Experimental Evaluation of Cruise Flap Deflection on Total Aircraft Drag using the NLF(1)-0215F

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1 Introduction

In 1981 NASA published Technical Paper 1865 (Somers, 1981) describing the design approach and wind tunnel results for the NLF(1)-0215F airfoil. The objective of this new airfoil was to bring the benefits of laminar flow sections to higher speed general aviation aircraft. The growing use of composite materials made possible the dimensional control required to make use of laminar section on general aviation aircraft. The NLF(1)-0215F utilizes a trailing edge flap with negative (up) deflection in cruise to reduce pitching moment while retaining the ability to achieve a high maximum lift coefficient.

Lancair first used this airfoil on the 200/235 model in 1984. Subsequently the slightly larger 320/360 series aircraft also utilized the NLF(1)-0215F. The Lancair 320/360 is an all composite General Aviation (GA) kit-built experimental aircraft. The airframe has a wingspan of 23.5 ft and a wing area of 76 sq ft. The aircraft is of traditional configuration featuring a tractor propeller, low wing, conventional empennage and retractable landing gear. The design seats two passengers side by side. The aircraft is typically powered by a normally aspirated 160 or 180 hp Lycoming engine.

The Lancair utilizes a negative 7 degree flap deflection in cruise.

2 Objective and Testing Approach

The objective of this study is to quantify the drag reduction associated with deflecting the flap up in the cruise configuration. While TP-1865 evaluates -10 degrees flap deflection, the Lancair 320/360 only incorporated a negative 7 degree flap deflection for cruise flight. The fuselage fairing incorporates this -7 degree deflection. Three flap settings were tested: -7, 0, and +4 degrees. To quantify the drag difference between these three flap deflections, drag polars were assembled for each configuration using flight test data. In addition, a sweep of flap settings was made.

3 The Test Aircraft

The aircraft used in this study was a Lancair 360 MKII, N91CZ. MKII designates a configuration with a larger, higher aspect ratio horizontal tail (14.2 vs. 12.2 ft^2), as well as, a 4 inch longer engine mount. The aircraft engine is a stock Lycoming O-360-A1A. The aircraft tested was previously modified to incorporate a plenum type cooling system. This modification was previously shown to substantially reduce cooling drag thus the total drag measured may not reflect the typical Lancair airframe (Zavatson, 2007). The test measurements will however still provides the impact of flap position on drag.

4 Theory

To fully understand the intent of incorporating a reflexed flap configuration into the Lancair 360 aircraft, NASA TP1865 is briefly summarized.

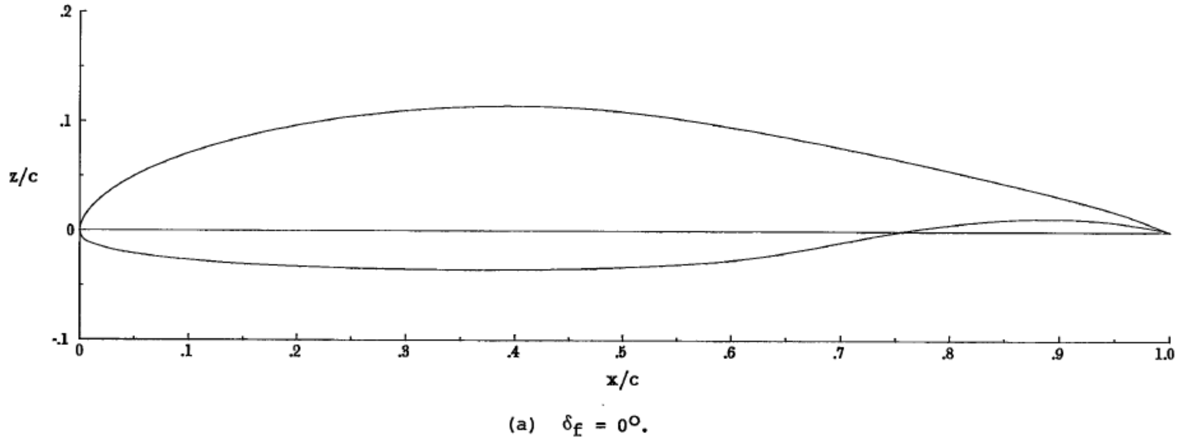


Figure 1,NLF(1)-0215F, 0 deg flap, (Somers, 1981)

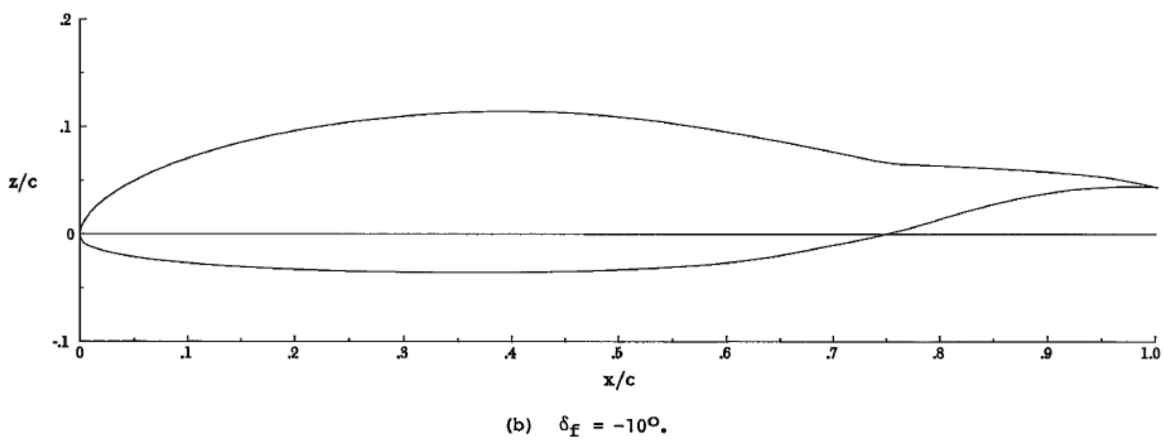
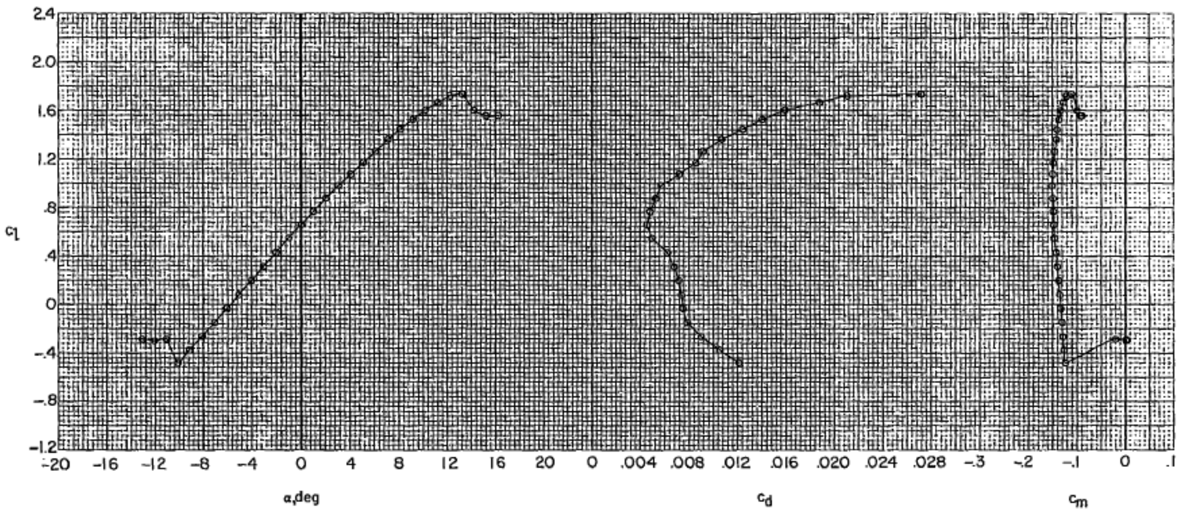


Figure 2,NLF(1)-0215F, -10 deg flap, (Somers, 1981)

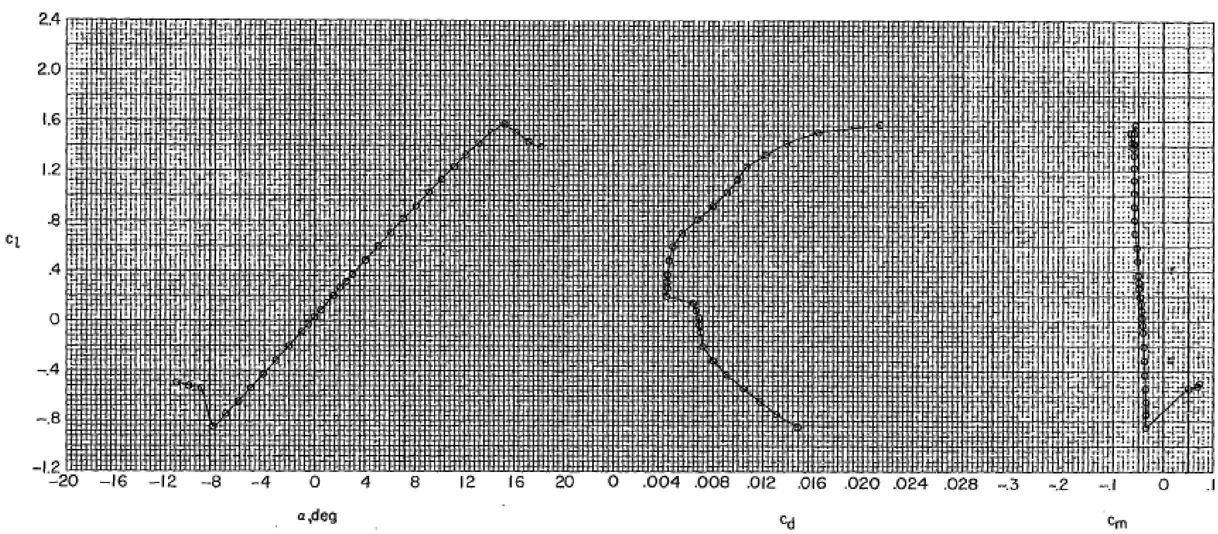
A new non-critical laminar airfoil section was to be designed that could be used to improve the performance of general aviation aircraft. Design constraints placed on the project were the following: t/c of 15%, design cruise C_l of 0.2, C_m not more negative than -0.05, flap chord of 25%.

Figure 1 and Figure 2 show the airfoil section with flaps 0 and flaps -10, respectively. The wind tunnel results show the drag bucket shifting to the cruise C_l of 0.2 with reflexed flaps. Figure 3 shows the zero flap condition while Figure 4 shows the resultant shift in the drag bucket. Also, noteworthy is the reduction in pitching moment from -0.15 to -0.05. This drop in pitching moment reduces the trim force needed from the horizontal tail. It also has a substantial impact on the pitch attitude of the aircraft, making it more favorable at high speed.



(b) R = 6.0 × 10^6.

Figure 3,Lift, Drag, Moment Curve from TR-1865, 0 deg flap, (Somers, 1981)



(a) R = 6.0 × 10^6.

Figure 4, Lift, Drag, Moment Curve from TR-1865, -10 deg flap, (Somers, 1981)

5 Instrumentation and Calibration

Calculating drag requires the aircraft airspeed, engine power, propeller efficiency and weight at each flight condition. The aircraft was instrumented with independent and carefully calibrated transducers to capture all the parameters required. Data recording allows for more accurate post-processing and provided the ability to verify that steady state had been achieved at each test point.

The primary values of interest in creating the drag polar are:

1. Calibrated Airspeed
2. Engine power
3. Outside Air Temperature (OAT)
4. Altitude (Pressure Altitude)
5. Aircraft weight
6. Propeller efficiency
7. Flap Position

Additionally elevator position was instrumented and measured for additional stability and control testing beyond the scope of this report.

6 Airspeed

A +/-1 psi differential pressure transducer, Omega part # PX139-001D4V was used to capture dynamic pressure. The unit was calibrated using a manometer. The low range of the transducer provides excellent resolution to a fraction of a knot.

6.1 Pitot-Static Position Error

Position error was determined at two different airspeeds by flying four orthogonal GPS tracks at a constant power setting. Only three legs are required for this technique.

The fourth leg was recorded for redundancy. Airspeed and GPS data were used to calculate winds aloft and true airspeed. Position error at the two different airspeeds 206 and 154 KTAS and found to be less than one knot at both speeds.

6.2 Pressure Altitude

Pressure altitude was measured using a 15 psia pressure transducer Omega part # PX139-015A4V. This unit was calibrated to 14,000' via manometer. The excellent linearity of the transducer allows use beyond the calibrated range.

6.3 Manifold Pressure

Manifold pressure was measured with a 15 psia pressure transducer, Omega part # PX139-015A4V. This transducer was also calibrated via manometer.

6.4 OAT

OAT was captured by multiple TC probes on the wing. An accurate OAT was found by comparing multiple temperature probe locations against theoretical stagnation temperature value through a range of airspeeds. Separate tests were conducted to determine the best location to capture stagnation temperature so that OAT could be determined.

6.5 Elevator Position

The elevator control from the pilot control stick to the elevator is via pushrods and rod end bearings. This results in a very solid and responsive control system with minimal lash or hysteresis. A 3 inch linear potentiometer, Panasonic PP1045SB, was used to measure elevator position by following the movements of the pushrod.

6.6 Flap Position

The flap is actuated via an electric linear actuator. It is capable of continuous travel between full up and full down positions. The flap can be stopped at any intermediate position. There are no detents. A 100 mm linear potentiometer, ALPS RSA0N11S9A0K, was used to measure flap position by mounting an arm to the flap torque tube. A calibration curve was generated to correlate voltage output to flap deflection.

6.7 Aircraft Weight

A fuel flow transducer and totalizer was installed in order to determine aircraft weight at each test point. The ready-to-fly aircraft and pilot were weighed prior to each test flight. Remaining fuel quantity was recorded for each test point in order to calculate a weight.

7 Data Recording

All data was recorded via a PIC microcontroller at 1 Hz and 12 bit resolution. Data was stored on an SD card for analysis. Cruise points above 100 KIAS were flown for a minimum of three minutes to establish and verify steady state conditions. Airspeeds at and below 100 KIAS stabilized much more quickly and were flown as required for stabilization.

8 OEM Provided Data

8.1 Brake Horsepower (BHP)

The engine is a Lycoming O-360-A1A rated at 180 hp. Since the engine was completely stock, assembled and tested by the manufacturer, the manufacturer's performance charts were used to obtain BHP for each flight condition (Lycoming Curve 13356). This chart was digitized and programmed such that inputs of pressure altitude, OAT, manifold pressure and engine speed would provide corrected brake horsepower.

8.2 Propeller Efficiency

Hartzell Propeller provided propeller maps for the HC-F2YR-1F/F7068-2 installed on the aircraft. Propeller efficiency is a function of engine speed, shaft horsepower, altitude, temperature, and aircraft airspeed. These maps were programmed into a Visual Basic routine that supplies the output parameters of efficiency, blade angle, thrust, and advance ratio of the propeller for any given shaft power, altitude, temperature and engine speed.

9 Test Data and Results

Three primary flap deflections were used to construct drag polars: -7, 0, and +4 degrees. In addition, flap position was varied with in finer increments at a selected weight and altitude in order to obtain a direct comparison of drag and speed. All test data was corrected for Reynolds number and is displayed at a Re of 6x10^6 and a Mach number of 0.3. Temperature data was corrected for stagnation effects.

Test data was gathered over 10 flights and a 3 month time frame. Two primary altitudes of 7,500’ and 14,500’ were used. Due to speed limitation on flap extension, WOT operation at +4 degrees flaps was only conducted at the high altitude. Reflexed flaps (-7 degrees) were flown across the entire altitude and speed range (80 KIAS to WOT).

The drag polar for the reflexed position produces a lower CD value across the entire tested speed range. Drag polars for 0 and +4 degree flap deflections intersect each other when plotted as a polynomial curve. C_{Dmin} values are however not co-incident. Linear fit curves in Figure 6 clearly show the delta in drag counts for each flap position. Reflexing or raising flaps from 0 to -7 degrees reduces aircraft C_{Dmin} by 48 drag counts or 19%.

The impact on drag can be observed directly in Figure 7, where at a fixed altitude and power setting (WOT), flap position was swept through multiple positions. These points were flown at high altitude to minimize loads on the extended flaps given the high true airspeed. Airspeed is reduced by approximately 10 knots between flap settings of -7 and 0 degrees. This change in airspeed agrees drag deltas found in the -7 and 0 degree drag polars.

Figure 7 does not show a peak, even at the -7 degree flap position. This implies that further drag reduction might be obtained with additional negative flap deflection. This hypothesis could not be tested since the design and construction of the flap leading edges would not for additional negative travel.

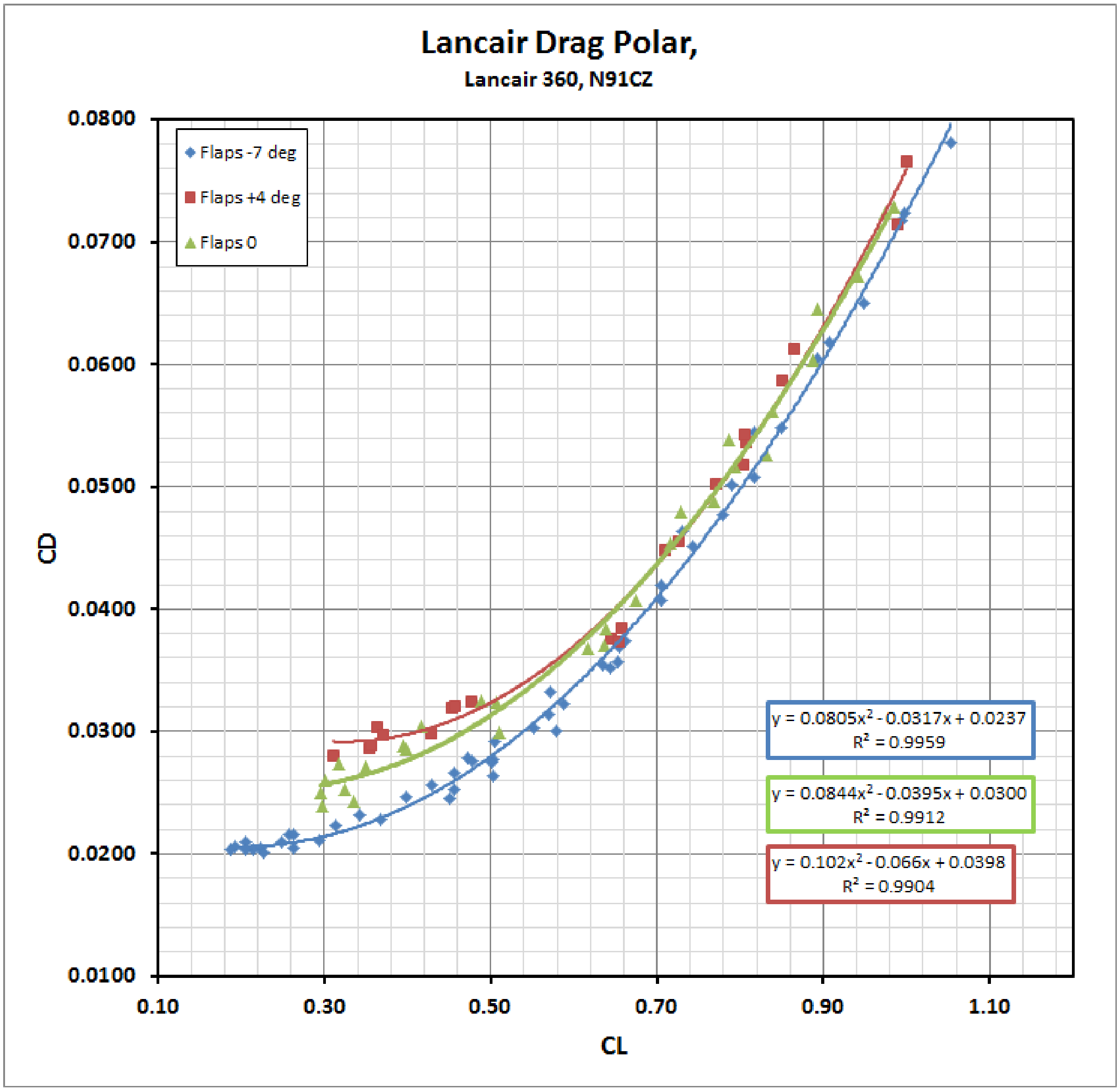


Figure 5, Lancair 360 Drag Polar [Polynomial Fit]

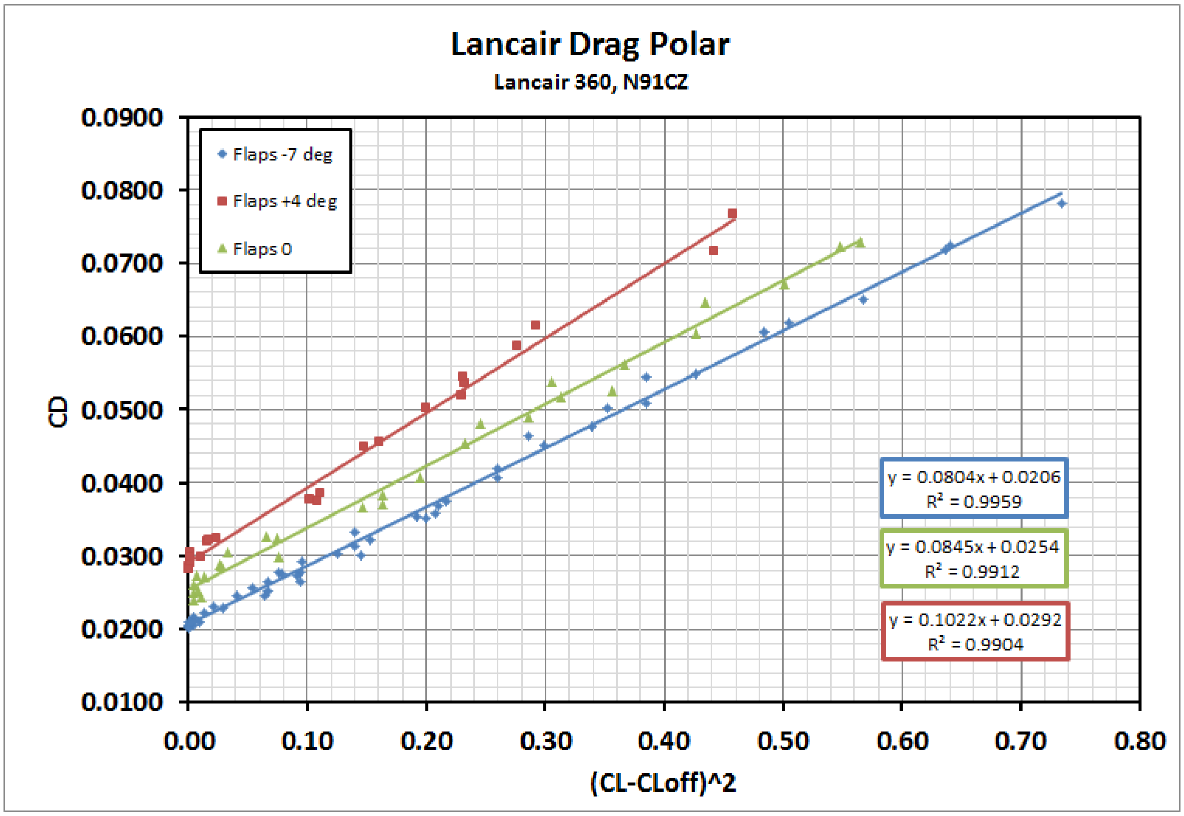


Figure 6, Lancair 360 Drag Polar [Linear Fit]

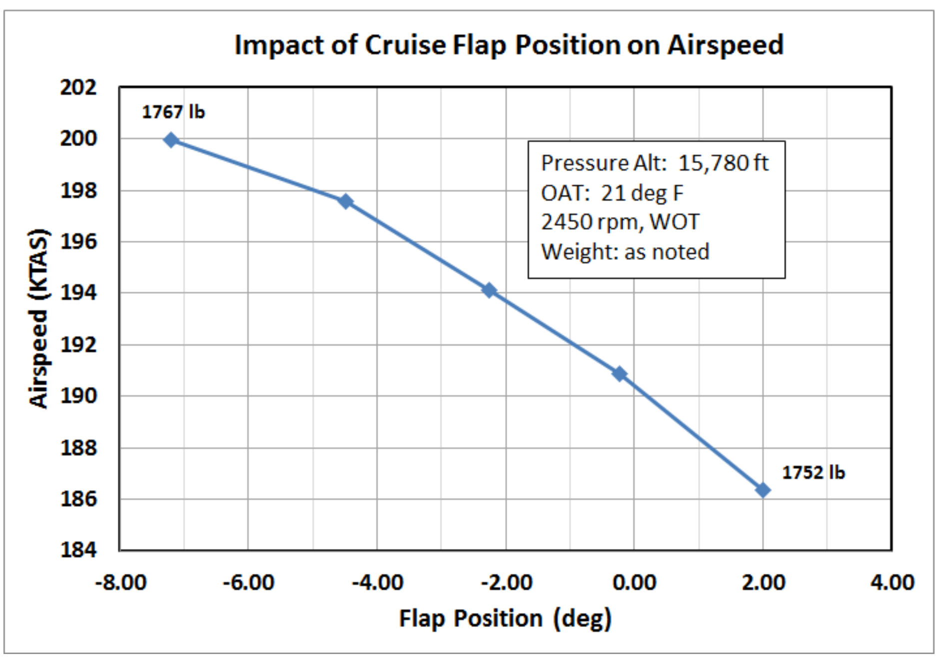


Figure 7, Cruise Speed with variable Flap Deflection

10 Conclusion

Flight testing clearly demonstrated the benefits of reflexed or negative flap deflection of the NLF(1)-0215F airfoil for cruise flight. The demonstrated reduction in C_{Dmin} corresponds well to the design goals of the airfoil section. A total aircraft drag reduction of 19% or 48 drag counts was obtained by reflexing the flaps to -7 degrees. This corresponds to a 10 knot increase in true airspeed. The data indicate that the Lancair could have likely benefited from additional negative flap deflection beyond the -7 degrees used in the design.

11 Acknowledgements

I would like to gratefully acknowledge the support of two colleges and friends in this endeavor. To Aleksey Matyushev for his encouragement to undertake this project in the first place and for his continued input on test techniques and data analysis. And to Andrew Ward who, from scratch, designed, assembled and programmed the data logger used for this project.

12 Works Cited

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