Aileron Flutter:

My man-on-the-street, seat-of-the-pants understanding of aileron-flutter is based upon an understanding of Simple Harmonic Motion (SHM). SHM results when an object (a mass 'm') experiences zero applied force at an equilibrium position, but when displaced experiences a restoring force that tends to push the mass back into its equilibrium position. To qualify as SHM this force must also be proportional to the displaced distance. Think of a fisherman's scale. Hang a 5# fish on the scale and it will sag to a rest position. If you pull it down the fish will bounce back up. If you lift the fish and release it, it will sag back down. In both cases the fish will bounce around a bit before an accurate weight is displayed. The weight-number-graduations on the fishermen's scale are all equal sized. So the bouncing fish exhibits SHM. It is said to be "simple" because the mathematics describing the motion can be easily derived and basic trigonometry can be used to provide even more information about the motion. The basic equation describing SHM is F = -k m, where k is a stiffness number of the spring. It can be shown that the Period T of the motion (the time for one bounce) can be calculated

Simple Harmonic Motion

Because $\omega = 2\pi f = \sqrt{k/m}$, **then**

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}},$$

$$T = 2\pi\sqrt{\frac{m}{k}}.$$

The above description of SHM applies to linear motion. However, Aileron-flutter is a Torsional-Vibration, and requires an altered set of equations. In general, when converting mechanical equations describing linear motion to equations describing rotational motion, distances are measured in angles (either degrees or radians) and often labeled with the symbol θ. Mass is replaced with the symbol ***I*** that represents the rotational inertia of the object. (***I*** is often difficult to determine but it is almost always some multiple of mass multiplied by the square of its distance from the axis or rotation).

A fine example of an object experiencing rotational oscillations would be the time-keeping balance-wheel in an old-fashion wind-up alarm clock. The balance-wheel has nearly all its mass concentrated on the rim of the wheel, so it has an ***I*** value of $\mathbf{m\ r^2}$. The spiral 'hair-spring' has a torsional spring stiffness-constant of k which represents how much torque is required to rotate it a given angle from its rest position. So the period of oscillation of an alarm-clock balance-wheel is given by the equation

$$T = 2\pi\sqrt{\frac{I}{K}}$$

You can see that increasing the Inertia of the wheel will increase the period of oscillation, This can be accomplished either by increasing the size of the wheel, or increasing its mass. Using a stiffer spring will cause the time for once oscillation to be smaller.

An aircraft aileron is in many ways similar to an alarm-clock's balance wheel. When properly rigged in flight, it rests at an equilibrium position. If the aileron experiences a rotational displacement from its equilibrium position, it tends to return to equilibrium. Greater deflections involve greater torque on the ailerons. The torques involved (the rotational forces) come from the air-pressures exerted on the airfoil and from the linear tensions of the control cables and associated hardware.

So let us now look at what happens when an aircraft experiences aileron-flutter.

Let' assume an aileron has started to flutter. A transient in the air-stream has pushed up/down on the aileron, rotating it out of its equilibrium position, This action stretches the control system, storing energy in the cables which are acting as springs. This energy is then released back into the aileron, returning the aileron to the equilibrium position but its kinetic energy causes it to continue rotating past the rest position and storing energy in the opposite manner as moments before. The process then continues as before with the torques, tensions, and rotations in the opposite directions. The flutter repeats.

So how is an instance of aileron-flutter stopped? Well in general, aileron-flutter is stopped by friction. Aileron flutter stops when the combination of parameters contributing to the flutter are changed so the the energy involved in the flutter becomes less than the damping forces in the environment. Basically, the friction in the hinges, cables, and control system exceeds the energy of the oscillations of the fluttering aileron.

Most aileron flutter occurs at high speeds. My guess as to why this occurs is that turbulent flow over the airfoil has insufficient energy at low speeds to induce flutter. The burble in turbulent airflow can also exhibit a form of resonance, depending on the airfoil contour, angle of attack, and atmospheric conditions, etc. Most severe aileron flutter will occur when the frequency of the airflow burble matches the resonant frequency of the aileron when experiencing torsional vibration.

So what can the experimental aircraft builder do to minimize flutter?

Here is a partial list of theoretical things we could do (not all options are possible or sane choices):

- Do what car-manufactures do to car suspensions ... Put shock absorbers on the ailerons that can soak up energy hydraulically and dissipate it as heat.
- Make very very stiff hinges and control-systems that use added friction to soak up energy (That's what keeps your throttle-quadrant from vibrating all over the place)
- Add electronic sensors and electromagnetic actuators to counteract unwanted vibrations (Done by Japanese to dampen shaking sky-scrapers during earthquakes)
- **Alter the size/materials/design of your ailerons so that normal operations and typical construction methods provide an energy-sink for any flutter that might be produced.**

Most builders choose not to mess much with the control systems for their ailerons, other than making sure that control cables are adequately tensioned and no free-play exists in the system. In general, pilots prefer a light-touch on their aileron-controls so friction is minimized whenever possible.

Builders experiencing flutter generally choose to alter the weight-balance of the ailerons themselves to remedy the problem.

Each aileron has a center of gravity (CG) which behaves in many ways the same as the CG of the aircraft itself.

Bearhawk ailerons are attached to the wing using a hinge system in which the axis of rotation is not at the extreme front of the aileron; the aileron does not swing from the back of the wing like a door on a hinge. Instead, a rather sophisticated aileron hinge is mounted to the aileron-spar which is located a substantial distance back from the leading-edge of the aileron (near the thickest part of the aileron's airfoil). This hinge location is still forward of the aileron's CG (the aileron CG is behind the hinge) giving the aileron the tendency to hang down toward the ground. A similar configuration on an aircraft's horizontal stabilizer causes the control-stick to flop forward. But since left and right ailerons are cross-connected with control cables, the weight of the ailerons is balanced by the opposite aileron and the effects of the unbalanced ailerons in not felt on the control stick.

Most builders choose to control flutter by changing the mass and/or mass distribution of their ailerons. Reducing mass of an aileron to control flutter would be an attractive option in an aircraft, but in a weight optimized airframe there is typically no mass to be removed. So builders typically add mass to the leading-edge of their ailerons.

Lets say we follow the standard procedures used by almost all builders; we will attempt to totally balance a misbehaving aileron. We will add mass to the leading edge of the aileron until the CG of the aileron moves forward to the rotational axis of the aileron (the fulcrum of a balanced aileron lines up with the hinge-pins). This method seems to always work....

If balancing ailerons eliminates aileron-flutter, the question I have is "Why does it work?"

Well for one thing, if ailerons are balanced, each aileron is balanced on its own. There is no interaction between ailerons; the weight of each aileron is not held in its equilibrium position by the weight of the the aileron on the other side of the aircraft; control-cable tension and aileron interaction is taken on of consideration to some degree.

Secondly ... I mentioned that aileron-flutter occurs when the frequency of air turbulence approximately matches the resonant frequency of the aileron vibrating in torsional-mode. So if we can change the resonant frequency of the aileron to be substantially different from that of the air turbulence we might also minimize flutter.

From the torsion equation above we see that the period of vibration is determined by the inertia $\boldsymbol{I}$ of the aileron. If we increase the inertia we will slow down the resonant frequency, maybe enough so the ailerons do not start dancing to the music of the burbles in turbulent airflow. However, any added inertia is determined by the product of added mass multiplied times the square of its distance from the axis of rotation. This is why mass is always added to the extreme front of each aileron.

So one might ask "Could I control aileron-flutter by making my aileron's trailing-edge heavier?"
My answer to that is "I don't know; it might help". A heavier trailing-edge would make the aileron even more unbalanced, slightly increasing the interactions between left and right ailerons and thereby possibly exacerbating the problem. However, the added unbalance would be slight. "Why slight?" you might ask. Well, if we are primarily interested in slowing down the vibrations of a fluttering aileron, and we want to increase the inertia of the aileron, why not add just a very small mass to the trailing-edge. We might get by with it for the following reason...
Lets say we balance our aileron by adding 5# of weight at a distance of 4.0" in front of the hinge-pins. We have applied 25 ft# of moment to our balancing act. If we use our inertia formula we will find that the added inertia is related to the product of (5 x 4 x 4) or a value of 80 (the actual units used in engineering include some other constants, but to simplify things we can use the value of 80).

If we wanted to add the same amount of inertia (80) to the aileron by adding a weight **W** to a trailing edge located (let's say) 16" behind the hinges, we can say (**W** x 16 x 16) must also equal 80. Since inertial of the aileron (the determine factor in the timing of aileron-flutter) depends on the square of the distance from the axis of rotation, we can add inertia to an aileron equivalent to 5# of lead up-front by adding a mere 5 ounces to the aileron's trailing edge.

If my priority is keeping my aircraft as light as possible, it might be worth a try.

Why don't you try in on your project?

Bergy