I Dedication to Performance by North American Aviation Management

The real key to the outstanding performance and control of the Mustang P-51 was attributable at the start and throughout its life history to the dedication of the North American management not only to basic structural design, packaging, etc., but to a strict adherence to the scientific principles necessary for good performance and control. This is indicated by the following examples.

A. Low Drag Airfoil

1. Gains vs. Risk.

This concept was a tremendous risk as the only data available was one NACA report of tests on a 25% thick airfoil. There could have been poor stall characteristics, stability and any number of unknowns. Yet the North American management had the faith to go ahead with this airfoil design. Much has been said about the results and the differences between conventional and low drag airfoil, which therefore will not be discussed.

On the first series of P-51's a nominal thickness section was used that would give the drag gains and yet minimize the risk. Slipstream and maintenance factors were also considered. This became important later as bomb racks
and other attachments were added to the airfoils. The airfoils selected proved quite good. Later on, in the G or H models, a new series of airfoils was adapted after discussions at Langley Field with Jacobson and others involved in airfoil design. At this time, a little more advantage was taken of the laminar flow by extending the peak negative pressures back from the 40-50% airfoil originally used to 50-60% airfoil. In the early P-51's it was necessary to compromise the laminar flow shape inboard because of the landing gear thickness requirements. However, this was eliminated on the P-51-G's and H's when smaller tires and wheels were available.

2. Wing Tip Shape

Tip shape of the wings was quite important. The one used not only produced good stall characteristics but also reduced drag. (See Sketch 2) It is a relatively minor point but indicates detail utilized in developing the 51 design. The square shaped wing tips preserves the laminar flow characteristics throughout to the tip whereas a rounded tip precludes laminar flow or spreads the vortex over a greater span. I took a 1/4 scale model of the two wing shapes to the University of Washington wind tunnel (only tunnel available large enough to allow tests without tunnel wall interference) and was greatly impressed with the improvement in stall characteristics, maximum lift and minimum drag.
3. Ailerons

The early ailerons were of a rounded nose shape and, although fairly close tolerances were observed, the air flow could go from one side to the other. For instance, at a high angle of attack there is a more positive pressure on the bottom than on the top and air flow will pass through gaps creating more turbulence and more drag. To obtain better control a paddle balance aileron (see Sketch 2 under control section) was adopted which also gave less drag.

B. In-line Engine

1. Ideal Fuselage Shape

The next major performance factor on the Mustang was the selection of an in-line engine in contrast to a radial engine. This gave an ideal thin nose shape to enter the air and spread the stream lines as gradually as possible.

2. Location of Cooling

The in-line engine also made it possible to locate the coolants and oil radiators in an advantageous position at the bottom of the fuselage slightly aft of the maximum thickness of the wing. This very important feature helped, along with the thermodynamic and aerodynamic features which worked out extremely well in
practice. Normally the heat passing into the radiators from the engines would be wasted. However, with air entering through the inlet being allowed to expand and slow down, the pressure increased and more heat was extracted from the radiator fins. The hotter air squeezed down and exited at a higher velocity.

This can be explained by considering an aircraft which moves through the air, picks up a molecule of air, brings it up to speed and then lets it out the back end at the same speed as the aircraft. This is an energy loss. What is desired is that the molecule be affected as though it hadn't been touched. This is what happened with the P-51 radiator. The molecule exiting at a high speed in the opposite direction to the aircraft meant the molecule would have been at zero velocity and act as though it had not been disturbed.

At one point this design began to look very bad as it was not producing the predicted effects. We were in the low speed tunnel at California Tech at this time and the air was not slowing down passing through the radiators. Therefore, it appeared that full scale application with a full scale radiator would not work. This was solved by one of the main inventions that came out of the P-51 effort, that of boundary layer
control or moving the inlet away from the adjoining body. This was very important as experimentation showed the lip of the radiator duct should be lowered about an inch from the fuselage. More than this gave improved radiator performance but increased the frontal area which increased the drag. Therefore, even though the inlet wasn't completely out of the turbulent boundary layer it was at the optimum position to give minimum external drag and the best internal airflow and thermodynamic performance. It can be stated that this boundary layer control in the radiator, the coolant and oil arrangement, and the low-drag airfoil were the outstanding attributes of the P-51 that gave it a phenomenal performance compared to competitive aircraft. Other aircraft had pretty much the same engines, propellers, metals, etc., but it was these scientific breakthroughs that made the Mustang what it was. Boundary layer control was also used on the P-51 and various models where the carburetor air inlet was on the top and, at high angles of attack, there might be a tendency for the airflow not to be uniform within the air duct. Therefore the same principle was used and the inlet was moved away from the adjacent fuselage to allow the turbulent air to pass by and allow the good air to enter the carburetor.
3. Propeller Selection

During this work on the in-line engine North American at all times had the valuable assistance of the technical people of Curtis Wright, Aero Products, and Hamilton Standard. These men and the aerodynamicists at North American had a good working relationship. In terms of the overall design, North American specified and obtained the gear ratios they wanted and propeller sections and plan forms, etc. It may not be recognized, but a great amount of work was done on shapes, cross sections of airfoils on the propeller, the plan form, cuffs near the spinner, spinner relationships, and so forth. All of this work contributed significantly to the performance.

4. Exhaust Stacks

A time came when there was a lot of pressure exerted by the military to come up with flame suppressing exhaust pipes on the craft for night operations. The ideal way would be to put on a 10 ft. muffler which would reduce detection of the aircraft at night. On the hand, this would mean great performance decrease. It was found that by going to some short stacks, good suppression was obtained although the noise would increase greatly. By increasing the exit flow velocity of the gases it was possible to get momentum gains and a small
increase in speed. Therefore this short stack arrangement was adopted as much as possible.

C. Faired Lines and Packaging

1. Second Degree Curves

Early in the design a relationship was worked out for the three dimensional body and that was the use of second degree curves. This means that the same application of the optimum pressure rise used to give laminar flow on a two dimensional wing was applied to three dimensional bodies. In those days the little work done on the drag of bodies was all empirical and used for different shapes such as in the report which shows the drag of fixed landing gears. This really doesn't tell how to theoretically design for minimum drag.

When air flows with no interference, the stream lines are all moving parallel to each other. With the second degree curves on the body, the stream lines are bent to go around the body with the minimum distortion. With a blunt body, for instance, the stream lines would have to bend sharply and be closely compressed. Then if they flowed around the front of the blunt body they would separate and, with turbulent flow, there would be a very high drag. By using a second degree curve, it was possible on all portions of the aircraft for the designers,
after changing some packaging, to come up with the minimum drag.

At the behest of the management, the designers and scientists worked closely together so that everything done on the airplane would give better performance. When it first became apparent that drop tanks would have to be used, this was a real blow to the aesthetic sense of the aerodynamicists. However, it was possible to streamline (second degree curves) the racks and tanks. Also on early tanks, "throw-away" swag braces were employed to further reduce the drag after the tanks were ejected.

2. Minimum Leakage

Any parts of an airplane which have high pressures inside or low pressures on the outside will have leaks creating disturbances and an increase in the drag. In all applications, particular care was taken with the detail to minimize any leakage. Also parts such as cowlings, gun bay doors, were made with a large number of fasteners for stiffness and prevention of leaks.

D. Outstanding Control Characteristics

This facet is another phase of performance and illustrates the attention to obtain the best. Early designs of the P-51 were criticized for possible high lateral stick forces to
move the ailerons and obtain high rates of roll. The original aileron as shown in Sketch 3 used a conventional radius. At a later date a balancing tab was used. A lot of thought was given to some kind of a leading edge balance, an aerodynamic balance, that would reduce the forces along with the high deflections required to get a good rate of roll. Normal overhang balances with high drag were rejected. As soon as possible in the design history, a so-called paddle wheel balance aileron was adapted. This gave the same effect as a conventional leading edge balance, but without its drag. Also, in this application, as shown in Sketch 2, a cloth seal was used to obtain the maximum pressure differential to give the balancing action to reduce stick forces. At the same time, as mentioned earlier, there was no leakage of air from either side of the wing to increase the drag. Remarkable roll and turning performance was obtained and was of great use in combat.

E. Miscellaneous

The high performance and the good control and stability of the P-51, lasted until many demands were made on the aircraft such as aft fuselage tanks. Then a bob weight was added to try to keep the stick forces during accelerations within safe limits.
The good control from the ailerons as mentioned above, the good speed and rate of climb, and good dive handling characteristics of the P-51 were responsible for its tremendous superiority over enemy aircraft during World War II.
II Kindelberger - Hunt Meeting

To illustrate the dedication to good performance of the management and the entire team at NAA there was an occasion when Larry Waite and I were staying at the Biltmore Hotel in Dayton, Ohio. We were there on some business with Wright Field and at about 11:00 one night we each were roused out of bed by Ronnie Burla who was the NAA Dayton representative, asking us up to his suite on the top floor where Mr. Kindelberger wanted to see us. So we dressed and went up. Mr. Kindelberger was there in a meeting with Mr. O. E. Hunt who, as I remember, was the Executive Vice President of General Motors, which, I believe, owned about 22% of the stock of North American.

The discussion centered around the question of why we weren't using more Allison (a division of General Motors) engines in the P-51 and why we were staying with the Rolls Royce Packard-built Merlin engines. Mr. Kindelberger explained to Mr. Hunt generally, how the heat flow and balances of the Merlin were much more adaptable to the coolant and oil radiator configuration mentioned earlier, producing better performance of the aircraft. Also, the gear ratios, superchargers, and characteristics of the Merlin were better than the Allison's by a significant amount. Hunt, I think, mentioned we could go to the P-40 arrangement with the radiators up front, etc., which would forfeit completely the large increment of performance. Mr. Kindel-
berger wanted Larry Waite and me to verify how many miles an hour this would sacrifice, etc.

Then Mr. Kindelberger mentioned other aspects such as the Merlin manufacturer, Packard, would always work with us in terms of anything we requested to help the packaging and cut the drag. For instance, at one time the Allison engines had a spark plug wiring problem that made us bulge out the cowling on the engine and destroy our second degree curve attempts at minimum drag. On the other hand, Merlin willingly made the changes and helped us get a low drag configuration.

These are just two of the several points covered at this meeting but in the end Mr. Kindelberger turned on and said, "This is it. We are out to build the best performing fighter in the world and we just can't go back to the Allison. We are going to stay firm." Mr. Waite and I were excused at this point and I don't know what else was said, but from then on the Packard engines prevailed. A few Allisons are used in P-82s, but NAA remained with the maximum performance arrangement of the Merlin.
III Post War Meeting With Willie Messerschmidt and Professor Modelung

In late 1953 or early 1954, Willie Messerschmidt and his brother-in-law, Professor Modelung, University of Stuttgart, visited the United States. They spent some time on the East Coast and then came out to the West Coast. I was fortunate enough to be assigned as their technical host for the week they were in the Southern California area. During this time we visited various aircraft companies and had panel discussions with the men who had worked on World War II aircraft. In the evenings we would have dinner and further discussions. One evening or two Mr. Ed Heinemann, who worked on Navy aircraft and had been with Douglas in World War II days, participated in the evening sessions. These were very, very interesting and very informative.

Mr. Messerschmidt was very intense and brilliant. He had some knowledge of English but was not too accomplished. He had very piercing eyes, and a very rapid, deep mind. This is almost apparent in his pictures. I considered him to be a very outstanding individual.

Modelung was more of an average appearance. He represented the University in the scientific community in Germany. It seems to be common in Germany that industrialists and universities are often close through family ties. He had a broad grasp of the English language and he knew the science features of avia-
tion very well. He was, in his own right, an outstanding man.

Messerschmidt was not only a brilliant man, but a practical man. He was a good designer. He used his knowledge of aerodynamics although he may not have been a good aerodynamicist. He was the designer type. He could lay things out and package them. For instance, one of his projects he discussed was that, during the early part of the war, he had to come up with a seaplane intended to be used as a troop ship. He was to use non-critical materials, such as plumbing pipe, etc. He was able to design, build and fly such a craft. On a trip through one company's plant, Messerschmidt was shown a problem area where tanks which had been accidentally bumped were being fixed by applying inside pressure (required fixtures, re-cleaning, etc.). He suggested that a piece of rod be welded to the low spot and the rod pulled on to make the fix. The rod could then be easily cut off and filed smooth.

Messerschmidt was in no way apologetic about his role as a designer. He felt his ME109 was a good fighter when it was built. Later, he felt the P-51 was much superior but by then he was into follow-on ME-263s and jets and rocket ships. In terms of total design, he felt he was certainly the equivalent of any of the American designers.
This visit to America was long enough after the war that politics could be discussed fairly openly and his attitude toward Hitler was somewhat patronizing. He was a man who was a success in his own right well before Hitler came into power. Modelung was part of the sophisticated university clan which was very, very strong and powerful socially in Germany. These men considered Hitler an upstart and I think they felt that he had some emotional problems and interfered too much in technical, industrial and war planning decisions to the detriment of the country. They were as patriotic to Germany as we were to America. However, I believe they were very shocked and upset about the things that were done under Hitler's rule as we would be if the roles had been reversed and we had had concentration camps in this country that were unknown to us until after the war. They were members of the international scientific, design and engineering communities; these fields were their main considerations in contrast addition to national priorities.

They were very interested in the P-51. The Germans had conducted many tests on portions of captured aircraft and were fascinated with all aerodynamics and thermodynamic aspects. They had enough data by the end of the war to realize this configuration was a considerable breakthrough, although they had not appreciated its full potential.
Boundary layer control was a concept of interest to them. We spent one full evening discussing the radiator facts, the effect of increasing performance by picking up the heat, etc. It was discussed that if the boundary layer gutter were not deep enough there could be a rumble condition (airflow instabilities and lack of pressure recovery). On the other hand, if it were too far out and into the air stream then the external drag would be too high. These men chuckled appreciatively at this point.

They were interested in all facets of aircraft as, by this time, jets were coming along and during the daytime visits to the different aircraft companies they could observe the state of the art that wasn't classified. This meant primarily the commercial aircraft. However, during the evening discussions, we compared the 109's and told them we had a 109 during the latter part of the war to test and how bad the cooling was on the ground. They said this was because their primary mission in Germany was to build an interceptor to use in colder climates where it worked all right.

The following was not mentioned earlier in the design section of this report, but the advantages of the P-51 installation were not only did we get performance improvement out of the radiator setup, but also the radiator was in the slip stream. This, combined with controlled exit meant good
ground cooling, we really had a breakthrough compared to the 109 in terms that it gave us not only extremely high performance but also a more practical, serviceable machine. As these things were discussed in the one or two evenings that were devoted to the subject, the primary consensus of Modlung and Messerschmidt, and they were in a position to make this judgement, was that the P-51 was unique in combining scientific and practical, inventive concepts. It was the result of the working of the designer and the scientist as a team. There was as much scientific background in Germany but it never got all together in the same way that the North American team got together.

Prior to this time, the designer usually would lay out something and make a three view and an inboard profile and start from there. He would ask the aerodynamicists and somebody else a few questions but it was pretty much the designer's project. The North American plan represented a team approach and it was probably the first time the scientists were brought in as partners in the design project. This concept grew at North American and led to the adoption of the F-86 swept back wing theory for the first time on a production aircraft. The F-100 as the first level flight supersonic, operational fighter, the B-70 bomber, the Apollo project and the space shuttle, and now the B-1 bomber are all evidence of the design ability of a fully integrated project team and weapon system concepts.
A final note on the Messerschmidt visit is a sort of commentary on life in the aviation industry. At one company's luncheon some of the management acting as hosts seemed to patronize Messerschmidt and Modelung. Later on, this same management group were involved in one of the biggest monetary losses on a bad project in the history of American aviation.

In summary, the experience with Messerschmidt and Modelung could be taken as the highest praise of all of the NAA P-51 team.
### Performance Dedication Summary

#### Sketch 1

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<tr>
<th>Item</th>
<th>P-51</th>
<th>Conventional</th>
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</tr>
<tr>
<td>Misc.</td>
<td>Sealing, Props et al.</td>
<td>OR</td>
</tr>
</tbody>
</table>
TIP SHAPE EFFECTS

P-51 TYPE:

CONVENTIONAL, ROUNDED TYPE:

"A" AIRFOIL CROSS SECTIONS IN THIS AREA NOT AMENABLE TO LAMINAR FLOW.

"B" PROBABLE WIDTH OF TIP VORTEX SHEET.
P-51 AILERON IMPROVEMENTS

ORIGINAL:

BALANCING TAB:

"PADDLE" BALANCE:

CLOTH SEAL

NOTE PLUS AND MINUS PRESSURES ON BALANCE BUT NO THROUGH-FLOW