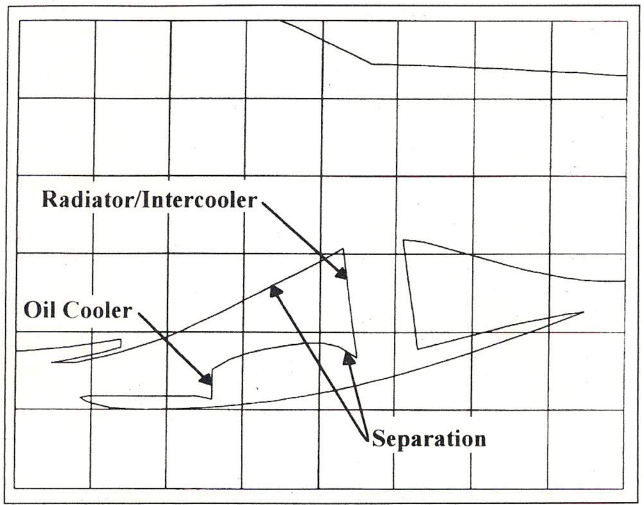

Figure 10. Calculated separation locations in the Mustang cooling system.

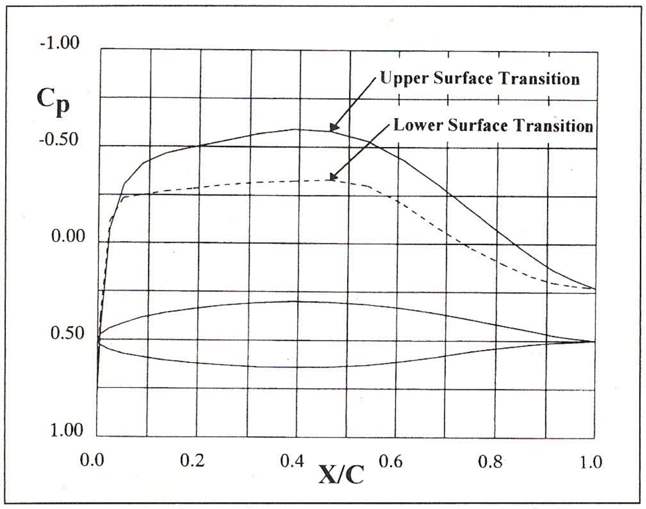

Figure 11. Calculated Mustang wing aerofoil pressure distribution.

was determined that the Spitfire cooling system drag, expressed as the ratio of equivalent cooling drag power to total engine power, was considerably higher than that of other aircraft tested by the RAE. This was attributed to "the presence of a boundary layer ahead of the duct tends to precipitate separation and makes the ducting problem more difficult"[16]. Similar problems are present on the early model Messerschmitt Bf109, up through the E model. A complete redesign of the cooling system, during development of the Bf109F, resulted in the use of a boundary layer bypass duct, which significantly improved the pressure recovery at the radiator face[17].

P-51 ANALYSIS HIGHLIGHTS

Early models of the P-51 also experienced boundary layer separation in the radiator inlet duct. Pilots reported a rumbling noise emanating from the duct work behind and beneath the cockpit on early model Mustangs. A complete Mustang fuselage was installed in a windtunnel at the newly opened NACA Ames Research Center to investigate this phenomenon. It was found that the rumble was the result of the separated flow in the cooling inlet duct striking the radiator[18]. Changes, both in duct shape and the addition of a deep boundary layer splitter on the inlet eliminated the rumble and improved the aircraft's cooling. The results of these changes can be seen in the VSAERO boundary layer calculation, which shows that boundary layer on the upper surface of the cooling system does not separate until far back in the duct (Fig. 10). The boundary layer on the lower surface of the duct, starting fresh behind the oil cooler makes it to within inches of the water radiator and intercooler before separating. The losses in this system are much lower than those of the Spitfire. This efficient cooling system arrangement is credited with much of the Mustang's superior performance over the Spitfire.

The P-51 Mustang is renowned for being one the first aircraft to make use of aerofoils capable of extensive runs of laminar flow. Both the Spitfire and Fw190 use aerofoils which do not support laminar flow. A two-dimensional cut through the wing pressure and skin friction distributions calculated by VSAERO (Fig. 11) shows that, at a representative cruise condition, the wing was capable of sustaining long laminar boundary layer runs, with transition occurring at roughly 47% of chord. However, this calculation is for an ideal case, for a wing without fasteners, gaps, misalignments or waviness. During World War II, a Mustang was flight tested by NACA with a wake rake behind the wing at roughly 66·7% semispan[19]. The results of this test show that, in service, the aircraft was unlikely to have a substantial laminar flow on the wing. Testing in an as-manufactured condition showed slightly lower drag and further, when the wing was refined to remove waviness and surface imperfections, a drag level was measured indicative of a substantial region of laminar flow. Wartime windtunnel tests of the Mustang's wing aerofoil in Germany gave similar results[20].

Fw190 ANALYSIS HIGHLIGHTS

At the time that the Fw190 first appeared in combat, in 1941, it was superior to the contemporary fighters on nearly every count. When the first flyable Fw190 was captured by the RAF in 1942, a thorough evaluation revealed the Achilles Heel to be a harsh stalling characteristic, which limited its manoeuvre margins[21]. This is no doubt in part due to the NACA 230XX aerofoils used in the wing design, which exhibit a sharp stall. A comparison of the calculated local wing lift coefficients at the aircraft's stalling speed (127 mph, flaps up) with the estimated two-dimensional lift coefficients of the aerofoils at the stall (Fig. 12) sheds more light on this behaviour. It can be seen that approximately the inner 40% of the wing reaches C_{lmax} at the same aircraft angle of attack. A wartime Focke Wulf report[22] indicates that at higher loading conditions elastic deformation of the outer wing shifts the load distribution outboard. This would cause even more of the wing to reach

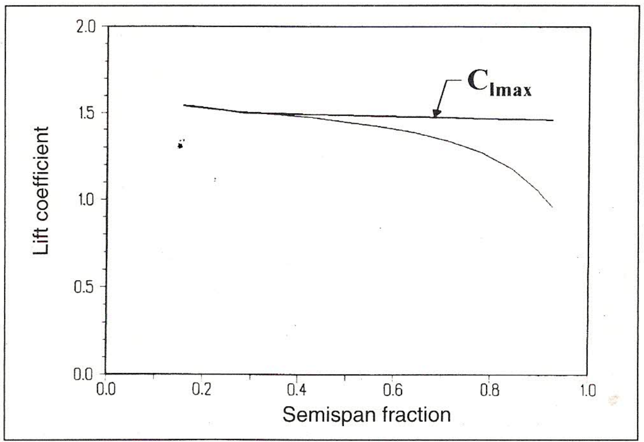

Figure 12. Fw190 calculated lift coefficient distribution at 1g stall.