A Dynamic Balance Primer

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Table of Contents

Hey! Skip the math!
just read page 12!!!

Overview

In early 1988, Garrett Brown asked Arnold DiGuilio to write an article for the summer 1988 issue of *The Steadicam Letter* on the real mathematics that describe a Steadicam's behavior.

For the past 15 years, Garrett and I have taught dynamic balance to hundreds of operators, and we have radically improved our practical methods and explanations.

Arnold's mathematics were complete and accurate. However, Arnold's wonderfully compact explanation left many non-mathematically inclined folks scratching their heads.

Many operators have never even seen this article, and a lot of confusion and misinformation still exist about dynamic balance today.

Therefore, it seems to be a good time to offer everyone in the Steadicam community a solid understanding of dynamic balance, including a full reworking of the basic physics and mathematics.

What is dynamic balance? How does one get a sled into dynamic balance? How important is dynamic balance? What are the real physics and mathematics that explain how a Steadicam behaves, both statically and dynamically?

This is an attempt to answer these questions in a reasonably full and complete manner.

First, we need some definitions to ensure we are all on common ground. Second, I will discuss – in some detail – the physics and mathematics of dynamic balance.

In the last section, I will describe a foolproof and easy way to get any Steadicam into good dynamic balance and a non-mathematical conceptual model of dynamic balance.

Although the math section is admittedly a chore to wade through, I believe all serious practitioners of "the art of Steadicam" will greatly benefit from a thorough understanding of the subject.

Definitions

A Steadicam is in **static balance** when, at rest, it hangs with the central post vertical, *regardless of the position of the gimbal on the central post*.

An exception: If the sled is perfectly balanced top to bottom, it won't hang vertically any more than it will hang at any other angle.

A Steadicam is in **dynamic equilibrium** if, when rotated about the central post, it pans consistently on that axis.

A Steadicam is in **dynamic balance** when it is in dynamic equilibrium and also in static balance. Both conditions must be met for dynamic balance.

Dynamic balance does not describe how fast or slow a Steadicam will pan when a force is applied. That is a separate – but related and important – subject of **inertia**.

A Steadicam can often be in static balance – i.e., it will hang perfectly upright – and not be in dynamic equilibrium, and therefore it will not be in dynamic balance.

In this condition, the rig will behave very oddly when it is panned. Prior to 1988, this is how Steadicams were routinely balanced (and designed!) because, in part, the Steadicam wasn't considered a quickly rotating object. Today, operators routinely do whip pans with rotational speeds in the order of 100 to 150 rpm's, and dynamic balance is critical for this type of work.

A minor note: It is possible for a Steadicam to be in dynamic equilibrium and not be in static balance. While this condition is possible to achieve on planet earth, it is useful only in outer space when the Steadicam is weightless.

Why is dynamic balance important?

As an operator, one wants to be able to frame shots with precision. Properly balancing the Steadicam increases the precision of one's operating.

If a Steadicam is out of dynamic balance, the operator constantly must make adjustments to keep the Steadicam level as it is panned. These adjustments reduce the precision of operating and can affect the quality or feel of the shot. The more the Steadicam is out of dynamic balance, the greater the corrective adjustments.

A Steadicam in dynamic balance will pan perfectly on its own, without constant adjustments by the operator. More precise pans and framing are the result.

Put another way, a Steadicam in dynamic balance will take full advantage of the excellent bearings and careful construction of the gimbal.

Dynamic balance fundamentals

Every component on the sled has a mass (or weight) and a position relative to all the other components. The major and most massive components are the battery, the monitor, and the camera.

Other components include the electronics, the junction box, the Steadicam's structural elements, and any accessories such as a small VCR, a receiver for follow focus control, or a video transmitter.

Each component has an effect on both static balance and dynamic equilibrium.

Each component also has an effect on the inertial quality, or "feel," of the Steadicam.

These effects can be represented mathematically, and a mathematical formula can be used to describe and/or find dynamic balance.

We can also use our understanding of the math to set up a rig and to test for dynamic balance empirically, without solving any equations.

Depending on the Steadicam model, the operator may have very few or a lot of choices in positioning the major components.

The operator first positions the major components in the best possible configuration for the shot, and then the operator balances the sled both statically and dynamically.

But before we get ahead of ourselves, let's first look at the forces that affect static balance and dynamic equilibrium.

Let's begin our discussion with two objects that are not Steadicams. This approach makes it easier to understand the concepts of static and dynamic balance.

Later we will examine a simple, three mass Steadicam, and we will use the math to put it into dynamic balance.

The physics and the math

The figures below, 1a, 1b, and 1c, represent an object with four weights on a common plane at the end of an axle, suspended by a gimbal. These weights are "coplanar."

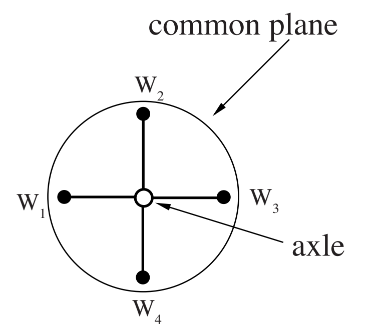


fig 1a (top view)

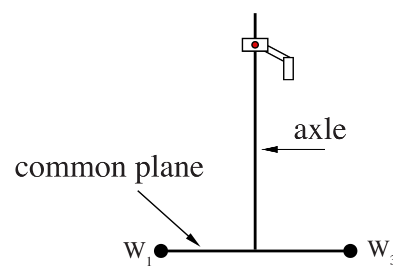


fig 1b (side view)

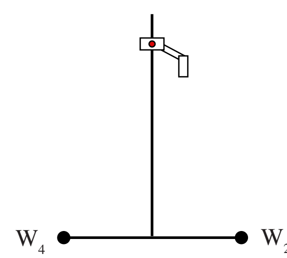


fig 1c (back end view)

If the weights $W_1 = W_3$ and $W_2 = W_4$ and the distances from the axle to the weights (the radii) are the same, it will hang vertically and be in dynamic balance. Sounds logical, but why?

Let's simplify further, and examine a two mass object suspended from the top of the axle and free to rotate and pivot. Figure 2a essentially represents a Model I Steadicam without a camera, hanging from its gimbal.

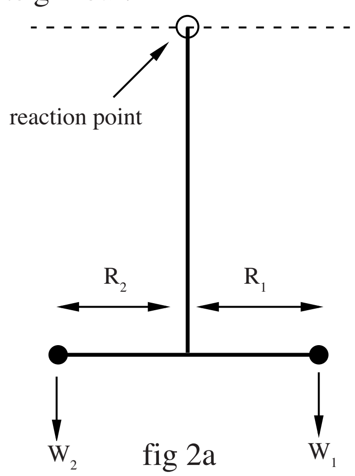


fig 2a

The down arrows represent the force of gravity acting on the object. If the object is not rotating, then the object will hang perfectly vertical if

(1) $\mathbf{W_1R_1 = W_2R_2}$

This is our basic formula for static balance.

Note: I am numbering the equations in **(blue type)** to make it easier to keep track of them. **Equations in red type** are the most important ones.

Also note: The force of gravity continues to affect the object as it spins.

If we spin the object, a second force is *created*. This force is the **centrifugal force**. See figure 2b.

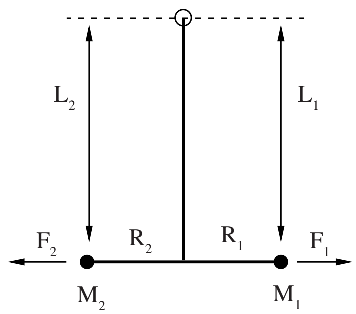


fig 2b

The formula for centrifugal force is

(2) $\mathbf{F = MR\Omega^2}$

where M is the mass of the object, R is the radius from the c.g. of the object to the axis of rotation, and Ω (Omega) is the angular velocity. A common unit for this is rpm.

The centrifugal forces, F_1 and F_2, pull the object in the direction of the arrows.

It is very, very important to understand that the centrifugal forces don't make the object rotate. The centrifugal forces are created because of the rotation, and these forces grow with the square of the rotational speed (Ω).

If the object was in static balance (i.e., $W_1R_1 = W_2R_2$), then it would be in dynamic balance if the *action* of the two centrifugal forces on the axle were equal, i.e.,

(3) $F_1L_1 = F_2L_2$

The equation is not $F_1 = F_2$. How much a centrifugal force tilts the axle depends upon how far away from the pivot – or reaction point – the force is applied to the axle.

Here is a practical way to demonstrate why the distances to the reaction point (the L_1 and L_2 of figure 2b) matter:

Balance your Steadicam statically. Take your finger and poke it at the gimbal, just below the bearings. This is close to the reaction point – and the force has little effect on the rig.

Using the same amount of force, poke the rig far from the gimbal. Big effect!

Hey, that's leverage for you, and why we use F times L in our formulas.

We need to assign a convention to the way these forces act on the object.

We will call the forces "positive" if they tilt the object "up" as in figure 2c.

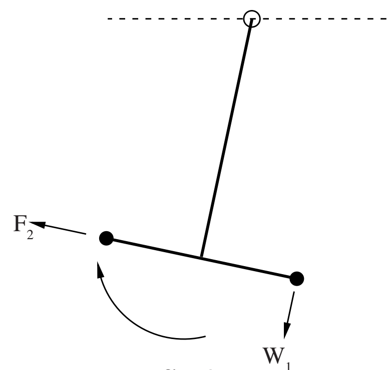


fig 2c
"positive" forces

We will call the forces "negative" if they tilt the object "down," as in figure 2d.

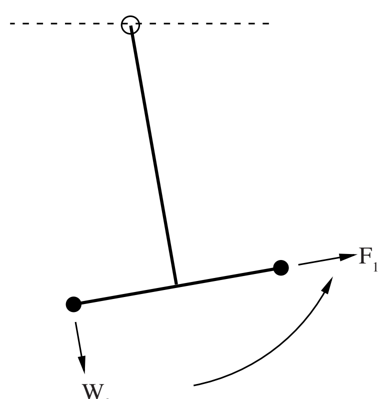


fig 2d
"negative" forces

Note: In the real world, we would have to run around the object as it rotated to maintain the "side view" in all these diagrams.

If all the forces that are "positive" equal all the forces that are "negative" then the object won't tilt as it is rotated, i.e., it will be in dynamic equilibrium. The formula:

(4a) $\mathbf{F_2L_2 + W_1R_1 = F_1L_1 + W_2R_2}$

Substitute $MR\Omega^2$ for F

(4b) $(M_2R_2\Omega^2)L_2 + W_1R_1 = (M_1R_1\Omega^2)L_1 + W_2R_2$

Because mass and weight are proportional, we can substitute weight for mass and get

(4c) $\mathbf{(W_2R_2\Omega^2)L_2 + W_1R_1 = (W_1R_1\Omega^2)L_1 + W_2R_2}$

We will come back to formula 4c, the basic formula for dynamic equilibrium, again and again.

Before we move on, take a look at figure 2e.

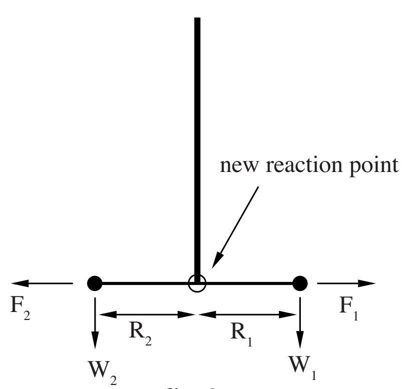


fig 2e

We've moved the reaction point down to the horizontal plane of the two weights.

Now the L's = zero, and therefore these centrifugal forces will not tilt the Steadicam, *even if they were unequal!!*

Mathematically, if L_1 and L_2 equal zero, then (4c) becomes

(4d) $(W_2R_2\Omega^2)0 + W_1R_1 = (W_1R_1\Omega^2)0 + W_2R_2$

which becomes

(4e) $W_1R_1 = W_2R_2$

In figure 2e, both F's are in the same horizontal plane. The object would tilt only if the static forces, W_1R_1 and W_2R_2, were unequal.

Now let's examine another object with 2 masses, but this time the masses are not coplanar. Figure 3a essentially represents a Model III Steadicam with a raised monitor and no camera attached.

Note that I've also changed the two radii, just for fun.

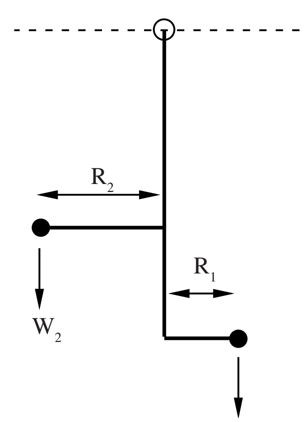


fig 3a

If this object is stationary, it will remain vertical if the static forces are equal.

This is our old formula,

(1) $W_1R_1 = W_2R_2.$

Note that static balance does not change no matter how much W_2 is raised above W_1. There are no "L's" in the formula for static balance.

Figure 3b represents the centrifugal forces acting on this object.

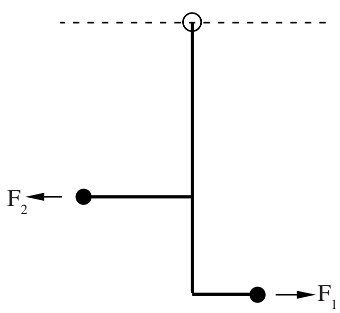


fig 3b

Look at the next three diagrams. Figure 3c represents all the "positive" forces.

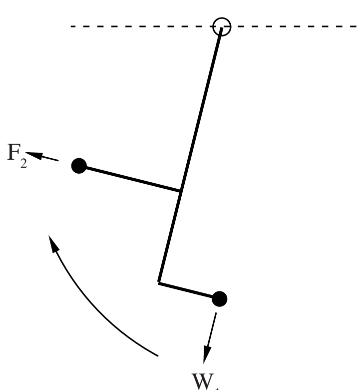


fig 3c
"positive" forces

Figure 3d represents all the "negative" forces.

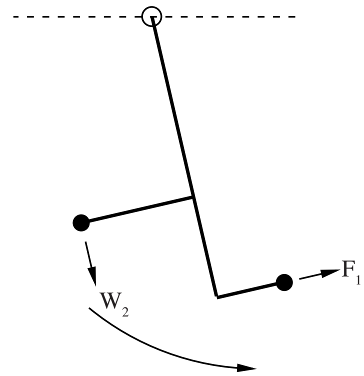


fig 3d
"negative" forces

Figure 3e represents all the forces and factors relevant to dynamic balance.

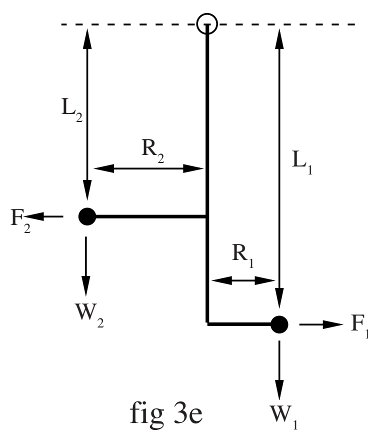


fig 3e

This object will be in dynamic equilibrium if

(4a) $F_2L_2 + W_1R_1$
$= F_1L_1 + W_2R_2$

But it can't be. Why?

Remember $F = MR\Omega^2$, and substituting W for M, we get

(4c) $(W_2R_2\Omega^2)L_2 + W_1R_1 = (W_1R_1\Omega^2)L_1 + W_2R_2$

If it is in static balance, $W_1R_1 = W_2R_2$.

Thus, equation 4c becomes

(4f) $(W_2R_2\Omega^2)L_2 = (W_1R_1\Omega^2)L_1$

Note that all the terms on one side of the equation are equal to the terms on the other side *except L_2 and L_1*.

Because L_2 is less than L_1, $(W_2R_2\Omega^2)L_2$ must be less than $(W_1R_1\Omega^2)L_1$, and therefore equation 4f cannot be satisfied.

This means if our two mass object has its masses on different horizontal planes, *it can not be in dynamic equilibrium if it is in static balance*.

But – thank goodness – a three (or more) mass object with masses on different horizontal planes, such as a Steadicam – can be balanced dynamically.

It's time to examine a simple three mass object – an object similar to a good old Model III Steadicam with a camera attached.

We will call the masses by name (camera, monitor, and battery) and look at the forces affecting the Steadicam both statically and dynamically.

Figure 4a represents our simple Steadicam and the various forces and factors that would act upon it.

It is drawn with the camera c.g. to the right of the central post, but we don't really know yet where to place the camera.

Just as with our two mass object, to be in static balance, the static forces must cancel each other out, i.e., add up to zero. Remember which forces are "+" and which are "–."

(5) $-W_mR_m + W_bR_b + W_cR_c = 0$

Just as with our two mass object, all the forces must add up to zero if it is in dynamic equilibrium.

(6a) $F_mL_m - W_mR_m - F_bL_b + W_bR_b - F_cL_c + W_cR_c = 0$

or, substituting $WR\Omega^2$ for F,

(6b) $(W_mR_m\Omega^2)L_m - W_mR_m - (W_bR_b\Omega^2)L_b + W_bR_b - (W_cR_c\Omega^2)L_c + W_cR_c = 0$

That's a lot of variables!

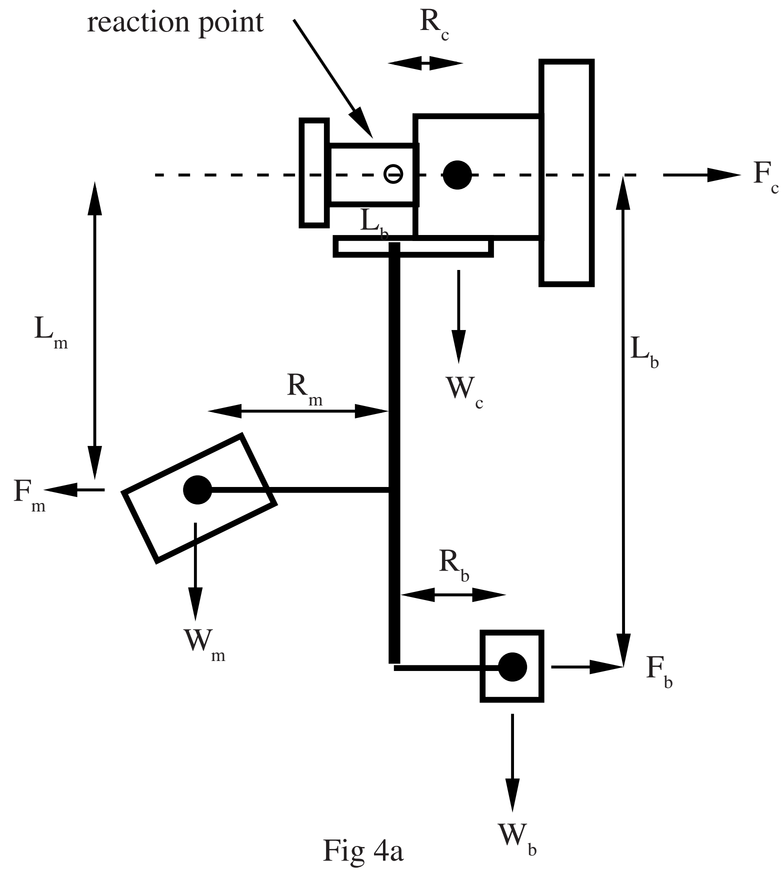


Fig 4a

However, if we choose our reaction point carefully, we can solve the equations.

Our first step is to make the reaction point at the same horizontal plane as the camera c.g., as in figure 4a.

Now, $L_c = 0$. Therefore, $(W_cR_c\Omega^2)L_c = 0$. And if the object is in static balance, $-W_mR_m + W_bR_b + W_cR_c = 0$.

So we can remove both "zero" elements from equation 6b and get equation 7a.

(7a) $(W_mR_m\Omega^2)L_m - (W_bR_b\Omega^2)L_b = 0$

or, expressed another way,

(7b) $(W_mR_m\Omega^2)L_m = (W_bR_b\Omega^2)L_b$

Since Ω^2 appears in both terms, we can eliminate that as well, and we get

(7c) $(W_mR_m)L_m = (W_bR_b)L_b$

Note that equations 7a, 7b, and 7c have no factors that depend on the camera weight or radius!!

This means that the proper placement of the monitor and the battery (the terms of equation 7c) will not change, regardless of the weight of the camera. They only depend on L_m and L_b, which are related to the vertical position of the c.g. of the camera.

We will first use equation 7c to find where to place the battery radius (R_b), and then we can solve equation 5 to find the camera radius (R_c).

Note: We could use equation 7c to solve for any of the variables, but there's a reason we generally use equation 7c to solve for R_b.

On page 3 we said, "The operator first arranges or positions the major components to the best possible positions for the shot, and then the operator balances the sled both statically and dynamically."

So let's try an example: First we weigh the camera, battery, and monitor, and we determine the position of their respective c.g.'s.

Next we choose the monitor radius and length for viewing and inertial purposes.

Then we choose the battery length because we need the sled to be a certain length (for instance, we want the lens high so we make the sled longer).

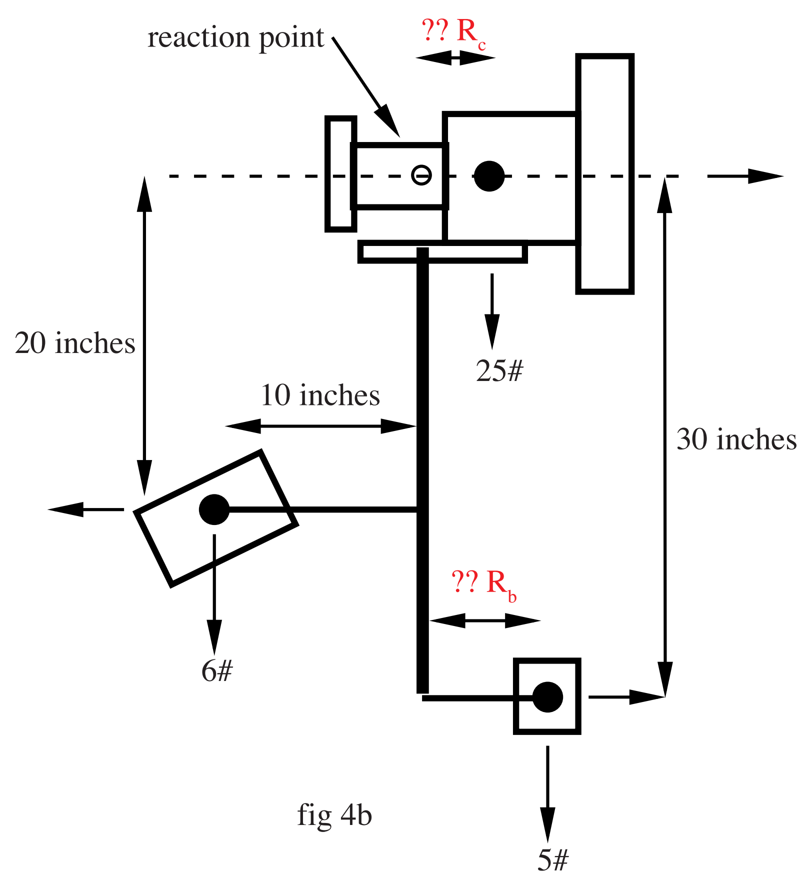


fig 4b

To finally put the Steadicam into dynamic balance, we need to find the battery radius and the camera radius. We first find R_b by solving equation 7c.

Then we can substitute the value of R_b into equation 5, and we can calculate the required value of R_c.

When the battery and the camera are set to these values, the Steadicam will be in perfect dynamic balance.

Remember, the reaction point may be moved anywhere on the axis of the post without disturbing dynamic balance.

To illustrate, let's assign some values. These are values that are fixed, or values that we can determine by choice.

Values that are fixed

W_c = 25#
W_m = 6#
W_b = 5#

Values that we can choose to some extent (depends on our Steadicam, of course)

L_m = 20 inches
L_b = 30 inches
R_m = 10 inches

See figure 4b.

First, we use equation 7c to find the battery radius (R_b).

(7c) $(W_b R_b)L_b = (W_m R_m)L_m$

(7d) $R_b = \dfrac{(W_m R_m)L_m}{(W_b L_b)}$

$R_b = \dfrac{(6 \text{ x } 10) \text{ x } 20}{(5 \text{ x } 30)}$

$R_b = $ 8 inches

Now we can use equation 5 to find the camera radius (R_c).

(5a) $-W_m R_m + W_c R_c + W_b R_b = 0$

(5b) $W_c R_c = W_m R_m - W_b R_b$

(5c) $R_c = \dfrac{W_m R_m - W_b R_b}{W_c}$

$R_c = \dfrac{(6 \text{ x } 10) - (5 \text{ x } 8)}{25}$

$R_c = $ 0.8 inches

If we set R_c to 0.8 inches, and we set R_b to 8 inches, the Steadicam will be in both static balance and dynamic equilibrium, i.e., in dynamic balance.

Now that we've solved equations 7c and 5, we can demonstrate that moving the reaction point has no effect on dynamic balance.

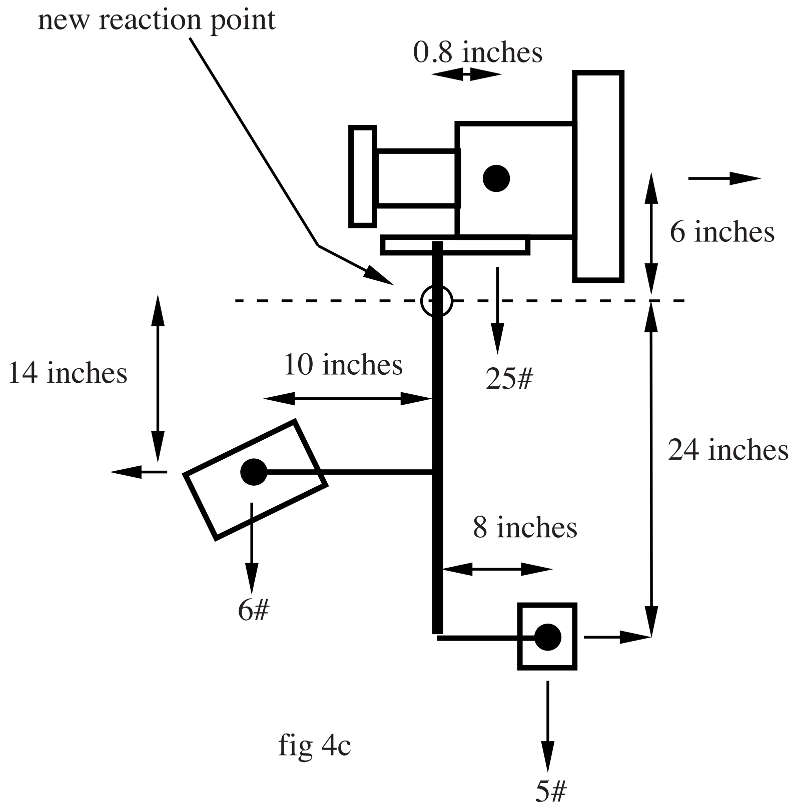


fig 4c

As an example, let's move the reaction point six inches lower down the post, to where a gimbal might be placed. See figure 4c.

We start by restating the equation 6b, our formula for dynamic equilibrium:

(6b) $(W_m R_m \Omega^2)L_m - W_m R_m - (W_b R_b \Omega^2)L_b + W_b R_b - (W_c R_c \Omega^2)L_c + W_c R_c = 0$

Again, if it is in static balance, the static terms equal zero. The Ω^2 appears in each remaining term, so we can eliminate Ω^2, and we are left with equation 8.

(8) $(W_m R_m)L_m - (W_c R_c)L_c - (W_b R_b)L_b = 0$

Dropping the reaction point six inches means that now

$L_m = 14$, $L_c =$ *minus* 6, and $L_b = 24$

Substituting these values into equation 8, we get

$(6 \text{ x } 10) \text{ x } 14 - (25 \text{ x } 0.8) \text{ x } (-6) - (5 \text{ x } 8) \text{ x } 24 = 0$

or

$840 + 120 - 960 = 0$

Which demonstrates that the Steadicam will remain in perfect dynamic balance, regardless of where we place the gimbal on the central post.

We have now discussed all the basic physics and mathematics that we need to understand dynamic balance.

But if we want a better mathematical model, all the major masses should be accounted for in the equations.

The Steadicam of figure 4c is only a three mass object. We have not accounted for the electronics, or the J-box, or the structure of the Steadicam, or any accessories we might add to the sled.

Each of these masses has a static effect and, when the Steadicam is rotated, each mass creates a centrifugal force. In figure 5a, we are illustrating what happens when just two more masses are added to the structure.

In our convention of plus and minus forces, a mass forward of the post (like the monitor) will have a positive centrifugal force and a negative static force. A mass added to the rear (like the battery) will have a negative centrifugal force and a positive static force.

As depicted in figure 5a, the focus motor receiver has a positive F_f and a negative W_fR_f. The electronics package has a negative F_e and a positive W_eR_e.

Each force must be added into the two balance equations.

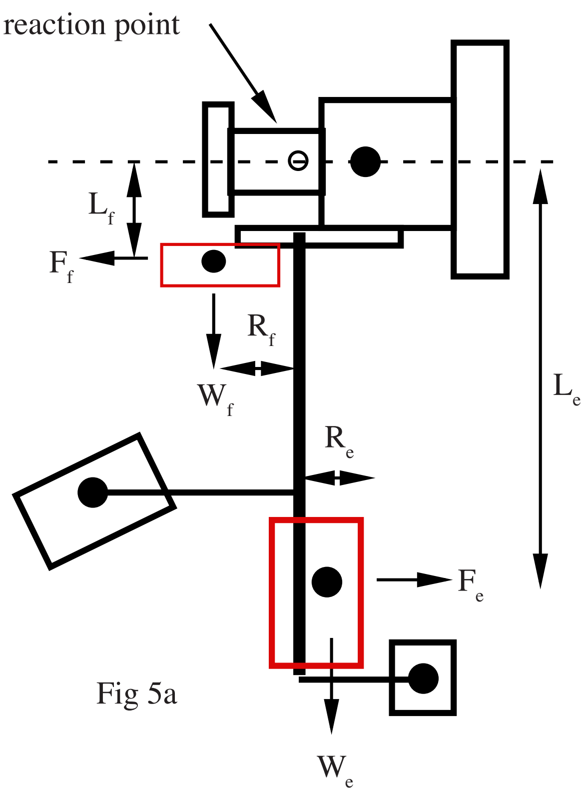


Fig 5a

Reworking our static formula (5) to account for the focus receiver and the electronics, we now get

(9) $-W_mR_m + W_bR_b + W_cR_c - W_fR_f + W_eR_e = 0$

and our dynamic equilibrium formula (6a) becomes

(10) $F_mL_m - W_mR_m - F_bL_b + W_bR_b - F_cL_c + W_cR_c + F_fL_f - W_fR_f - F_eL_e + W_eR_e = 0$

We would solve these equations in the same manner as before, by starting with equation 10 and assuming the sled is in static balance. We would then remove the static elements and substitute $MR\Omega^2$ for F, and W for M.

Again we would solve the equations for the proper battery radius, and then use that value in equation 9 to solve for the camera radius.

If we want to sufficiently model the Steadicam, we should account for the J-box of the Steadicam, significant structural components, and every accessory we might add or remove. For instance, the Ultra's computer program accounts for five major components, any camera, and three accessories.

It's clear that solving these equations quickly becomes a nightmare, unless one has a computer program.

Some practical limitations

Our mathematical model is rather simple, and doesn't account for many things, including wind effects, or the uneven distribution of mass in a given object. For instance, not all internal parts of a monitor have the same density, so the monitor doesn't behave *exactly* like a tiny, very dense mass at the c.g.

The key thing to remember is that our formulas are only a model of reality.

So why did we just go through all that math?

Because the math clearly describes the major forces affecting dynamic balance.

Because over the last 15 years, this model has been proven to be an extremely useful tool. In spite of its simplicity, the model works extremely well in practice, where it all matters.

For instance, using the math (and a Palm Pilot™ computer to solve the equations), one can generally place the battery within .25 inch of the ideal position. A quick spin test can fine tune the system to the needed degree of precision.

But that's only one minor reason that the math and theory are important.

Without measuring or weighing anything, or solving any equations, our understanding of the math can make our life – both on and off set – much, much easier.

If we understand the basic theory, we can quickly and easily position the sled components very closely to a condition of good dynamic balance.

We also can use our knowledge to closely predict what changes we need to make if we move a major component, or if we add an accessory, change lenses, or tilt the monitor, etc.

We can use the theory to know that after moving a component, all we ever have to do to get back into dynamic balance is to move the battery in or out a bit, and then static balance with the camera.

We can use the theory to know how to add or place components on the sled where it doesn't make it difficult or impossible to get the sled into dynamic balance.

We can use the math to understand why a given camera will always be placed in a very narrow range of positions.

We can use the math to avoid tests and procedures that are irrelevant or wasteful of our time and energy.

If we have a sled that allows us many choices in the configuration of major components, we can use the math to make a setup chart for various modes – long, short, medium length, monitor high or low, monitor extended, with and without a VCR attached, etc. We can use the chart to quickly get the sled very close to dynamic balance.

If we have a sled with relatively few choices in the configuration of major components, we can use the math to discover how to add accessories in a manner that will continue to make it possible to achieve dynamic balance.

If we have some sort of customized hybrid conglomeration of parts, we can check to see if this sled can get into dynamic balance in all its configurations, or if we should go back to the shop and make some new parts.

We can use the math to understand why dynamic balance in low mode can be just as easy to achieve as dynamic balance in high mode.

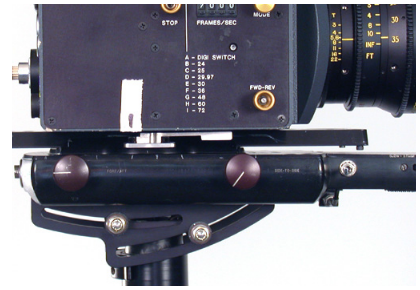
And that's just a start....

A simple, empirical method to get any Steadicam into dynamic balance

Mount the camera to the dovetail, and add all lenses, mags, film, motors, etc., to the camera. Mark the fore-aft c.g. position.

Position all the components on the sled, making sure they all line up in a single *vertical* plane fore and aft, i.e., don't add components to the side of the sled.

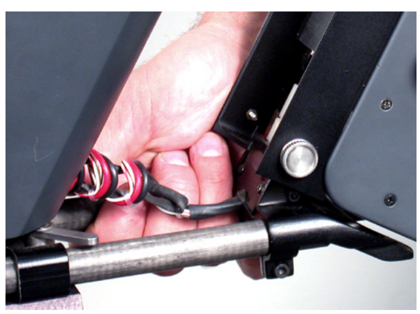
If you have a choice, make the sled the length you want. Position the monitor high or low, and/or in or out, to the best possible advantage for the shot.



Mount the camera to the stage, and slide the camera so that the camera c.g. is about .75 inch to the rear of the centerline of the central post.

Place the gimbal on the balancing stud of your stand and balance top to bottom so that you have a relatively long drop time, say 3 to 4 seconds.

Balance precisely side to side by moving the camera.



Balance fore and aft as best as you can using *the battery*. This is very important.

Now fine tune the fore and aft balance using the camera.

Be sure to get the rig into very good static balance, both side to side and fore and aft.

Give it a few spins, but not too fast a spin, say 20 to 40 rpm to start. If you are close to dynamic balance, you can spin it as fast as you want.

If it's not in acceptable dynamic balance, move the battery in or out about .25 inch. Static balance with the camera and try again. Is it better or worse? Change it again until your rig pans consistently on the axis of the post.

Done.

A good tip: make a note of the camera radius, and the procedure will be even faster the next time.

This whole balancing process should take about two minutes. Do not spin the camera at excessive speeds and do not fuss too much.

If you change lenses, add focus motors, etc. to the camera, the sled will be out of dynamic balance, but usually only very, very slightly. Moving the camera fore and aft to restore static balance will keep you in good dynamic balance. Why?

The placement of the battery only depends on the vertical distance of the components to the c.g. of the camera (as in formula 7d), not on the camera's weight or radius.

$$(7d) \quad R_b = \frac{(W_m R_m) L_m}{(W_b L_b)}$$

Changing lenses or adding focus motors, glass filters, etc. usually doesn't change the vertical c.g. of the camera very much; therefore it will not affect the proper placement of the battery very much either.

We can easily determine where to place the "altered camera" by static balancing on the stand. Note that the math we would use to determine the camera radius, formula 5c, is an expression of static balance.

$$(5c) \quad R_c = \frac{W_m R_m - W_b R_b}{W_c}$$

Now let's look at a simple, non-mathematical model for understanding dynamic balance.

Figure 6a looks like the Model I or the SK. The camera c.g. is centered over the post; the monitor and battery are on the same horizontal plane, and their *common* c.g. – the red dot – is under the post. This unit is in dynamic balance.

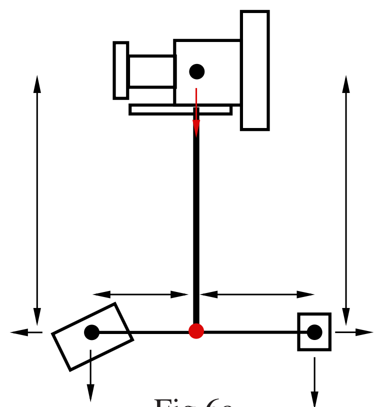


Fig 6a

In figure 6b, the monitor radius remains the same, but the monitor raised a bit.

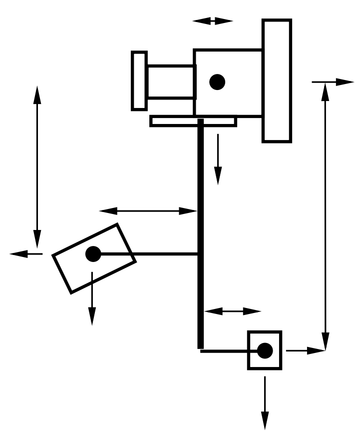


Fig 6b

Figure 6b looks like a Model III in dynamic balance. The battery c.g. is closer to the post, and the camera c.g. has moved to the rear.

Why?? See the third figure.

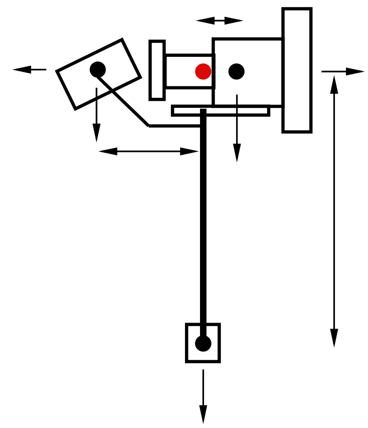


Fig 6c

In figure 6c, the monitor has been raised all the way up in front of the camera. The *common* monitor and camera c.g. – another red dot – is now over the post, the battery's c.g. is under the post, and this Steadicam also is in dynamic balance.

Figure 6c is an absurd arrangement, of course, but it makes a point. As the monitor is raised, the camera c.g. must move to the rear and the battery c.g. must move towards the post.

A rule of thumb: If the monitor is raised about 25 to 30 percent of the way up from the battery level, the camera c.g. will be about .75 inch behind the centerline of the central post, more or less.

What to do if we make the sled longer or shorter?

Assume we have a sled in dynamic balance. If we extend the sled by moving both the battery and monitor away from the camera, we create a new situation. It is useful to think in terms of how much – percentage wise – the monitor is raised above the battery.

As in figure 6d, the monitor is raised by *a smaller percentage of the total distance* from the battery to the camera than before. Therefore, the battery will be more to the rear, and the camera moved forward.

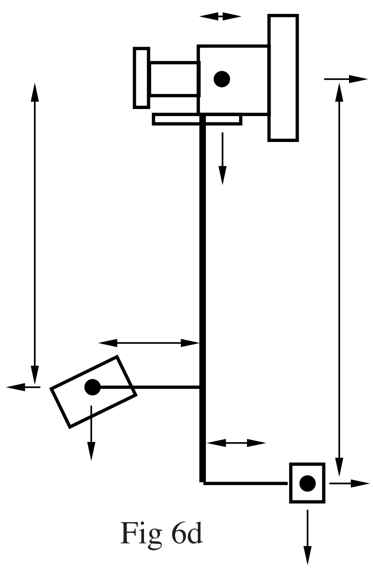


Fig 6d

If we shorten the rig (or just raise the monitor), the monitor is raised *a greater percentage of the total distance* from the battery to the camera. Therefore the battery will be moved forward, and the camera further to the rear, as it is in figure 6e.

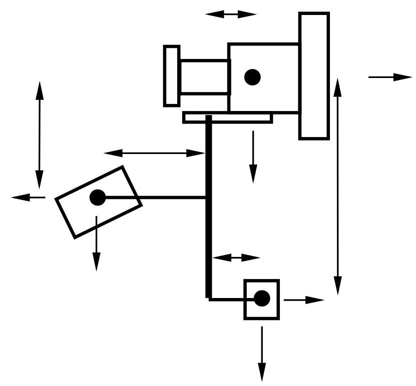


Fig 6e

What to do if we add accessories?

Our simple method of getting a rig into dynamic balance, the non-mathematical conceptual model on page 13, and our mathematical model all attempt to place the battery in the right position as the first step to get a rig into dynamic balance.

Therefore, when I add an accessory, I like to think of how the placement of the accessory will change how much "work" the battery must do to achieve dynamic balance.

Thus, if an accessory is added in front of the post, the battery must "work harder" to counteract this mass and its forces, and I would move the battery more to the rear. See figure 6f. Also, the lower the accessory is placed, the harder the battery has to work.

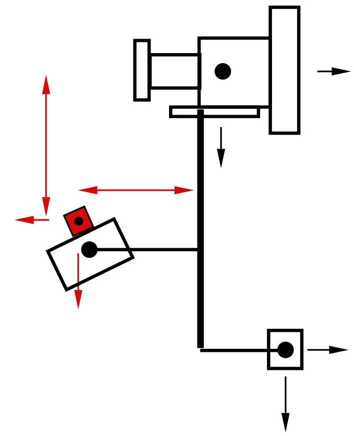


Fig 6f

If an accessory is added behind the post, as in figure 6g, it "helps" the battery do its work.

Therefore I would move the battery forward before I would static balance with the camera and spin test for dynamic balance.

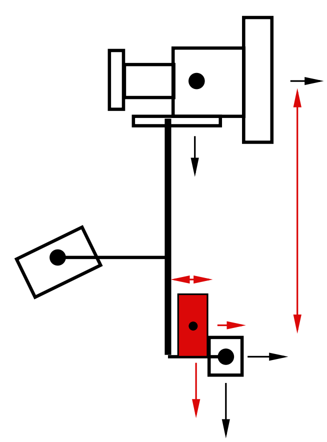


Fig 6g

Using a dynamic balance program

A computer program for dynamic balance is a great educational tool. It will show *exactly* what happens to the battery and camera radii when any specific change is made to the sled. It will demonstrate which changes make a lot of difference, and which do not.

A good dynamic balance program can also help an operator get the rig into dynamic balance quickly, regardless of the many possible configurations of the rig. A good program accounts for all the major masses of the Steadicam, any camera, and for many accessories.

As the Steadicam is reconfigured on set, the operator only has to take three new measurements (at most), and the computer determines the exact placement of the battery and the camera. Spin balancing is generally unnecessary, which is really great if you flip to low mode and lengthen the sled.

Some things not to do if you want your sled to be in dynamic balance

Do not add components to the side of the rig, and do not balance side to side using anything other than the camera mounting stage. Why?

Take another look at figure 7a (the same figure as 1c).

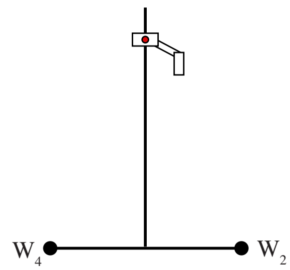


fig 7a (back end view)

The components W_2 and W_4 can represent accessories mounted on each side of a sled. The forces they generate act to tilt the post *sideways*, not fore and aft like all the others we have been discussing. W_2 and W_4 create an entire new set of forces that must also be equal, just as the "fore and aft" forces have to be equal for dynamic balance.

While it is possible to do the math (with a computer, of course) to determine where to position the battery and camera, it is quite difficult to determine empirically what to do. Should one move the battery – and/or the camera – side to side to correct a problem, or fore and aft, or some combination of the two? There is no way to know.

Worse yet – for dynamic balance – is to balance side to side with the battery. Assuming the other rig components are nicely organized fore and aft, if the operator balances side to side with the battery, it means that the camera c.g. was displaced to the other side for static balance. See figure 7b.

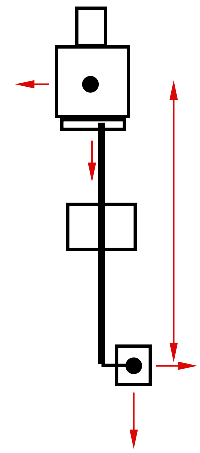


fig 7b (back end view)

We have created a situation identical to that of figures 3a through 3e. We've already shown that this arrangement of masses *cannot* be in dynamic equilibrium if it is in static balance, i.e., it can not be in dynamic balance. (See pages 5 and 6.)

The Model I, II, and III Steadicams "wagged" their batteries side to side. If one was lucky, the camera was mounted on the dovetail so that the camera's c.g. was close to the axis. But from the perspective of dynamic balance, it wasn't a good design.

A static test for dynamic balance?

Alas, it can not be done. The centrifugal forces are not created until the rig is rotated. All static tests – no matter how finely conducted – can only account for static forces. If you don't spin it, the centrifugal forces don't exist. How else can I say it? For instance, if you lay the sled horizontally, the test (fig 8) is exactly like the static test of figure 2e. (See page 5.)

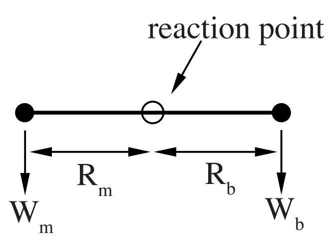


fig 8 (back end view w/ horizontal post)

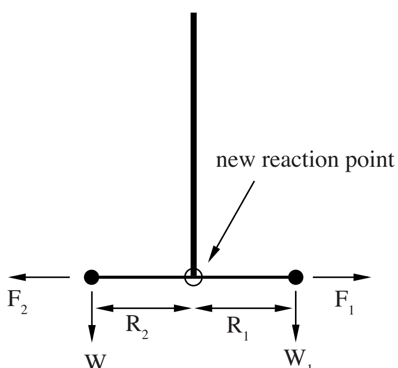


fig 2e (side view)

If a static test "works," it is only because the rig is in a unique configuration, with the monitor and battery on the same horizontal plane.

Additionally there must be either no other components on the sled, or only pairs of components carefully balanced on the same horizontal plane. *The simple procedure on page 12, however, works with any Steadicam in any configuration.*

Trimming for headroom

Operators should always use the balance of the Steadicam to get a shot.

Often we deliberately move the camera to set the sled at some angle other than vertical. If the shot has only slow pans, the centrifugal forces are small, and it may be far more important to have the sled hang at a given angle than to be in dynamic balance.

On the other hand, try this test. Get your rig into perfect dynamic balance on the stand. Then move the camera forward to tilt the sled (and the camera) a few degrees and give it a good spin. What happens? The rig behaves very strangely, very quickly.

If you want to angle the camera up or down and also remain in dynamic balance, you need either an integral tilt head or a wedge plate. See the Ultra Manual for more information about an integral tilt head.

Tilting the monitor

Try this test: Get the rig into perfect dynamic balance on the stand, then tilt the monitor and spin it again.

Unless the monitor tilts on its c.g., both the L_m and the R_m of the equations have changed, and the sled will no longer be in dynamic balance.

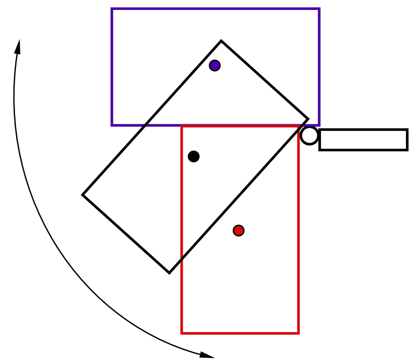


fig 9
tilting a Model III monitor

Try the test with the sled both very long and short. What happens now?

This monitor tilts close to its c.g., so that tilting it has very little effect on the dynamic balance of the sled.

Conclusion

Dynamic balance is important for precise operating.

A solid conceptual understanding of dynamic balance will help the operator get any Steadicam into dynamic balance quickly and efficiently, *without doing any math*.

It will also make it easy to get the Steadicam back into dynamic balance if any changes are made to the configuration.

Understanding dynamic balance – what it is, what it is not, and its practical limitations – will also help the operator decide how important dynamic balance is in any situation.

Understanding and using the math not only helps conceptually, but, with the aid of a handheld computer, it can be an extremely useful tool on set.

The math is also crucial for those who modify their equipment and want to be able to get their rigs in dynamic balance in all possible configurations.

It is my hope that this document will help operators everywhere understand this important subject.

Jerry Holway,
April 1st, 2003

A couple of extra things

Here is a quick and easy method (no math!) for getting your sled into dynamic balance when the monitor is displaced sideways, or you want the camera facing a direction other than forward.

The conceptual trick is to think in terms of all the c.g.'s – the black dots of our diagrams. In our model, the orientation of any particular part does not matter, nor does it matter what shape it is. We are only interested in the mass of the object and the position of the c.g.

All one has to do is to keep the c.g.'s in one vertical plane, (as we always should do) and the Steadicam easily can be put into dynamic balance.

Which is to say, keep the battery directly behind the monitor, and aim the camera in any direction you choose. Start by placing the camera c.g. about .75 inch behind the post ("behind" the post is always in the vertical plane of the battery and monitor). Balance as described on page 12.

It's easier to operate if the monitor and camera face in the same direction or exactly 180˚ from each other.

A fun thing to do

Put your sled into perfect dynamic balance, then place the gimbal so that the sled is neutrally balanced top to bottom. Now the sled will hang at any angle and still spin consistently on the axis of the central post.

This is even more fun if the sled is very long, as you can set the rig panning and also gyrate the whole thing in huge arcs.

You can move through space at the same time, and the Steadicam becomes a really elegant and magical object.