In-Flight Flap Measurement

In the late 1990s, the Bearhawk was first introduced to the homebuilt scene when Bob Barrows, the designer, would famously park the prototype at airshows such as AirVenture and Sun 'n Fun with the flaps full down. It was an impressive sight with those long span flaps deflected down 50 degrees. "Everyone knows" that flaps allow an airplane to land slower and thus shorter. If you are trying to sell a design as a STOL airplane, showing a lot of flap is certainly one way to do it. (*Personally, I built the airplane because it was a high wing four place, not because of STOL back country capabilities. The wheel pants give away that this airplane mostly lands on pavement.*)

Figure 1. Bearhawk parked with flaps full down

The reality is that the flaps don't actually deploy that much while in flight. While the actual deployment is sufficient, as we will discuss later, it just doesn't look like it does on the ground. Anyone who has flown a Bearhawk with the flaps deployed and bothered to turn around and look at them while airborne will notice the difference. It also turns out to be a good thing that the flaps don't deploy any more than they do.

A while back, Jared Yates was talking with Bob Barrows about how much the flaps actually do deflect while in flight. They both knew it was less than the flaps deflect on the ground, but no one had ever actually measured the deflection. Seeking to find out, Jared contacted his favourite Bearhawk flight tester to investigate this issue and find out what we could learn about it.

I had always assumed the difference was because of "cable stretch" but hadn't bothered to actually investigate this hypothesis. Now that someone else was asking the question, it was time to design a flight test program.

The Difference Is Visible

Since you may not have your own Bearhawk to go fly and see for yourself, let's take a look at some pictures taken during our flight test. Each of these pictures is taken the with the camera in roughly the same position, so you can compare the pictures directly.

Figure 2. Flaps Up, Cruise Speed 112 KCAS

In Figure 2, the flaps are in the UP position, with zero notches of flaps on the flap lever. Note that the flap does not line up with the root fairing but is actually reflexed by one degree. The reflex of the flap comes from the adjustment of the length of the pushrod. I'm pretty sure that I originally adjusted the pushrod so that the flap would line up with the root fairing on the ground with no load, but the flex in the system under flight loads results in a slight reflex of one degree.

The UP stop on the flaps is caused by the flap pushrod pushing against the steel tube of the flap drive mechanism. Shortening the pushrod will result in a reflex (negative deflection) of the flap in the full up position. In the early days of Bearhawk building there was much discussion of reflexing the flaps to get a higher cruise speed. The thought was that at cruise speed, the airfoil of the wing is working at a lift coefficient below the design lift coefficient, so it was creating more drag. Reflexing the flaps would require the airfoil to increase its angle of attack, thus approaching the design lift coefficient and reducing the drag. Also, reflex was expected to line up the fuselage with the flow and not be oriented nose down. Pat Fagan tried reflexing his flaps on Bearhawk #232 by shortening the flap pushrods. The amount of reflex available before the leading edge of the flap contacted the rear spar was minimal. Pat reported no noticeable change in cruise airspeed, which pretty much ended the discussion of reflexing the Bearhawk flaps. Additionally, every degree of reflex was one less degree of flaps down deflection available. In my case, it just ended up that way and I saw no reason to change it.

Also visible in this picture is that the horizontal tail is trailing edge down (leading edge up), showing that at cruise trim it is pushing the nose down (nose down trim).

Figure 3. Two notches of flap at 75 KCAS

In Figure 3, the flaps are two notches down, which is supposedly 25 degrees of deflection. Note the size of the gap between the trailing edge of the flap and the trailing edge of the wing root fairing. (For some reason we failed to get a picture of the flaps at one notch of deployment.)

Note that the elevator is now aligned with the horizontal tail at this slower speed. This means it is trimming more nose up than in Figure 2, which is expected at a lower speed.

In Figure 4, the flaps are three notches down on final approach at 65 KCAS, which is supposedly 40 degrees of deflection. Note the size of the gap between the trailing edge of the flap and the trailing edge of the wing root fairing and compare it to Figure 5.

Note how the elevator is now trimming more nose up than it was in Figure 3 at this slower speed, again as expected.

In Figure 5, the flaps are three notches down, but with the air loads removed. Notice how much larger the gap is between the trailing edge of the flap and the trailing edge of the root fairing compared to Figure 4. This very noticeable difference in deflection in the air and on the ground for the same flap lever position is what led to this investigation.

Flight Test

The test item for this test was Bearhawk #164 “Three Sigma”, which is a four place Bearhawk of the original design (Model A). The flaps of the Model A stopped at a wing root fairing about 12 inches from the fuselage. Later Bearhawk designs have flaps that extend right up to the fuselage.

The flaps were mechanized in a Piper style design. A flap lever pulled a cable, which pulled an arm on a torque tube at the wing root, and another arm on the same torque tube pushed a pushrod that deflected the flap. Flaps were held up/pushed up by air loads (lift) in flight, and were held up by springs while on the ground. The flap cable ran from the flap lever by the pilot seat, underneath the floor, and up behind the rear cabin bulkhead. Through a fitting

Figure 4. Three notches of flap at 65 KCAS

Figure 5. Three notches of flap at 0 KCAS

and three turnbuckles, the flap cable formed a "Y" with the upper two branches running to the top of the fuselage and forward to each wing root, where they attached to an arm on each torque tube. The total length of cable from the flap handle to the torque tube arm, minus fittings and turnbuckles, was approximately 172 inches.

Bob Barrows specified the flap limit airspeeds in miles per hour of calibrated airspeed. I fly my Bearhawk in knots (*knots vs. mph diatribe deleted*) so I converted the limits into knots, which are posted on my panel and shown in Table 1. Also shown in Table 1 are the "easy pilot math" values that I actually use while flying.

Table 1. Flap Limit Speeds
Bearhawk #164, N6786E

Notches	Deflection deg	Limit Speed KCAS	Easy Pilot Math Limit
1	15	87	85
2	25	74	75
3	40	65	65
4	50	56	55

Actual flap deflection was measured by holding a digital level against the bottom surface of the center of the flap. Because the airplane was clearly not level while measuring, a bias reading was made with the trailing edge of the flap aligned with the wing root fairing. This bias was subtracted from the measurement to get the deflection from a reference zero, as shown in Figure 6. Because of the Y-cable implementation, the flaps were not necessarily matched in deflection on the ground. The flaps were adjusted to be close to matched while measuring, and then the average of the left and right measurements was reported.

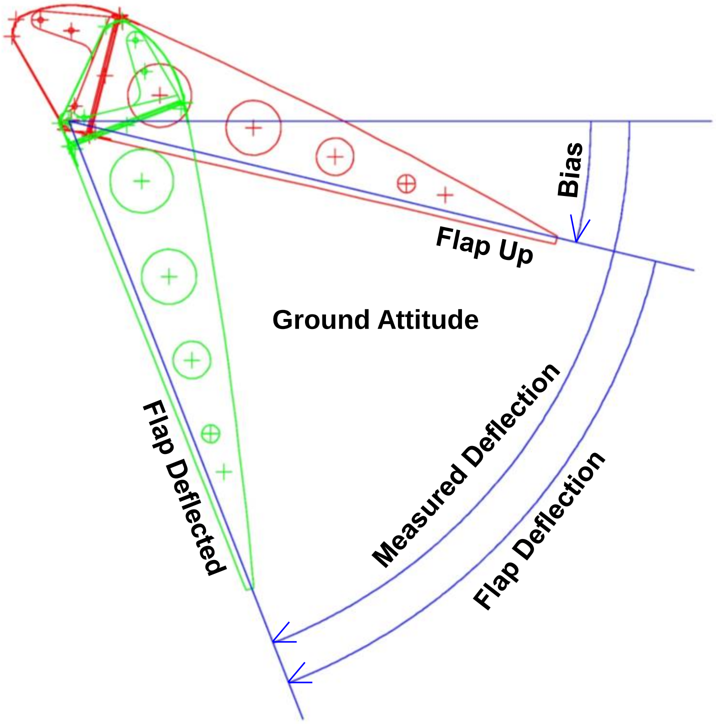

Figure 6. Measuring Flap Deflection

For determining the actual flap deflections in flight under load, standing under the flap with a digital level wasn't going to work. A method was needed to be able to pinpoint the position of the flaps in flight, and then recreate that position in the hangar to measure the flap deflection with the digital level.

A theodolite of sorts was set up by tying a piece of cord between the front seat shoulder strap anchors. This cord had an overhand loop knot in the middle and was pulled very tight. Another cord was tied tightly between this loop at the ceiling and the fuselage tube between the front seats at the floor. In this cord were several overhand knots tied at arbitrary locations.

On the left rear window, a curve was drawn with a dry-erase marker roughly approximating the visual location of the trailing edge tip of the root end of the flap as it swept through its deflections. An arbitrary scale was drawn on this curve, as shown in Figure 7.

Figure 7. Flap Position Theodolite

In flight, the Flight Test Engineer (FTE) would sit on the right side of the rear seat. To record the flap position, the FTE leaned forward, sighted through an appropriate knot to the tip of the flap trailing edge, and recorded the number from the window scale that his sight line passed through and which knot was used for the sighting.

For better access while reading the flap position, the right front seat was folded forward and held in place with a bungee cord, as seen in Figure 8. The right control stick was removed to avoid interference with the seat.

Figure 8. Right Front Seat folded forward to make room for data sighting

After the flight, the FTE sat in the same position, and I pulled down the flap by hand at his direction until he saw it in the same position as it was in flight. Holding the flap in that position, I measured the flap deflection with the digital level.

The flight test was flown on 1 April 2023 (no foolin') for 0.6 hours. Each flap position was measured at the flap limit airspeed, which would give the minimal deflection for the selected notch. My FTE was Aaron Wenner, a fellow staff member at the USAF Test Pilot School.

Results

The measured flap deflections are shown in Table 2 and in Figure 9.

Table 2. Measured Flap Deflections
Bearhawk #164, N6786E

Notches	Nominal Deflection deg	Ground deg	Flight deg
0	0	4.3	-1.0
1	15	14.6	2.2
2	25	29.1	6.4
3	40	42.8	17
4	50	55.1	N/A

Bearhawk #164, N6786E
Flap deflections measured at flap limit airspeeds

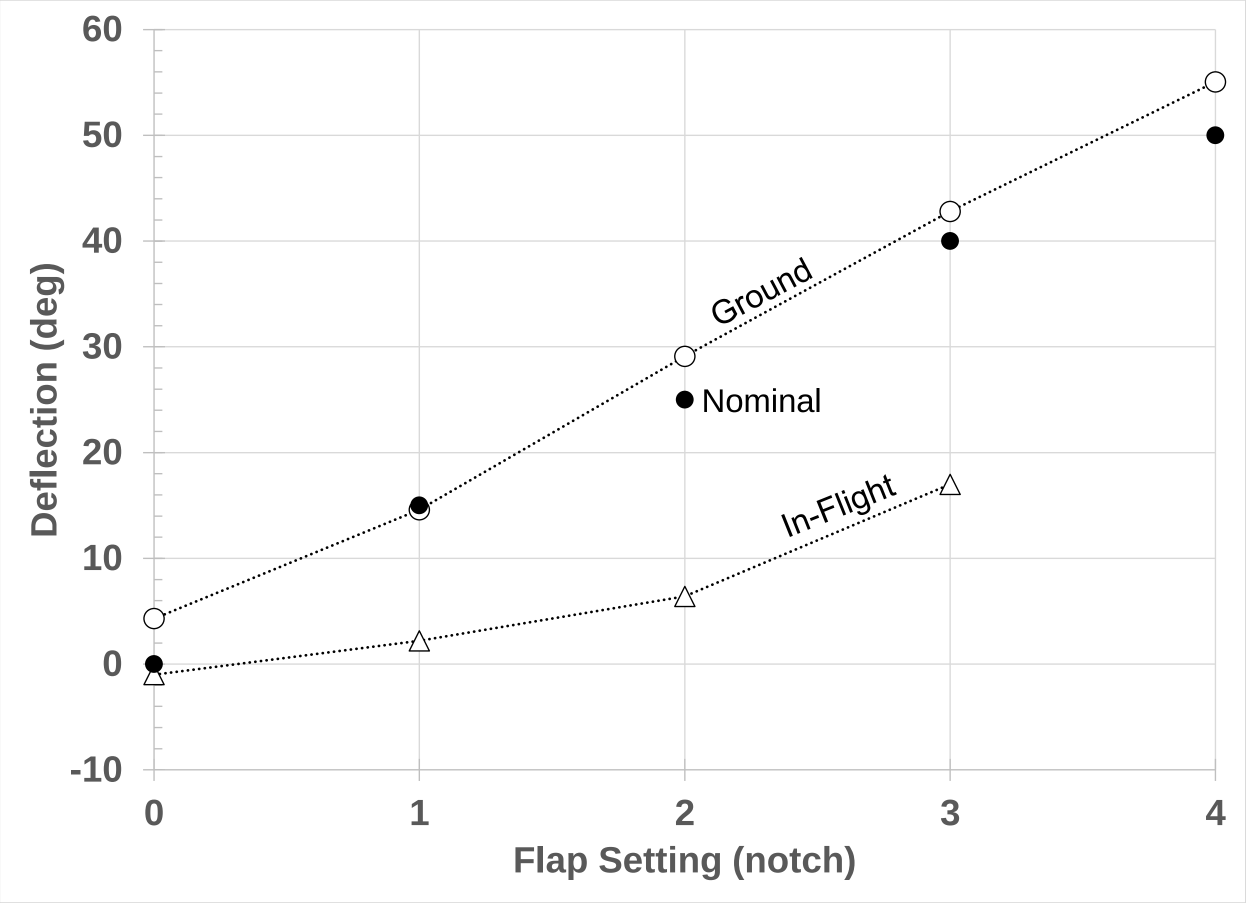

Figure 9. Ground and In-Flight Flap Deflection Measurements

In Figure 9, the black dots show the nominal flap deflections, i.e. the values shown on the plans.

In-flight data at four notches of flaps were not collected, because at an airspeed of 55 KCAS I was not able to pull the flap handle more than about halfway from the third notch to the fourth notch because of high aerodynamic forces. Tests later with a force gauge estimated that the required force to pull on the last notch of flaps was in excess of 75 pounds, which was more than my (apparently wimpy) arm could pull. I tried multiple times with no success. I do not routinely use the fourth notch of flaps, but I have been able to deploy it in flight on a previous occasion. I don't know what was different this time.

The most significant thing seen in Figure 9 is that the in-flight deflections are around half of what was expected based on the ground results. This is consistent with what we saw earlier in Figures 4 and 5.

On the ground with no air loads, my flaps have a resting deflection of 4.3 degrees while the flap lever is in the zeroth notch. I made this adjustment years ago when I realized that with the flaps adjusted to have the trailing edge line up with the wing root fairing on the ground, airborne the flaps did not move at all when pulling to the first flap notch. Thus, I shortened the flap cable slightly so that the flaps would actually move slightly at the first notch. In flight, the air loads push the flaps up to the up stop, stretching the cable as required.

Analysis

My first suspicion was that the flap cable was stretching under load, resulting in reduced flap deflection. While I am an engineer, I have not specifically studied twisted steel cables and their properties. What follows is my best analysis based on information I could find during my research, but these statements have not been peer reviewed.

According to *Five facts about wire rope stretch* (Ref 1), "There are two ways wire ropes stretch when under load: elastic stretch and structural stretch. Elastic stretch refers to stretching caused by elongation of the wires in the wire rope. It gets its name from the fact that the rope tends to return to its initial length once the load is released. Conversely, structural stretch is caused by the adjustment of wires and strands, lengthening of rope lay, and compression of the core."

How to Calculate Wire Rope and Cable Stretch (Ref 2) states that the expected structural stretch of a cable is less than 1 per cent of the total cable length. Reference 2 also gives a formula for calculating the elastic stretch:

$$\mathrm{E} = \frac{\mathrm{W} * \mathrm{G}}{\mathrm{D}^2}$$

where

E elastic stretch as a percentage of length
W weight of load in pounds
D diameter of cable in inches
G stretch factor

Different stretch factors for different types of cables are listed in a table in Reference 2. For 7x19 302/304 SST cable (the type used for the flap cable), G = 0.0000162. The units of G are not specified, but I assumed they were correct such that the result comes out as a percentage of length when all of the other units specified above are followed. Note that the result is a percentage, which is a factor of 100 different than an actual strain.

To identify how much cable stretch would be required to get the deflections measured in flight, I set up a CAD model. The geometry of the flap lever, the "Y" joint, the torque tube, flap pushrod, and the flap were modeled. All deformation was assumed to be cable stretch. No deformation was modeled for the flap lever, the torque tube, flap pushrod, or the flap horn.

To validate the CAD model, I first modeled the movement of the flap lever and the resulting deflection of the flap with no stretch (or "strain") in the flap cable. Figure 10 shows the results from the CAD model ("Calculated Deflection") compared to the actual ground test ("Actual No-Load Deflection"). The results are very close, which shows the CAD model to be valid for the ground, no-load case. It was therefore reasonable to use this model with the in-flight deflections to determine the amount of cable stretch under load.

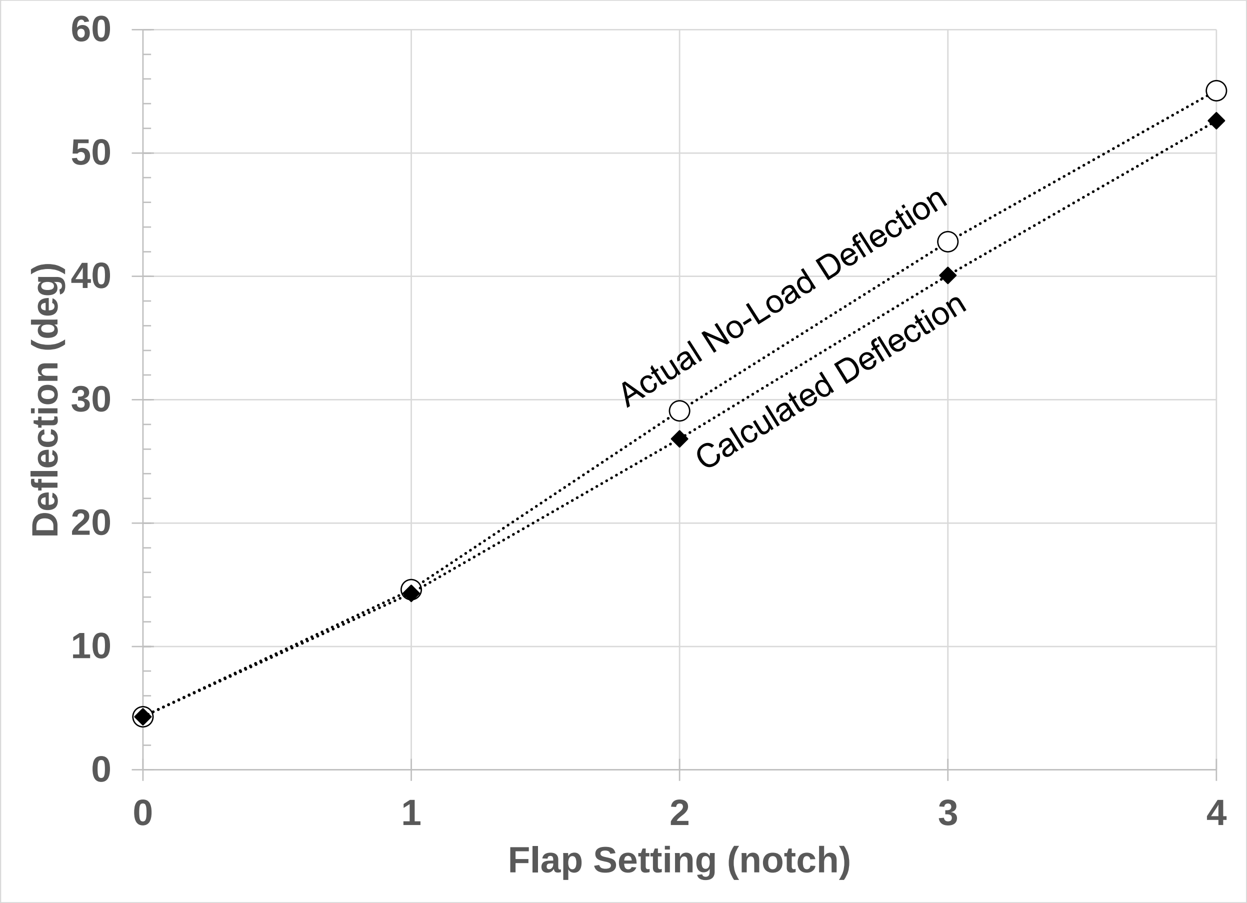

Figure 10. Validation of CAD model for no-load deflection

With confidence in the CAD model, the flap lever was set to the deflection of each notch, and the flap was set to the deflection measured in flight. The resulting length of the cable was measured in the CAD model and compared to the no-load length. These calculated lengths are listed in Table 3 as “Cable loaded length”.

Table 3. Measured Flap Deflections
Bearhawk #164, N6786E

Flap Notch	Cable no-load length	Cable loaded length	Total Strain	Flap Handle Estimated Force	Cable Tension	Elastic Strain	Elastic Strain	Structural Strain
	inches	inches		pounds	pounds	per cent		
0	172	172.3570	0.002076	20	67.6923	0.055896	0.000559	0.001517
1	172	172.8465	0.004922	25	84.6153	0.069870	0.000699	0.004223
2	172	173.4910	0.008669	30	101.538	0.083844	0.000838	0.007830
3	172	173.7778	0.010336	55	186.153	0.153715	0.001537	0.008799

Mechanical engineers define strain as the loaded length divided by the unloaded length, which is a non-dimensional number. The total strain is listed in Table 3 for each flap notch.

Using a force gauge (normally used for measuring control stick forces), I estimated the flap handle forces by pulling on the force gauge how hard I remembered the flap handle forces being. Note that the force on the flap handle in the zeroth notch is not zero, because some load is placed on the cable as aerodynamic forces lift the flaps from their ground deflection of 4.3 degrees to the flight deflection of -1 degree.

Measurements of the flap handle indicate a mechanical advantage of 3.38. This value was multiplied by the estimated force to calculate the tension in the flap cable.

The cable from the flap handle to the Y junction was 93.5 inches long and carried the full tension for both flaps. The cable from the Y junction to the flap horn was 78.5 inches long and carried roughly half of the full tension for both flaps. The angle between the cable from the flap handle and the cable to the flap horn was approximately 25.5 degrees. Because of this angle, there is an additional lateral load across the fuselage. To determine the tension in the cable, the flap handle cable tension was divided by 2 (for two cables) and then divided by cosine(25.5°) to account for the lateral load. Because strain is linear with tension, we can calculate a multiplier for the force that will let us calculate the elastic strain as if the cable were a single straight cable 172 inches long.

$$\text{Multiplier} = \frac{93.5}{172} + \frac{78.5}{(172)(2)\cos(25.5°)}$$

$$\text{Multiplier} = 0.796$$

The cable force from the flap handle was multiplied by the multiplier and substituted in the elastic stretch formula above. This calculation gave the elastic strain. This formula gives a result in per cent strain, so the values were divided by 100 to get the non-dimensional elastic strain. The elastic strain was then subtracted from the total strain to give the structural strain.

Comparing the elastic strain to the total strain, we see that the elastic strain is as much as 15 per cent of the total strain, with the remaining 85 per cent being structural strain. At three notches of flap, the structural strain was 0.0088, which is still less than the 0.01 (one per cent) which Reference 2 states is the maximum structural stretch for this type of cable.

Looking at Figure 9, the slope between notches zero and two for the in-flight data was less than the slope between the same notches for the ground data. This difference was a result of the structural and elastic stretch of the cable. From notch two to three, the in-flight slope was roughly parallel to that of the ground measurements, hinting that the structural stretch had neared its maximum. Extrapolating the segment between notches two and three, we can estimate that the in-flight flap deflection at four notches would be about 24 degrees.

Can We Do Better?

If by "better" you mean get more in-flight deflection, then probably not with the current design. But I contend that there is little to be gained with more deflection.

The aileron control cables and elevator control cables are each a complete loop, which we pre-tension with turnbuckles. This absorbs the structural stretch in these cables so that we can then make precise control inputs. With no other guidance to go by, I adjusted my cables such that when the control surface hit the stop, I could not push the control stick enough (with a reasonable force) to cause slack in the return cable. Knowing what I have learned in this investigation, I feel confident saying that I put enough tension into the cable to use up all of the structural stretch, leaving only the elastic stretch.

There is no pre-stretch in the rudder cables other than what you put there with your feet because the cables are not a complete loop. This is acceptable because, unlike the elevator or ailerons, there is no significant aerodynamic lift on the rudder in its neutral position, and the required precision of control is less.

The cable that we use for the flaps is not prestretched, which is apparent because you can grab the strands and easily untwist them. Reference 2 states "structural stretch can be removed by prestretching", which apparently is a service they offer. We don't want these cables to be prestreched, because the stranded nature of the cable was chosen specifically because it can go around a pulley easily. It is the fact that the strands can move relative to each other that makes the cable flexible enough to go around a small diameter pulley. I'm guessing, but I imagine that a cable prestretched hard enough to have no structural stretch at zero load has probably become like a solid wire, very inflexible.

The Bearhawk flap cables don't see enough tension for the structural stretch to take a set, which allows the cables to remain flexible.

You could always shorten the flap cable to get more in-flight flap deflection, but this will cause two problems. First, depending on how much ground deflection you add, you may add enough that the cable won't stretch enough for the flap drive to hit its hard stop, meaning that all of the flight loads on the flap will be carried by the flap handle mechanism. Second, doing this preloads the flap system, so it will take even more force on the flap handle to move the flaps into the desired deflection.

My operational experience would point to the conclusion that the flaps are fine as they are. My investigation into the best configuration for an instrument approach (Ref 3) showed that two notches of flaps was the minimum deflection needed to control airspeed for the final approach and landing. For 13 years I have generally used three notches of flaps for final approach, which allows for a slower approach speed and produces sufficient drag to maintain an approach angle steeper than the 3° ILS/PAPI/VASI glideslope if desired. Yes, the flaps don't deflect as much in-flight as the plans claim they do, but the actual deflection is sufficient for the mission as designed. Thus, no changes are recommended.

Besides, full flaps still look cool at fly-ins.

Designer's Comments

A pre-publication copy of this paper was provided for review to the designer of the Bearhawk, Bob Barrows. He acknowledged that when he designed the Bearhawk he knew that the in-flight flap deflection would be less than the ground deflection for the reasons detailed in this paper. In fact, the deflections would vary as the dynamic pressure changed with airspeed, extending slightly more as airspeed decreased, increasing the drag coefficient. This test only measured in-flight flap deflection at the flap limit speeds to find the minimal deflection compared to the ground deflection.

While this paper focused on cable stretch as an explanation for the difference between in-flight deflections and ground deflections, Bob suggested that twist in the torque tube should also be investigated as a contributor to the difference in deflections. Assuming that the twist contribution would be small compared to the stretch of the cable, a decision was made to ignore the twist contribution. Showing that the cable stretch accounted for a majority of the difference in deflection satisfied the requirement to explain the difference in deflection.

Bob confirmed that getting the flaps to the fourth notch required slowing to close to stall speed, and that he did not always use the fourth notch. He explained that current plans have modified the placement of the flap lever, raising it several inches above the floor. According to Bob, this change in geometry makes it somewhat easier to pull on the fourth notch of flaps by changing the muscle groups required.

Bob would also like to remind the community that forward slips are a wonderful way to control descent angle, and can be more precise than changes in throttle or flap deflection.

- Russ Erb

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