Dear Mr. Byrnes,

May 24, 1946.

I wanted to thank you and acknowledge receipt of the two papers on the Mustang. They are a welcome and very desirable addition to the Mustang Collection, which is still growing.

We have known here at the lab for many years (since the 40's) about the net positive thrust of the radiator ducting, and the value of the variable exit flap. The comparison and contrast with the Spitfire is very interesting—and worthwhile. One can never know, but only speculate, how many more German aircraft would have been downed, or conversely, how many British pilots would have been saved by the higher speed Spitfire. The great potential increase in speed (all important at the time) would suggest hundreds at least—of both.

Jack Reeder, who was a Langley test pilot (eventually Chief Test Pilot, and Division Chief) from the early 40's, and who flew many Mustangs (including NAT3), never tired of talking about the value of the radiator ducting. He also liked to talk about the "tail tail," a Langley innovation, and how that helped lateral stability and control (important for a war-time gun platform, no?) The tail tail was finally on the "H" model, I believe, but never on the high production "Bs" & "Ds" for the War.

Again, Thanks

Richard T. Layman
NASA Langley, Historical Program Manager
A Lo-Tech Analysis of the Meredith Effect on the P-51 Mustang Airplane

This subject has been misunderstood or poorly described in literature available to me, and even Meredith's original report No. 1683 in 1935 does not seem to have been clearly understood by a considerable number of airplane designers in the 1930's and 1940's. Basically, modern mathematical tools, including finite element analysis and Navier-Stokes equations, are not necessary to describe the phenomenon in approximate terms. Neglecting small fractions and secondary aerodynamic effects at the speeds involved, the result can be calculated by elementary algebra to a reasonable degree of accuracy.

First, we must agree on a minimum speed at which full cooling balance must be maintained in a climb at that altitude—say 25,000 feet—and the radiator is sized for minimum pressure drop.

The power required—power available chart, but with a propeller, it must indicate a fairly wide band around rate of climb, probably showing maximum available for climbing somewhere near 200 mph (true) at 25,000 feet. I have selected 180 mph, or 260 feet per second, at this altitude as the minimum full power speed for cooling. At 25,000 feet air weighs .034 pounds per cubic foot and \( \rho \) (Rho) is .00106 mass units per cubic foot.

Thus pressure = \( \frac{1}{2} \times .00106 \times (260)^2 \) = 35 pounds/square foot.

We can consider back pressure as zero with the exit open, so the pressure drop is also 35 pounds. At 437 mph, or 640 feet per second, the dynamic pressure is 220 pounds per square foot. If we close the exit just enough to produce a back pressure of 185 pounds per square foot, we maintain the pressure drop of 35 pounds and produce the pressure jet. (This neglects the low velocity of the flow through the radiator.)
The velocity of the jet can be determined by two approximate methods—first the hydraulic analogy:

$\text{Head} = \frac{P}{W}$

$W$ of air $= .034$ pounds per cubic foot at 25,000 feet

$H = 185/.034 = 5500$ feet which would be the depth of the atmosphere above the airplane to produce 185#/sq.ft. pressure if the air were incompressible.

$\text{Velocity} = \sqrt{2gH} = \sqrt{64 \times 5500} = 590$ ft./sec.

Alternatively, an identical value can be obtained from

$\text{Pressure} = 1/2 \rho V^2$

$\text{Velocity} = \sqrt{2 \times 185/.00106} = 590$ ft./sec.

Concerning the location of the reaction to the jet or "push," it is, of course, on the rear face of the radiator. This is easy to sustain in the hydraulic comparison where the unbalanced pressure inside a tank with an open side orifice discharge is equal and opposite to the dynamic impact pressure of the jet stream.

This force restores most of the momentum (mass x velocity) to the air, which was lost in passing through the radiator.

An excellent reference is the Encyclopaedia Britannica under the rubric "Jet Propulsion." In a rudimentary way the cooling system processes air in the same way without the fuel burning. While the text may be somewhat different in later editions, my copy has the following equation for the cycle neglecting the weight of the fuel—equation (2):

$$F = F_p + W_a / g(V_1 - V_0)$$

Where $F$ is total thrust and $F_p$ is propeller thrust, which is not applicable, $W_a$ is weight of air per second, $V_0$ is vehicle velocity in the air (640 ft./sec. at high speed), $V_1$ is velocity of the exhaust jet relative to the vehicle (590 ft./sec.), and $g$ is the gravity constant, 32.2 ft. per sec., per sec.

To obtain the weight of air ($W_a$) passing through the radiator, assume the outlet area to be one square foot (which it actually is, approximately). The volume is then $V \times$ area or 590 cubic feet per second or $.034 \times 590 = 20$ pounds per second.
Using the derived velocities and this weight of air:

\[ F = \frac{20}{32} (590 - 640) = +370\# \text{ (thrust)} - 400\# \text{ (drag)} \]

\[ = -30\# \]

Being a negative number, the result is the net drag of the cooling cycle. The total airplane drag is equal to the full power propeller thrust or 1360 horsepower (1 hp = 550 ft. lbs./sec.) x 550/640 which, with 85% propeller efficiency, equals 1,000# total thrust and/or drag.

This number is consistent with the approximately 3% of total drag for cooling purposes (see Mustang's Margin). Of course, the air scoop profile affects the watted area and form drag of the airplane.

As I indicated, the methods are crude, but I think this sort of illustration helps to focus the fundamentals. I would confuse this method with a rigorous analysis.

Some additional factors could be mentioned. The exit is quite critical, and I have a short article here in 1942 by the Rolls-Royce Experimental Department outlining the difficulties of properly mechanizing a control factor to take full advantage of the exit discharge through heat. The temperature lag and sensor response time made essentially unmanageable with the electrical or thermal response equipment available at that time. The Mustang installation did not solve this problem either and provide continuous and infinitely variable control which would have optimized the energy recovery for all flight conditions. However, the radiator cooling capacity allowed the exit closure to be in its minimum opening position for most of the time, and this opening—approximately one square foot—was well selected by the power plant engineers and, though not always optimum, served the purpose very well.

It is also interesting to note that the 400# drag from the equation above would have reduced the Mustang speed to about 370 miles per hour, comparable to that of the P-40 or the Hurricane, if no restoration of the momentum to the cooling air had been provided.

J. Leland Atwood
6/1/96
June 14, 1996

Dear Dicki:

Thank you for your prompt and kind response to my letter with the all-weld P-51 stories. I showed it and made a copy for him, and he was very pleased with your comments. He had just finished a more detailed and technical paper on the Meredith Effect, which I do not understand, as an addendum to the papers I sent to you, and gave me the edited copy to send on to you. Incidentally, if you want to get any further information on the P-51 or any other NAA aircraft for that matter, let me know, or you could contact him directly at 1691 Alta Mira, Pacifi Pkwy, CA, 90272.

Warren Clark & Sklar
I am also enclosing a copy of the cover page and address of a very good book published by the Rolls Royce Heritage Trust about the P-51 and the Merlins, and a lot more. If you don't already have it, you might want to try to acquire one. By coincidence I'm leaving next week for three weeks in England, and hope to go back to the Imperial War Museum Aircraft Museum at Duxford, where some of the test flying on the Merlin installation was done. (Incidentally, the RR book talks about "the tail tail" on the P-51 H.)

I was talking yesterday to a friend of mine, Al Blackburn, who was the test pilot at NAA on the F-100 ZE.
"Zero larceny" program and was much involved in the Air & Space article recently on it and the V-2 "Reenactment of Fire," and I also working on a book on the F-86 and supersonic flight. I gave him your name as a possible source of information, and if he calls, you may find him a good source for a lot of information that may be helpful. I'd just to thank you for the Jack Reeder article, excellent. See Atwood had called him Nebraska and I gather they're walk said that his memory is failing (or has...
failed) is that true? she would be a good source.

Anecdotally, I saw last week at the Santa Monica airport a "Hurricane" take off - great fun and a feast for eyes. Nice museum there, they also have a pair of beautiful flying Spirit drones.

Thanks again for the invite.

Best regards

Dear Byrnes,

P.S. The Rolls Royce book is Britwood's; I just mine, otherwise I would lend it to you.

BYRNES
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Cover: AL965, the fourth mustang to be converted to take the Merlin 65. Seen here it features the
dorsal extension to the fin, later removed and replaced by an increase to the chord giving an
additional 3 sq ft of area. The photograph was taken at Duxford where the aircraft was under
evaluation by the Air Fighting Development Unit. (Photo. Cliff Gladwell).

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Mustang RA's

Q15