DEVELOPING A NEW FLAP FOR A LIGHT UTILITY TRANSPORT AIRCRAFT

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Abstract

The Bush Hawk XP is a small, piston-engined utility transport aircraft suitable for bushplane operations, produced by Found Aircraft of Canada. The original version was made in the 1960's and it uses a sealed, plain hinged flap. The latest production version increases gross weight by 25% and power by 20% from the original, so an improved flap was needed to achieve improvements in airfield and climb performance.

This paper describes the aerodynamic design and development of a new single-slotted flap for the Bush Hawk. The flap shape and locations when deflected were optimized using modern CFD methods and wind tunnel tests were bypassed. The features of the flap aerodynamic design and testing of the structure and flap drive systems are described. Flight test results are presented for the Bush Hawk with the new flap and they show outstanding performance in its category.

1 Introduction

The Bush Hawk XP (FBA-2C1) made by Found Aircraft of Canada, is a rugged, five-place, piston-engined aircraft suitable for bushplane type of operations, see Figure 1. The original FBA-2C version was produced in the 1960's and it uses a sealed, plain hinged flap and a 250hp Lycoming engine for power. Examples of the original aircraft are still flying regularly in bush operations in both Canada and Alaska, which is a testament to the durability of the airframe.

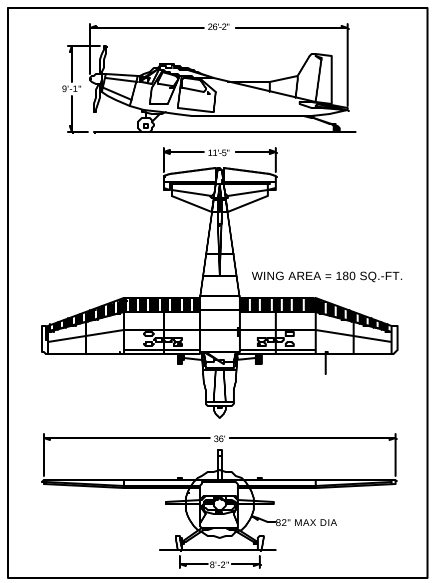

Figure 1: Three view of Bush Hawk XP, FBA-2C1 300hp landplane with slotted flap

The aircraft is now back in production but substantially redesigned to meet recent structural requirements. Relative to the original version, the Bush Hawk XP increases gross weight about 25% to 3500 lb and engine power by 20% using now a 300 hp IO-540 Lycoming. An improved flap was required to obtain further gains in the takeoff and climb performance, which are of particular importance for floatplane operations. Accordingly a new, single-slotted flap was designed using modern CFD methods. At some risk, to reduce time and costs, no wind tunnel tests were undertaken.

This paper describes the design features and development of the new flap and presents flight test results. Obtaining the Canadian and US FAR23 certification for the XP was a formidable challenge for Found as all aspects of testing were handled in-house, including the complete structure, landing gear, flight test and the airfield noise qualification.

2 Aerodynamic Design

The resources available to a small, start-up company are very limited so an aerodynamic development program involving wind tunnel testing was not practical from either time or cost considerations. Therefore it was decided to risk undertaking the aerodynamic design of the new flap using modern 2-D CFD methods and then proceed directly to the test aircraft to prove the performance and handling qualities.

The aerodynamic design of the flap was done cooperatively by Found and research staff at the University of Toronto Institute of Aerospace Studies (UTIAS). The CFD methods used included a UTIAS Navier Stokes analysis code called Tornado [1],[2] and the viscous Euler code MSES by Drela [3]. The main features of the new slotted flap and the original flap are compared in Figure 2 below.

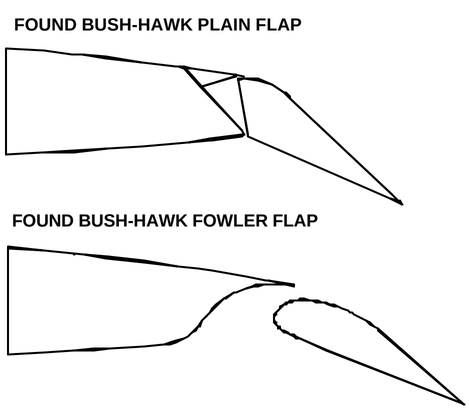

Figure 2: Bush Hawk plain flap and new slotted flap

The shapes of the new flap, the wing shroud and the gaps and overlaps were optimised on the computer for high lift/drag ratios and high maximum lift coefficients at deflections up to 35 degrees as could be used for landing. The resulting locations were to be suitable for either four bar linkages or slotted tracks to support the flap. The aerodynamic estimates were made at a chord based Reynolds number of 3.5 million and 0.15 Mach number.

The inner flapped part of the wing uses a NACA 23016 section and the lift results predicted using the Tornado and MSES codes are shown in Figure 3. Tornado predicts a higher stall angle and maximum lift coefficient and this was also found later in cases with flaps deflected. For comparison the NACA data of [4] indicates a stall angle about 15 degrees and a C_{Lmax} about 1.5 which are closer to the MSES estimates.

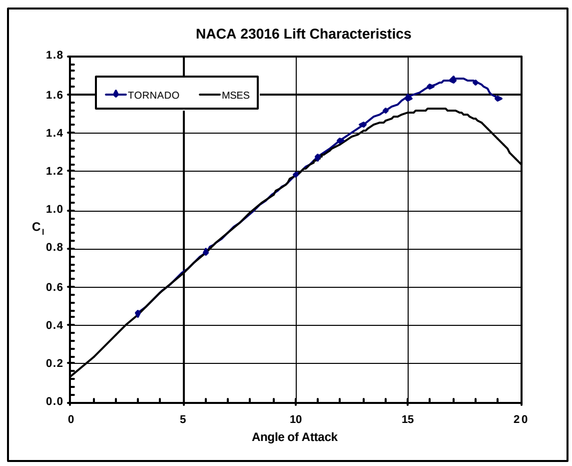

Figure 3: Lift curve estimates NACA 23016

The lift effectiveness of flaps can be compared using the increments obtained in C_{Lmax} at various flap deflections. Such a comparison is summarized in the following Figure 4. Estimates are included for the original plain flap from MSES and also for the new slotted flap using both MSES and the Tornado codes. For comparison 2-D estimates were made for a Cessna Skyhawk airfoil and flap based on the measured geometry from an aircraft.

The new slotted flap is predicted to increase section maximum lift coefficients by

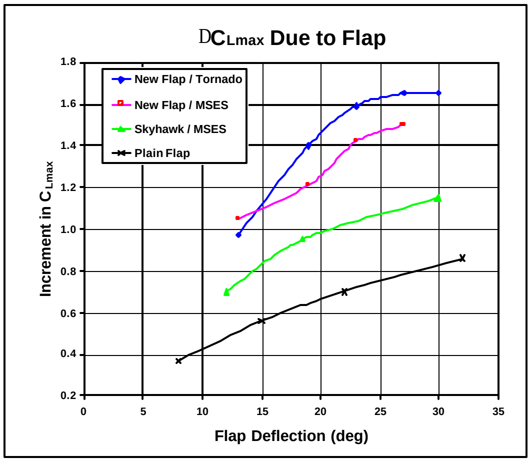

Figure 4: Increase in 2-D CLmax due to flap deflection

about twice the increments obtained from the plain flap across the range of flap angles. The predicted Skyhawk values fall intermediate between these two results. The Tornado code was again found to predict larger increases in both maximum lift and stall angle than estimates given by MSES.

Typical chordwise pressure distributions predicted about the airfoil and flap, as obtained using Tornado at a nominal flap deflection of 27 degrees, are shown in Figure 5 below.

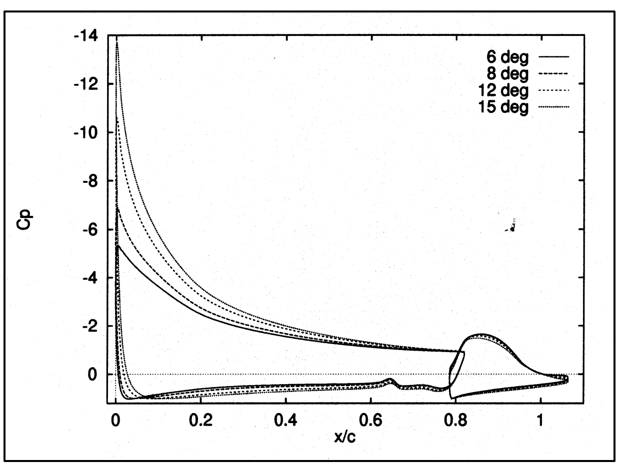

Figure 5: Chordwise pressure distributions on airfoil and flap at 27deg deflection

Some trailing edge flow separation is evident on the flap throughout the incidence range shown, however the main airfoil does not begin to separate even at the highest incidence of 15 degrees. This last incidence must be very close to stall as the peak negative suctions at the wing leading edge correspond to near sonic conditions. In practice the real aircraft with practical construction tolerances is unlikely to achieve such high stall incidences.

3 Structural Design and Systems

The design airloads on the flap were based on the Appendices to FAR23, [5], as embodied in the computer programs of [6]. These methods are known to be conservative and it would have been preferable to adapt the available 2-D CFD results to predict the flap loads. However, at the time Found had no proven, reliable methods available to make spanwise corrections to the 2-D flap loads.

Later on, to gain some insight, a flap pushrod was instrumented on the test aircraft to measure loads in flight. This will enable comparisons to be made with FAR23 load estimates and also with loads from the CMARC 3-D panel code which is now used in-house.

A scheme showing the flap structure and the support arrangement is given in Figure 6. A track system was adopted rather than using external hinges as the tracks could be fully enclosed within the airfoil profile. This also answers operators' concerns over long hinges projecting below the wing and possible injury to personnel during docking of floatplane versions. The buried track arrangement will also serve to reduce aircraft drag at cruise.

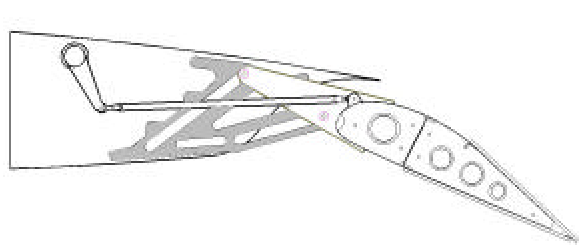

Figure 6: New flap structure and supports

The flap supports and drive system are also shown in the wing in the following Figure 7. Each flap is carried at two spanwise stations inset from the ends. At each station there are two rollers carried on arms projecting ahead of the flap. These run in tracks slotted into stainless steel plates attached to strengthened ribs to distribute the flap loads into the wing box.

Each flap is extended by a single pushrod attached at the flap mid point and driven by an arm on a spanwise torque tube. The flap drive uses a single, irreversible, electrically driven actuator which rotates the torque tube.

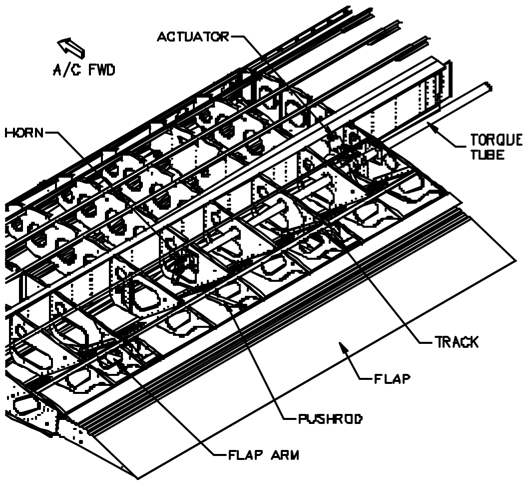

Figure 7: Flap drive system

Half hard stainless steel plates are used for the flap tracks and their dimensions were based on limiting the peak roller contact stresses on the tracks. One side of the flap system was structurally tested to ultimate conditions when mounted from a box representing the aft part of the wing structure, see Figure 8 below.

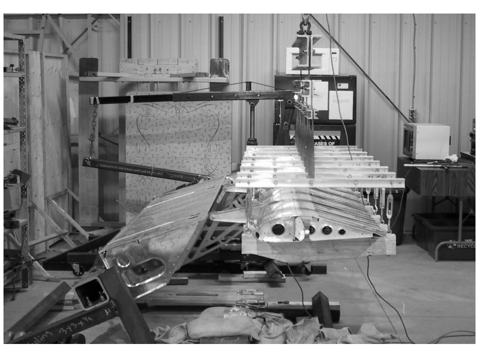

Figure 8: Structural test rig for new flap

The flap actuator was sized to higher capacity than needed for the flight loads so precautions were taken to limit the drive system loads in the event of the flap binding in a track or overrunning the stop switches and bottoming. The final design simply uses a load resistor placed in series with the drive motor to limit the peak current drawn to acceptable levels and there is a circuit breaker for backup. A series of ground tests were needed to iterate and find the required values for the load resistor. Later on flight tests were made to demonstrate acceptable shut down behaviour.

There was concern over unusual flap torsion loads and lateral deflections resulting from flap jamming on one side due to debris or some other equivalent event. Tests were made in the ground rig with such a flap jam simulated. At limit loads the lateral deflections were low and there were no resulting permanent deformations of any structure or drive component. Such tests are beyond the applicable certification requirements for this category of aircraft and they were done to demonstrate additional safety.

A failure in the flap drive system is considered a very remote possibility as design stress levels were kept very low throughout. However if a flap pushrod or connector on one side did fail it would cause that flap to retract completely and impart large aerodynamic rolling moments. Rather than attempt a complex failsafe design to cover such an event it was decided to wait until test flights to see if the available aileron roll power was sufficient to contain the full flap asymmetry.

The original Bush Hawk flaps were hand operated via a long lever which rotated the torque tube for extending the flaps. This feature was retained on the test aircraft as it enabled several special tests to be done in flight, particularly those to clear the flap and drive systems for failure cases. It also conveniently allowed the flap drive system to be cleared to limit loads on the ground prior to first flight.

4 Flight Tests

Stalls

The first part of the flight test program to meet FAR23 requirements was concerned with the stall handling characteristics of the aircraft and measurement of the maximum lift coefficients achieved. Testing followed the procedures given in [7].

The stall behaviour in straight and turning flight was found quite benign with good natural stall warning and no undue tendency to drop a wing. As a result, neither stall fences nor leading edge droop were required to be fitted on the wing, unlike the original version.

The maximum lift coefficients derived from the minimum stall speeds are listed in the following Table 1 which compares values for the new flap with the original plain flap. All values shown are for the most forward CG condition. The table also includes values for the similar sized Cessna 206H aircraft for comparison.

	Bush Hawk Plain Flap		Bush Hawk XP Slotted Flap		Cessna 206H Slotted Flap	
	δF	C_{Lmax}	δF	C_{Lmax}	δF	C_{Lmax}
Takeoff	0	1.46	0	1.69	0	1.35
	8	1.51	10	1.86	-	-
	22	1.61	20	2.03	20	1.69
Landing	32	1.61	30	2.16	30	1.87

Table 1: Aircraft maximum lift coefficients C_{Lmax} at forward CG.

At landing deflection the new flap increases aircraft maximum lift coefficients by more than 30% above the original plain flap. There is also a significant 16% increase in C_{Lmax} with flaps retracted, as residual leakage through the slots energizes the flow over the flaps. The maximum lift coefficient values obtained for the Bush Hawk XP are also higher than its immediate competitor.

Spins

The aircraft flight test program also included spin testing and safe recoveries from single-turn spins were demonstrated without any difficulties. No spin chute was fitted based on prior favourable experience but for safety the crew entry doors were fitted with rip hinges and the pilot had a parachute. In all 30 individual spins were done to cover a matrix of conditions of flap, CG location, engine power and control actions at entry and during the recovery. Later on spin tests were made with floats on the aircraft and again the spin recovery was found satisfactory.

Flap Asymmetry Tests

In order to demonstrate meeting cases where a flap pushrod might fail, or some equivalent event, the aircraft was flown in steady flight with one flap fully retracted and one fully extended. The aircraft demonstrated safe controllable flight, including cases with 100% power, down to a speed of 50 knots IAS. These tests showed additional safety beyond that required by FAR23.

5 Performance

The airfield and climb performance of the aircraft were determined operating to FAR23 requirements, for use in the aircraft flight manual (AFM). The special flight test instrumentation package utilised is described in another paper by Found [8] also being presented at this Congress.

The following Table 2 compares the performance of an earlier Bush Hawk plain flap version with the XP and also includes the similar sized Cessna. The airfield and climb performance of the Bush Hawk XP are now superior in all respects to the earlier version despite the significant increase in maximum weight. It is also now very competitive with the Cessna performance.

		Bush Hawk Plain Flap	Bush Hawk XP Slotted Flap	Cessna 206H Slotted Flap
Maximum Takeoff Weight	(lb)	3200	3500	3600
Engine Horsepower	(hp)	260	300	300
Empty Weight	(lb)	1750	1900	2210
Takeoff to 50ft height at Sea Level ISA	(ft)	1785	1566	1860
Landing from 50ft at Sea Level	(ft)	1455	1394	1395
Rate of Climb Flaps Up at Sea Level	(fpm)	960	1009	989
Cruise Speed at 75% Power, 6000ft	(kts)	132	150	142

Table 2: Aircraft performance comparison

The significant increase in cruise speed shown for the XP is the result of a drag clean up exercise taken in conjunction with the flap changes and the power increase.

6 Conclusions

This paper has described the development of a new, single-slotted flap system for the Found Bush Hawk XP, which is a small utility transport aircraft. From this work it is concluded:

1) Modern CFD methods for 2-D airfoils and flaps are now sufficiently mature that they can dramatically save time, cost and lessen the risks involved when developing new high lift systems.

2) The replacement of the earlier plain hinged flap with a new, CFD designed single slotted flap enabled the aircraft maximum lift coefficients to be increased at all deflections and by more than 30% for landing.

3) To fully exploit the benefits of CFD in the future, Found will need reliable 3-D CFD methods to replace the simple chart based methods used here for flap loads.

4) The new flap and increased engine power have enabled the XP to achieve performance superior in all respects to the earlier, lighter gross weight versions.

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