Cooling System Evaluation on N91CZ

C. Zavatson, 4-18-2006

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Abstract

In an effort to more fully understand and quantify the effectiveness of the cooling system on N91CZ, a series of tests were conducted. Several key parameters that indicate how efficiently the cooling system is performing were measured. Existing temperature data had already confirmed much improved cooling as a result of the complete cooling system redesign in 2004 (Ref. Efficiency Improvements for the Lancair 360). In addition, overall system efficiency was known to have improved as indicated by a 5 knot gain in airspeed. Results of this investigation revealed that excellent pressure recovery is being achieved in the plenum chamber. The entire pressure recovery was found to be occurring inside the inlets and diffusers as expressed by a velocity inlet ratio near 1.0. Oil cooler mass flow comprised about 8% of the total flow. Mass flow was obtained using two independent methods with good agreement between them.

Introduction

A major piece in the cooling puzzle is the quantity of air (mass flow) moving past the cooling fins of the engine. This is typically measured as a pressure drop across the engine. For any given installation there will be a direct correlation between this pressure drop and mass flow. Unfortunately, leak paths that bypass the cooling fins contribute to mass flow but not cooling. Leaks lower the overall resistance to flow. This degrades the cooling system in two ways. First and most obvious, the engine does not see all of the cooling flow, degrading cooling. Secondly, the inlets are allowing more air to enter the engine compartment than is needed and that excess air then needs to exit the system. This translates into extra drag on the air frame. The significance of leak paths cannot be overstated and the magnitude of leaks in a conventional cooling system may be quite surprising. As described in NASA report CR3045, the cooling system of a Piper Aztec was tested. Mass flow through the cowling inlets had to be increased by 55% in order to achieve the manufacturer's engine pressure drop data. With a solid plenum top and the use of RTV sealant, all leaks were eliminated and the manufacturer's data was duplicated.

As a basis for evaluating the cooling system currently installed, the following parameters were measured:

1. Pressure above cylinders
2. Pressure below cylinders
3. Pressure at cowling exit
4. Pressure oil cooler inlet
5. Pressure oil cooler exit
6. Cowling inlet velocity

Cooling System Description

The aircraft cooling system on N91CZ is not standard for the Lancair. The cowling inlets are 2 inches long and slightly forward of the stock configuration. They retain the 3.5 inch nominal diameter in the throat for a total area of 19.2 in^2. These feed into a fully sealed plenum chamber through two diffusers. The oil cooler (SW10599) is located in front of the #2 cylinder. The face area of the cooler is partially blocked with 21 in^2 exposed. The cooler exit air is funneled towards the engine centerline through a 5 in^2 opening, in addition to a 1.5 inch diameter duct for cabin heat air. The cowling exit is approximately 50 in^2.

Figure 1, Cooling System

Figure 2, Oil Cooler

Test Setup

Pressure data was taken with a spare airspeed indicator (ASI), UMA 40-200 kts, SN B4157 (Fig. 7). Piccolo tube probes were made of 3/16 inch and 1/4 inch diameter aluminum tubing for measuring static pressures above the engine(Fig. 3,4), at the cylinder exits(Fig. 5), the cowling exit (Fig. 6) and both the oil cooler inlet and exit(Fig. 9). A pitot tube was fabricated for measuring the velocity in the throat of the inlet (Fig. 8). In groups of three, the probes were plumbed to a central manifold with needle valves on each leg. For most tests the main line off the manifold was plumbed to the pitot side of the test ASI and the static side of the test ASI was plumbed to the aircraft static system. Prior to testing both the test ASI and the aircraft ASI were calibrated using a water manometer. The aircraft ASI read slightly low across the envelope, while the UMA test ASI had a parabolic excursion in the mid range, reading too high. Both errors would have led to results higher than actual. The resulting calibration curves were used to correct for instrument error in the measured data. After connecting the test equipment, a pitot-static check was performed to ensure a leak proof system.

Figure 3, Piccolo tube above engine

Figure 4, Piccolo tube above engine

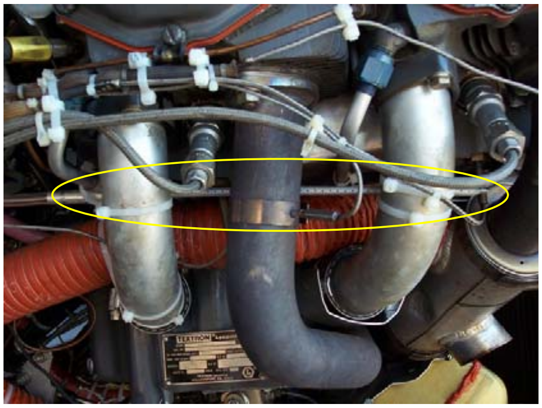

Figure 5, Piccolo tube below cylinders

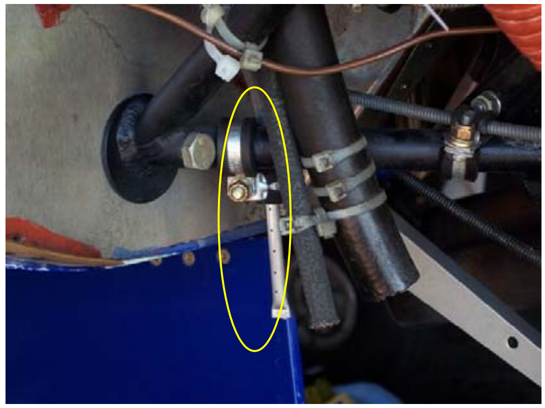

Figure 6, Piccolo tube at cowl exit

Figure 7, UMA Test ASI

Figure 8, Inlet Pitot Tube

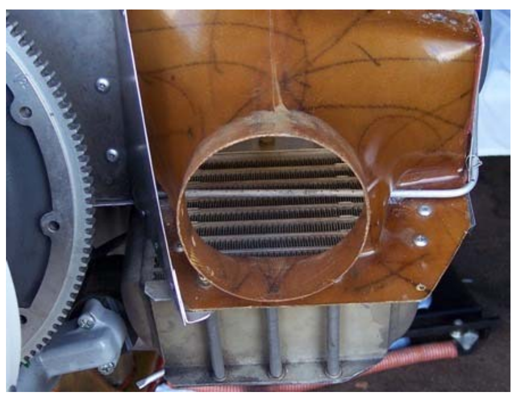

Figure 9, Piccolo tube in front of Oil Cooler

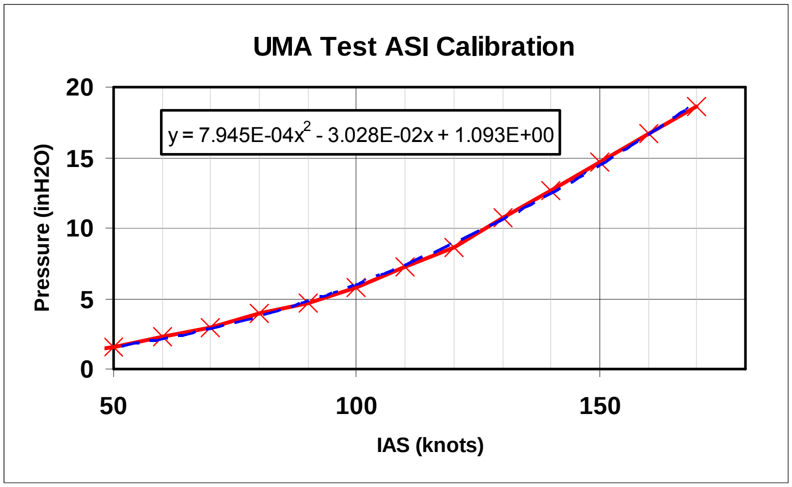

Figure 10, Test ASI Calibration

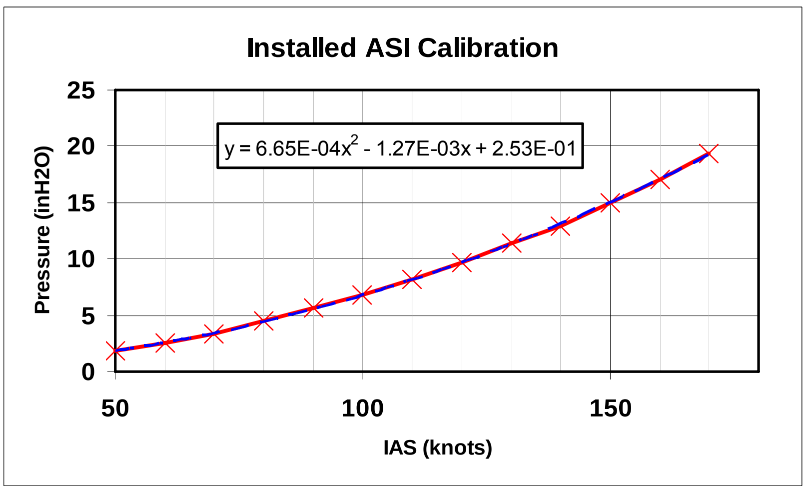

Figure 11, Aircraft ASI Calibration

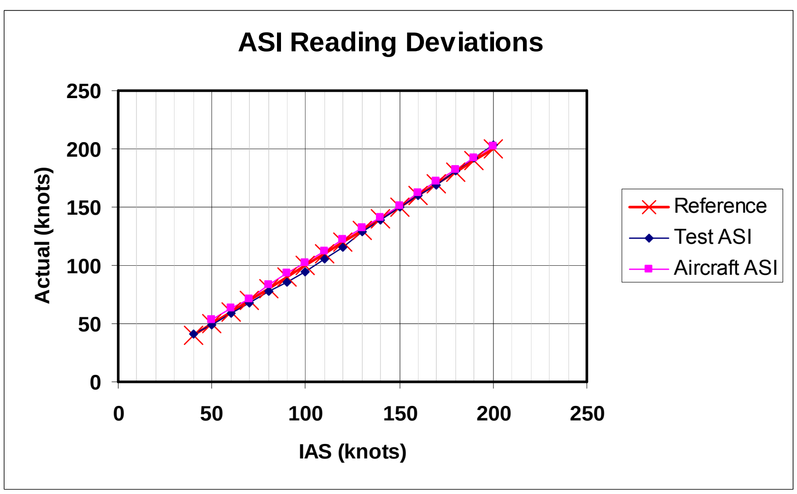

Figure 12, ASI Error

Data Collection

Measurements were taken on three separate flights. Since the switching manifold only had three incoming ports, a minimum of two flights were required for all six measurements. During the first flight, upper and lower engine pressures and cowling exit pressures were recorded. Measurements were taken on 10 knot intervals from 80 to 200 IAS. On the second flight, oil cooler inlet and exit pressures and inlet velocity were measured. A third flight was added with the test ASI plumbed across the oil cooler to get a direct reading across the cooler. This was done to reduce the amount of error in taking the difference between two separate readings that were very close to each other.

Data was collected at 7,500 +/- 1,000 feet. The higher indicated airspeeds at that altitude required a descent during measurement even at full power.

Results

Static pressure measurements are shown in figure 13. The computed engine pressure drop is shown in figure 14. Lycoming chart 13245-B, (Cooling Air Requirements 0-360 & IO360 180 BHP) (Fig.15), provides pressure drop and mass flow data that define the upper operating thermal limits for the engine. As expected, based on temperature history, the engine operating points are located in a very favorable region, well clear of maximum temperature limits. (A similar chart exists for the O320/IO320 series engines. The pressure drop/mass flow curves are identical. Less air flow is required, however, due to the lower heat generation of the 320 series.)

Pressure drop across the oil cooler is shown in figure 16. Using Stewart Warner cooler performance curves the air side mass flow through the oil cooler was determined. There was relatively little pressure drop across the oil cooler. There was, however, a significant pressure drop between the oil cooler exit and the cowl exit pressure. This may be the result of the constricted exit area of the funnel attached to the bottom of the cooler. Only 5 in^2 is available for exit air from the cooler to enter the lower cowl area.

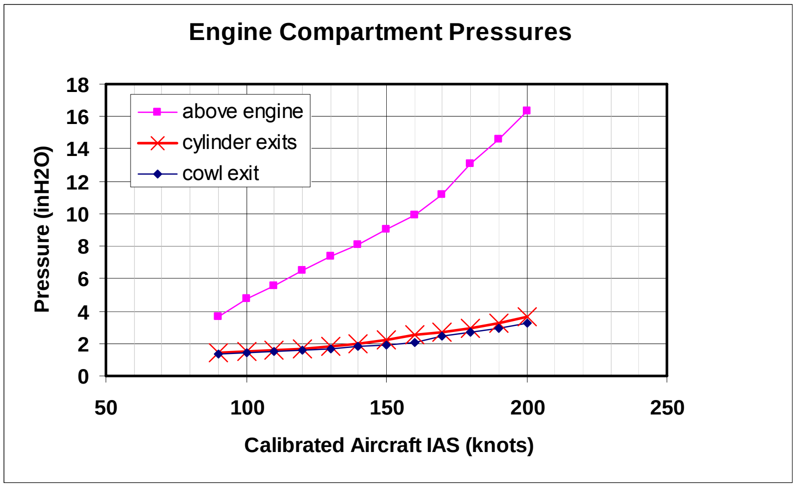

Figure 13, Engine Compartment Pressures

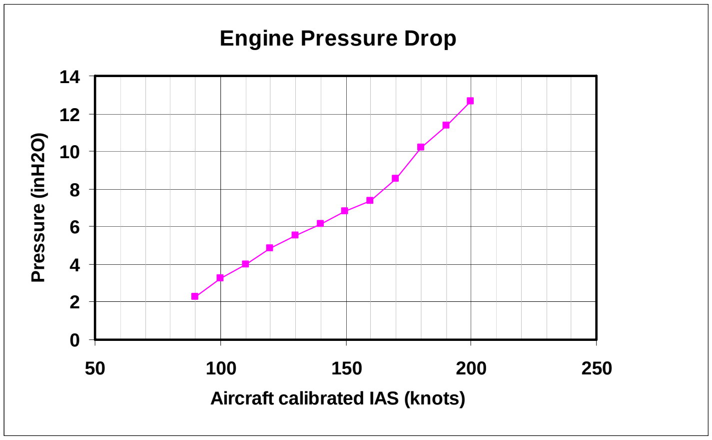

Figure 14, Engine Pressure Drop

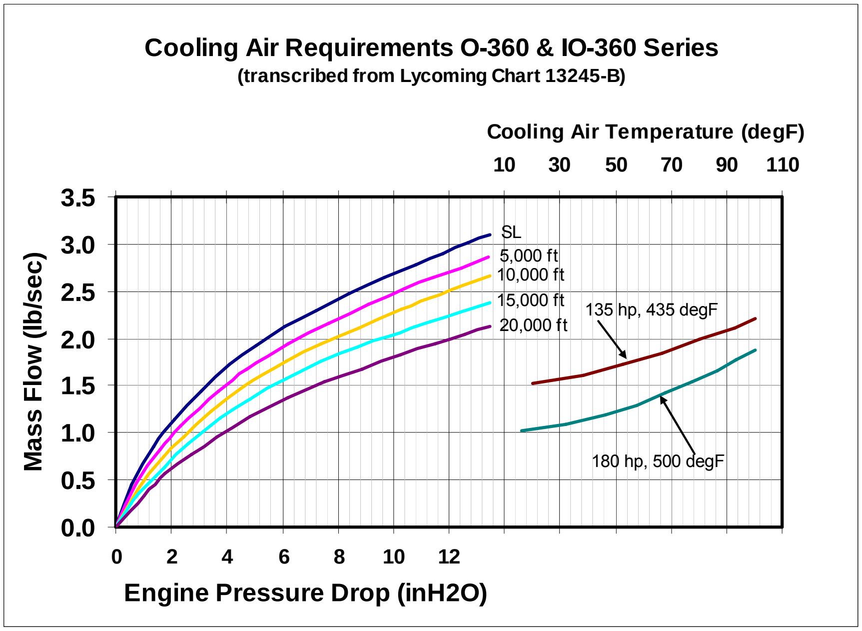

Figure 15, Lycoming Cooling Air Requirements

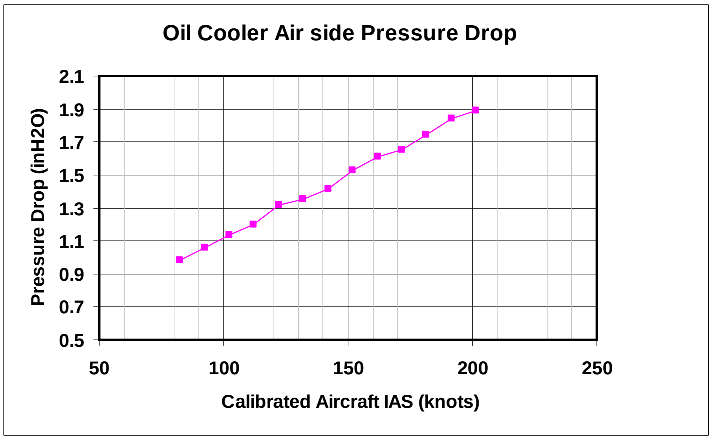

Figure 16, Oil Cooler Air Side Pressure Drop

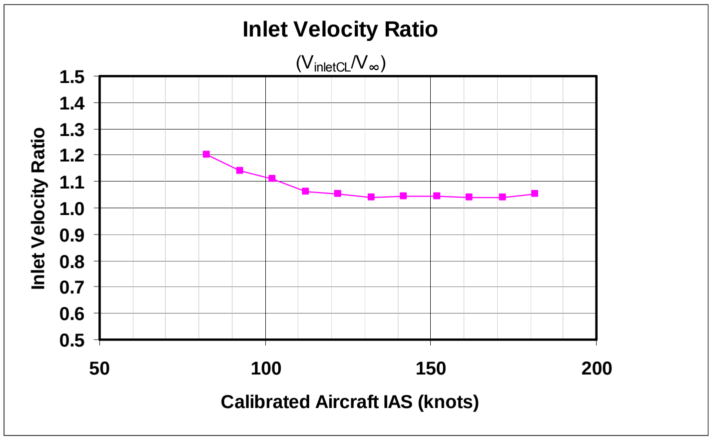

Figure 17, Inlet Velocity Ratio

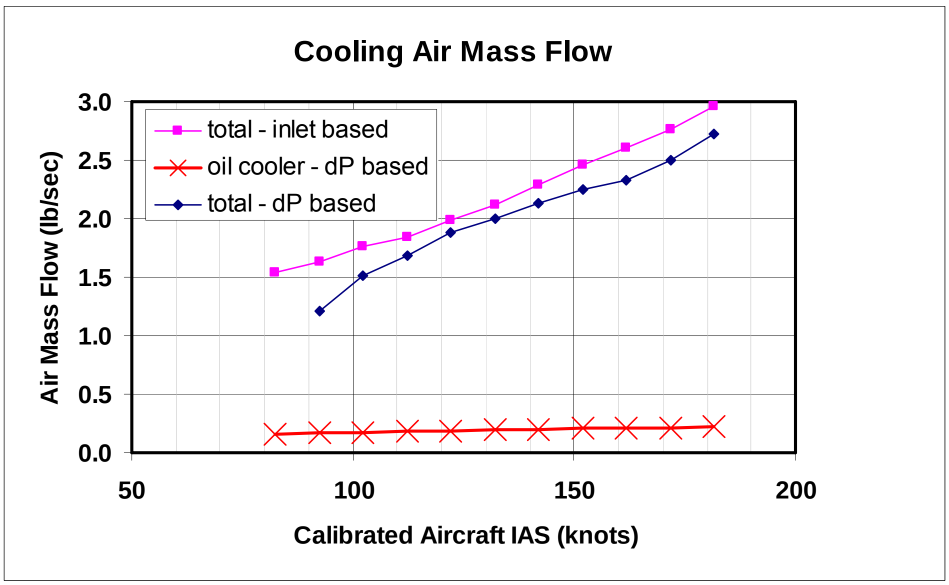

Figure 18, Cooling Air Mass Flow

The oil cooler mass flow was added to that derived from engine pressure drop to determine the total mass flow. This total was then compared to mass flow obtained via inlet velocity measurements.

Inlet velocity was measured in the throat of the cowling inlet. Only the centerline velocity was measured. The velocity profile and the ratio of average to centerline velocity are not yet precisely defined. A mapping of the velocity profile using rakes may be done at a later date. Until the profile is actually measured, the following assumption will be made. The Reynolds number for the inlet throat ranges from about 200,000 to 600,000 over the operating speed range. The flow is clearly turbulent in this region, but will not be fully developed, having just barely entered the duct. Fully developed flow with the given Re values would reduce the average velocity to about 0.86 of the measured center line velocity. This ratio would cause an excellent fit to the data. However, this assumption is not valid until several diameters down stream. Given that the measurement is so close to the duct entrance one would not expect to see anything close to fully developed flow. There may be other factors influencing this ratio: The proximity of the passing propeller, the converging/diverging duct, slip stream angles and so on. For preliminary evaluation a ratio of 0.9 was used.

A comparison of engine mass flow rates computed via pressure drops and using inlet velocity is shown in figure 18. The measured inlet velocity ratio is shown in Figure17. The inlet velocity ratio is near 1.0 across the entire speed envelope. This is not typical of cowling inlets seen in general aviation. A more typical range is 0.3 to 0.7 where a substantial portion of the pressure recovery is done in front of the inlet. A potential down side to a high velocity ratio is the propensity for large losses during expansion of the flow past the inlet. This is typically the more difficult place to achieve good pressure recovery. With such high velocity air passing through the inlet, the need for controlled expansion behind the inlet is amplified.

Despite the very high velocity ratio, the static pressure and Cp obtained in this installation is very good. The values achieved are equivalent to those measured in the NASA report CR3045 with much lower inlet velocity ratios. Extrapolating the trend found in the NASA report indicates that the pressure recovery achieved in this test would far exceed the values measured in the NASA report. The extent to which good diffusers were design and built for the NASA test was not well documented. Cp ranges measured in the Lancair ranged from 0.60 to 0.75 for a velocity ratio near 1.0. The NASA test indicated 0.60 for an inlet ratio of only 0.6, the highest ratio tested.

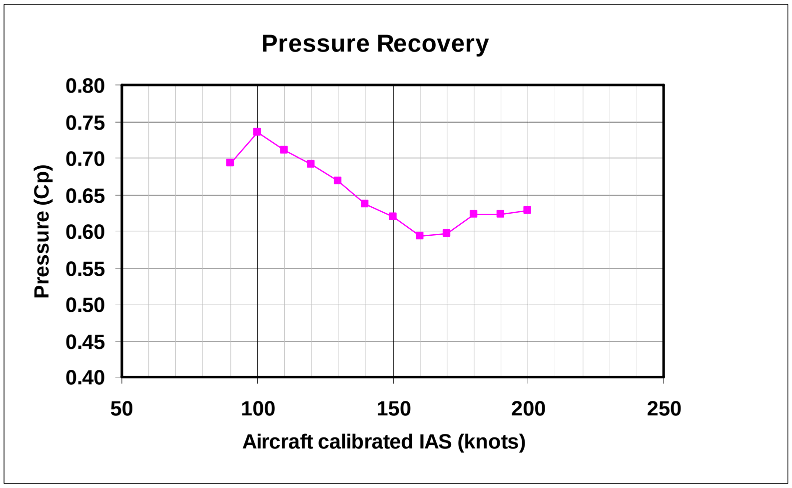

Figure 19, Plenum Pressure Recovery

Conclusion

Despite an unusually high inlet velocity ratio, the current cooling system configuration is very effective in terms of both pressure recovery and cooling. The measured inlet velocity ratio indicates complete dependence on internal diffusion for pressure recovery. This validates the effectiveness of the diffusers. Air flow was found to be more than required for adequate cooling and could be throttled by reducing exit area.