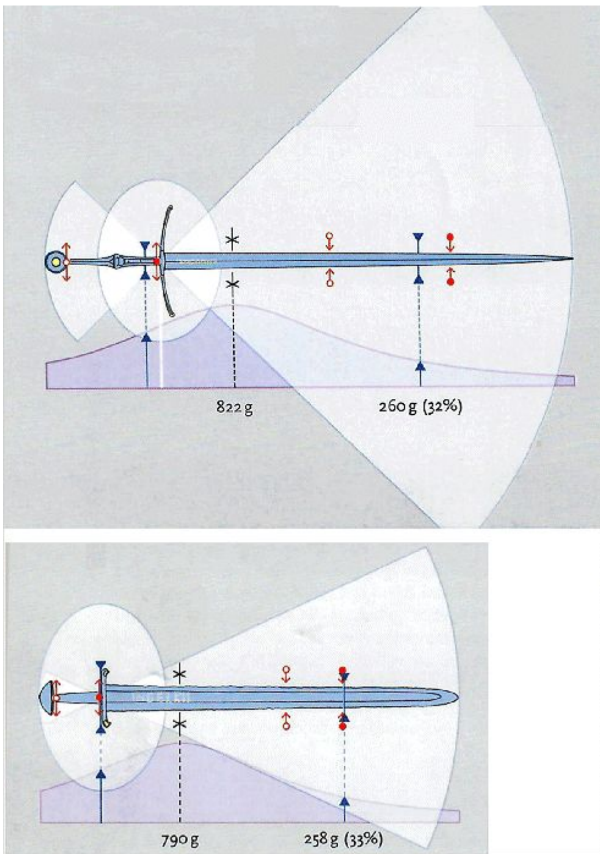
1. You see the basic *shape* of the sword in some detail and you find the *mass*.
2. The *effective mass* curve is shown below the sword and the effective mass at some special points may be given as a number and in percent of the full mass.
3. The *center of mass* is indicated.
4. Two *pivot points* are chosen, always close to the cross guard or to the pommel. The corresponding *percussion points* on the blade are calculated and shown. Since the real pivot point will be somewhere between the two shown, the blade part between the two percussion points is where you want to hit (with some preference to the front one).
5. The two *nodes* of the second order side-to-side vibration are shown.
6. The sword's response to attempts at *translations* are shown as an oval centered at the cross guard pivot point. The smaller the distance from the pivot point to somewhere on the oval, the harder it is to move the sword in that direction.
   For straight thrusts the full mass is used, for movements at 90° to the blade the (reciprocal) effective mass in that direction is used. For movements in arbitrary directions, a suitable mixture of the two values is employed. Assumed is that you just apply a force in the specific direction which, except for the straight thrust, always results in translation plus some small rotation.
7. The sword's response to attempts at *rotations* are shown as two cones centered at the cross guard pivot point. The larger the cone, the easier it is to rotate the sword around the cross guard pivot point. The essential parameter for this is the moment of inertia for rotations around the pivot point.
8. Some more information, e.g.. effective masses at some special points, might be given as the need arises.

The power of these diagrams (from the Solingen book) becomes clear when you use them to compare swords.

- The sword on top is described as a hand-and-a half Sword from 1480 - 1500. It is 105 cm long with a the blade length of 81.5 cm and weighs only 0.822 kg
  The sword on the bottom is actually an "Ulfberht" sword. Its length is 83.3 cm, with a 70.2 cm blade. It weighs in at 0.79 kg, quite low too.
  The "Solingen Swords" Link provides a lot of pictures like the ones discussed here plus some data. It includes very light and very heavy swords, long and short ones, and allows a lot of data extractions like the one below.
  Here are the two characteristics of these swords:

Illustr. Link

"Solingen" Swords



Property comparison of a hand-and-a half Sword from 1480 - 1500 and a Ulfberht sword from ca. 1000 AD.

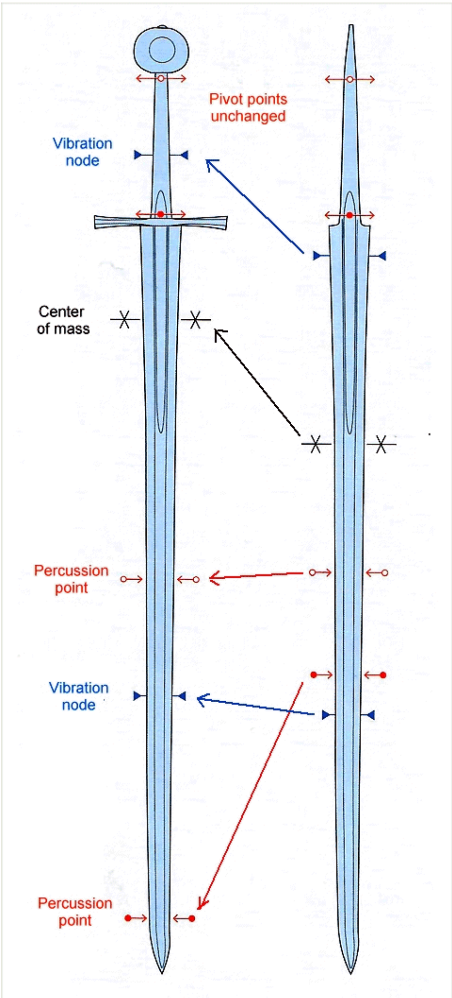
- The Ulfberht has a slightly better translational response, simply reflecting its slightly smaller weight. Its lower percussion point coincides with the vibration node but is a bit far from the tip. The effective mass at the node point is respectable but practically the same as that of the longer sword. The long sword has a far better rotation response. That means that you can get it to swing with a larger rotational speed than the Ulfberht. Its percussion point (also close to the node point) thus moves considerably faster that that one of the Ulberht and thus delivers far more punch (the power goes with effective mass and the speed squared!). It is just a much better sword - if wielded by an expert. It needs more room for swinging and that needs practice.
    - I doubt very much that the longer sword was intended for "one-and-a-half" hands. There is actually ample space for two hands on the hilt but given its small mass I tend to believe that it is meant for one hand only. Why then the long hilt? The answer is simple:

Optimizing the dynamical properties of your sword means optimizing: the pommel and the the blade taper

    - The long sword obtains its superior properties to a large extent because its pommel is far away from the center of mass without taking too much mass away from the blade. The blade is actually thicker then the Ulfberht blade but more slender and cunningly tapered. There are many interesting pictures of people (including angels) wielding those swords always with just one hand, here is the link.
- Finding the best pommel mass and distance plus a fitting taper Is not easy because of all the parameter interdependence. There are no simple rules. I'll give you a few examples of what can be done.

Optimizing Pommel and Taper

- I'll show you two pictures, one from the "Solingen book" and le Chevalier's / Johnsson's work, the other one from Turner's seminal contribution.



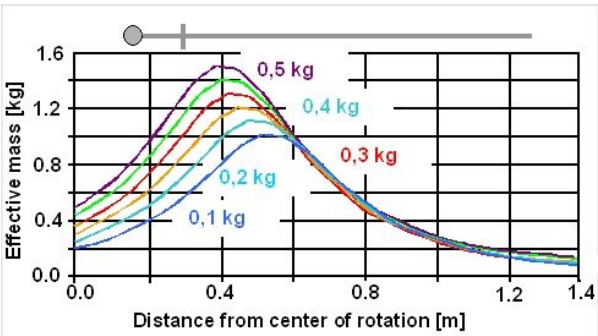
What a optimized pommel can do

Unfortunately, the basic data of the sword are not given but it is quite obvious that an optimized pommel will:

- Add some mass, making the sword heavier and thus a bit less agile.
- Move the center of mass much closer to the hilt, substantially increasing agility,
- Move the vibration node close to the hilt "up" quite a bit into the hilt. This substantially reduces the vibration amplitudes your hand will feel.
- The vibration point close to the blade tip only move a little bit "up" on the blade. You actually would like it to be farther out and closer to the tip but there is no way to achieve this with a pommel. So be happx that it only moves a little bit in the wrong direction.
- The percussion points move quite a bit down on the blade. That is good. Having a percussion point coincide with the vibration node might be even better but for those kind of long swords this is not practical. Anyway, considering that for a pivot point around the vibration node of the hilt, the percussions point will not be too far from the blade node, this is quite acceptable.

We have a first quite instructive example for what can be done, and that you always must compromise.

Turner looks a the effect of pommel from many directions (read his book if you want details). What I will show you from his work is what a pommel will do to the effective mass: The pivot point here is assumed to be somewhere between your wrist and your elbow but that doesn't matter much.

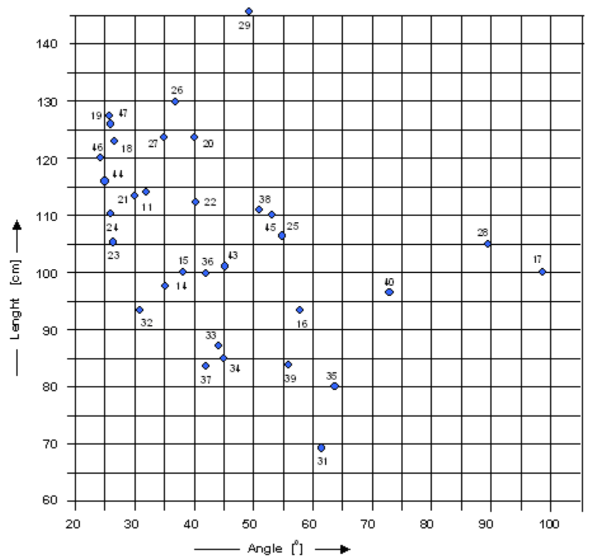


Adding various pommels to a 1 kg blade and their effect on the effective mass

You see the increase in mass and the shift of the center of mass towards the hilt. You also see a large increase of the effective mass around your hand position (around 0.3. m) that will decrease the translational response (you more or less feel the full increase in weight there). The rotational response, , however, is far less impaired because the COM gets closer to the hilt.
What you probably don't see is the 30 % increase in the effective mass at the tip of the blade for the 0.5 kg pommel!
It is there, believe me, you just need to "enlarge" the tip region in a (precise) drawing to see it. In other words: Increasing the weight of your sword by 50 % by a substantial pommel will not impair maneuverability very much (far less then 50 %) while giving you 30 % more "punch" for hits close to the tip region. That might well be worth the effort.

- We see once more the importance of optimizing the pommel or better yet, pommel and the rest of the hilt.

Far more could be said about pommel and hilt, followed by lengthy discussions of blade design (length, width, thickness, taper on thickness and width, number and length of fullers, cross-sectional geometry, ...) but I will have mercy on you (and me). I will just five your the results of extracting some data from the wonderful work in the "Solingen book".



Relation between the length of a sword and its rotational response
Large size version

What I did was to measure the angle of what I have called the "rotational response" in the drawing above. Then I plotted the length of the sword versus this angle; the result is shown above.
I did the same thing for the relation between the "rotational response" and the mass, the result is shown here.

- When I started this I had no idea of what I would get. What we see is very little correlation. For any given angle or length you care to select, there is wide range of length or angle values, respectively. The same is true for mass and angle values. What that tells us is

  - The "bandwidth" for optimizing your blade is rather large. You can obtain high agility for any reasoable length (or mass) if that's what you want.
  - You will have to pay a prize, however. If you go for extremes, some other properties will also get extremes. A great rotational response will always cost you impact power because your effective mass near the tip goes down (and vice verse), for example.

Summarizing in a somewhat superficial fashion, let me say this:

- One certainly *can* produce swords that have good masses, are well put together, employ good steel and other fine materials, and looks good - but they are definitely lousy swords. Just look at their "dynamical behavior diagram " and you shall see.
  Turner claims that quite a few replica swords out there are lousy in this respect (with percussion points in front of the tip, for example). I see no reason not to believe him but I cannot supply objective prove.
- One certainly *cannot* produce "the" superior sword. Any good sword is a compromise, emphasizing some properties at costs to others. Which compromise is best for *you*, depends on you. There is no "one sizes fits all".

[1] Vincent Le Chevalier; selected papers, all accessible via his home page or directly if links are given below:

1. "A dynamic method for weighing swords" November 15, 2014.
   The title is a perhaps a bit unfortunate because the article describes much more than "weighing" your sword. In essence, it discusses the important parameters of a sword, how to obtain them experimentally, and how they connect mathematically (lots of equations in the appendix). It also introduces the "two masses on a stick" model for simulating dynamics. It helps you to find the parameters of your sword that you need to supply for the:
2. On-Line weapons dynamics computer. You have to find it in the Net, the link may help.
3. Modelling impacts and damage. The article does exactly what the title says. If does so with equations on just a few pages.
4. Simulating Sword Properties. Explaining how the simulation program works and in particular some information about vibration modes computation.

[2] "**Solingen book**
""Das Schwert - Gestalt und Gedanke ("The Sword - Form and Thought"). Hrg.: Barbara Grotkamp-Schepers et al. The book to a special exhibition at the "Deutsches Klingenmuseum Solingen", Sept. 2015 - Feb. 2016.