MEMORANDUM For Associate Director

Subject: Comments on Patent Office action regarding patent application of Richard T. Whitcomb for BOUNDARY-LAYER CONTROL MEANS FOR LIFTING WING, Serial No. 696,297, Filed Nov. 13, 1957, Navy Case No. 25432

References: (a) NACA Hqs. Let. to Lang., Aug. 13, 1958, re subject patent application. JAH:ld
(b) Stack, John: Tests of Airfoils Designed to Delay the Compressibility Bubble. NACA TM No. 976, December 1944 (Reprint of ACR, June 1939)
(c) Polhamus, Edward C.: Summary of Results Obtained by Transonic-Dump Method on Effects of Plan Form and Thickness on Lift and Drag Characteristics of Wings at Transonic Speeds. NACA TM 3469, November 1955
(e) Whitcomb, Richard T.: Special Bodies Added on a Wing to Reduce Shock-Induced Boundary-Layer Separation at High Subsonic Speeds. NACA TN 4293, June 1958
(g) Gambucci, Bruno J., and Wyss, John A.: Experimental Investigation of the Drag Due to Wedges Along the Trailing Edge of a Swept Wing. NACA RM A58D15, June 1958

1. The reference (a) letter transmitted to the undersigned the initial Patent Office action on the subject patent dated June 30, 1958. The following comments are submitted to the patent counsel for his assistance in the preparation of a response to the Patent Office action.

2. As pointed out by the patent examiner, the inventions of W. W. Beman, U. S. Patent No. 2532753, and A. V. Stephens, U. S. Patent No. 2800291, are similar to the subject application in that they incorporate additions or modifications to the surface of the wing for improving the aerodynamic characteristics. However, the subject invention differs fundamentally in the specific objective, intended action, and physical form from the inventions of the cited references, as will be shown. Because of these differences, the additions of the subject invention provide significantly greater effectiveness in improving the aerodynamic characteristics of high-speed airplanes.

3. The general objective of the Beman invention is the same as that of the subject invention, that is, to reduce the adverse changes of the aerodynamic characteristics of lifting surfaces, such as wings, which usually develop near the speed of sound. However, the basic approaches utilized in
the two inventions to accomplish this objective are significantly different. It has been established that the adverse changes of the characteristics of such lifting surfaces are due to the direct effect of shock waves which form near the surfaces, and to boundary-layer separation induced by the abrupt streamwise gradients of increasing pressure associated with these shock waves. At the lift coefficients normally utilized in level flight, this boundary-layer separation is usually the major cause of the aerodynamic changes. The specific objective of the subject invention is to lessen the adverse changes of the aerodynamic characteristics by reducing this more important boundary-layer separation, while that of Beman's special wing is to improve the characteristics by reducing the strength of the shock waves. Although Beman does not consider the boundary-layer separation, the reductions of shock strength provided by his modifications could possibly, by chance, reduce this adverse flow. However, because his invention incorporates no other means to specifically improve the boundary-layer flow, as does the subject invention, any such reduction of separation would be relatively small compared with that for the subject invention. Because of this lesser reduction of boundary-layer separation, the improvements of the high-speed aerodynamic characteristics provided by the Beman invention usually should be much smaller than those produced by the subject invention. Also, the characteristics at lower speeds should be less satisfactory.

4. The greater effectiveness of the subject invention, compared with that of Beman's, in reducing shock-induced boundary-layer separation results from several unique actions of the subject invention. These effects are provided primarily by the extension of the subject additions downstream of the wing trailing edge. These actions cause larger reductions of the overall strength of the shock waves, as well as a lessening of the separation associated with a given shock strength. The forward portions of the modifications of both inventions provide reductions of the strength of the basic shocks, which usually form somewhat aft of the maximum thickness on conventional wings. While the detailed actions whereby this effect is accomplished differ somewhat for the two inventions, the order of magnitude of the effects should be similar. However, for the Beman wing, the sharp convex curvatures at the ends of the thicker sections cause severe accelerations of the local flows with associated increases of the local shock strength. The adverse effect of this action offsets to a great extent the favorable effect of the weakening of the basic shock provided by the forward portions of the modifications, so that the overall effective reduction in the strength of shock waves is relatively small. In the subject invention, the extension of the aft ends of the added bodies downstream of the wing trailing edge allows the convex curvature of the middle parts of the bodies to be relatively gradual. Consequently, they do not cause severe local accelerations of the flow, together with associated increases of the overall shock strength, as do the modifications of the Beman invention.

5. Further, in the Beman invention, the pronounced slopes of the aft ends of the thicker sections cause severe streamwise gradients of increasing pressure near the trailing edge of the wing which greatly exaggerate the boundary-layer separation induced by the shock wave. This effect offsets to a significant extent the favorable effect of any reduction in shock strength provided by the modifications. Also, these severe adverse pressure gradients significantly increase the boundary-layer losses at lower speeds. For the
subject invention, with the added bodies extending downstream of the trailing edge, the gradients of increasing pressure associated with the aft ends of the bodies are downstream of the trailing edge of the wing and thus have little adverse effect on the boundary-layer flow on the wing. Also, for the subject invention, the gradual streamwise gradients of decreasing pressure associated with convex curvatures of the middle portions of the bodies partially counteract the increasing pressure gradient associated with the aft portion of the wing with a resulting improvement of the boundary-layer flow. These favorable effects on the boundary layer also essentially eliminate excessive boundary-layer losses at lower speeds. These actions of the subject invention are described in the disclosure of the subject application starting on line 3, page 4.

6. Beman attempts to show a substantial favorable effect of his special spanwise variation of airfoil on high-speed aerodynamic characteristics by comparing wind-tunnel results for a model having such sections with another model having a uniform airfoil with a section indicated by the outer solid line of figure 2 of his patent. Such a comparison is completely unreasonable, since the extremely unconventional airfoil shape used as a basis of comparison has much poorer characteristics than conventional airfoil shapes at all speeds. The characteristics of the special airfoil invented by Beman should be compared with those for one of the conventional airfoil shapes designed to provide satisfactory characteristics for high-speed airplanes and utilized in such airplane designs. Most logically, the comparison should probably be made with a NACA 16-series airfoil (ref. (b)) since such an airfoil is quite close to the mean of the various chordwise airfoil sections of the subject invention. (See fig. 1 attached). Such NACA 16-series airfoil sections were in broad use as propeller sections at the time that Beman applied for his patent. In figure 1 a comparison is made of the variations of drag coefficient with Mach number for a lift coefficient of 0.1 for Beman's invention and for a wing with a uniform NACA 16-series airfoil section, as determined from NACA wind-tunnel data by the procedure described in the next paragraph. It may be seen that at Mach numbers above approximately 0.9, the drag for Beman's airfoil is approximately the same as that for the NACA 16-series airfoil. At Mach numbers below 0.9, the drag for Beman's airfoil is considerably higher than that for a NACA 16-series section. Wind-tunnel experiments of configurations having components with blunt aft ends similar to the maximum sections of the Beman airfoil have indicated that increasing the lift coefficients from the low value of the comparison of figure 1 to those usually utilized for airplane cruise normally results in considerable exaggeration of the adverse effects of the bluntness. The effects of the Beman invention in improving the pitch and lift characteristics of a wing are also very much less than those shown in his patent when the comparison is made with a wing having an NACA 16-series airfoil section.

7. (The characteristics for the NACA 16-series airfoil section shown in the attached figure 1 were arrived at from wind-tunnel results utilizing the following procedure: Since measured transonic drag results depend on the test technique, the wing planform and section thickness as well as section shape, the comparison has been made with results for which these factors are approximately the same as for Beman's test. Beman does not describe the test technique or the aspect ratio or section thickness of the test model utilized in arriving at the drag results presented in his figure 6. However,
at the time his application was proposed, transonic wind-tunnel results were obtained only by what is considered the bump-flow technique. Also, assuming that his test wing was similar to the configuration shown in figures 1 and 2 of his patent, it is probable that the test wing had an aspect ratio of approximately 6, and a wing thickness ratio of 9 percent. Bump-flow results for an unswept wing of such an aspect ratio and thickness with an NACA 65-series airfoil are available (ref. (e)). Characteristics of a wing with an NACA 16-series airfoil have been estimated from these results on the basis of the measured differences between NACA 16-series and 65-series airfoil characteristics described in reference (d).

3. The significant favorable effectiveness of the added bodies of the subject patent application in reducing shock-induced boundary-layer separation and providing improvements of the high-speed aerodynamic characteristics has been demonstrated by extensive wind-tunnel tests at the Langley Aeronautical Laboratory of the NACA (ref. (e)) and by wind-tunnel tests conducted by several aircraft manufacturers. Some of the drag results from reference (e) are presented in the attached figure 2. The variations of drag coefficient with Mach number for a configuration with and without added bodies are shown. The basic configuration is a wing-fuselage combination, the wing having 40° of sweep, an aspect ratio of approximately 6, and approximately NACA 65A210 airfoil sections. (This configuration is quite similar to that of the jet transports now being built.) Five bodies were added to each wing panel, the bodies being designed on the basis of the procedure presented in the disclosure of the subject patent application. Results are presented for a lift coefficient of 0.3 which is close to the values normally utilized in level flight. It may be seen that the addition of the bodies results in a significant reduction in drag at Mach numbers greater than approximately 0.9. At lower Mach numbers, the added bodies increased the drag slightly. This increase can be attributed almost entirely to the skin-friction drag of the added wetted areas associated with the added bodies. Wind-tunnel results not shown indicate that these added bodies also greatly improve the lift and pitching-moment characteristics.

9. A further advantage of the additions of the subject invention compared with the special wing sections proposed by Beman is that such additions may also be used to enclose engines or other bulky equipment. Also, they are more readily applied to existing wings.

10. An indication of the general ineffectualness of the special sparwise variation of airfoil section invented by Beman is provided by the fact that such a variation has not been utilized in any known wing or propeller during the eight years since the patent was granted in spite of the great need for improving the high-speed aerodynamic characteristics of these components during that period. In contrast, because of their distinct usefulness, the added bodies of the subject invention are already incorporated in the design of the Convair 600 jet transport (ref. (f)). This application was decided upon very shortly after the results of reference (e) became available to the Convair engineers.

11. The object of the additions proposed by Stephens is to reduce low-speed boundary-layer separation. Nowhere in his disclosure does he suggest that they will reduce shock-induced boundary-layer separation, the primary object of the present invention. Any possible chance effect of these additions
on such separation almost certainly would be slight. Numerous tests have established the fact that it is considerably more difficult to reduce the boundary-layer separation caused by the abrupt increasing pressure gradients associated with shock waves than to control the separation resulting from the more gradual increasing pressure gradients at lower speeds. Recent transonic wind-tunnel tests of wedges very similar to those proposed by Stephens (ref. (g)) have indicated that these wedges provided no reduction of shock-induced boundary-layer separation. Also, these wedges caused a significant increase of the subsonic drag. It is probable that, as with the modifications proposed by Beman, the pronounced slopes of the rear portions of these additions caused significant increases of the local positive pressure gradients. These increased gradients probably resulted in adverse changes of the boundary layer which offset any favorable effect of the forward portions of the additions. As pointed out earlier, for the subject invention such adverse effects are essentially eliminated by actions associated with extending the added bodies downstream of the wing trailing edge.

12. To indicate more explicitly the object of the subject invention, it is suggested that, if possible, the title of the subject application be changed to: "MEANS FOR REDUCING SHOCK-INDUCED BOUNDARY-LAYER SEPARATION ON LIFTING WINGS". To define the primary unique feature of the subject invention in comparison with those of Beman and Stephens, it is suggested that claim 5 be made part of the generic claim 1.

13. To emphasize other unique features of the subject invention, as well as to describe improvements of the forms of the proposed added bodies suggested by the results of wind-tunnel tests made since the original application was submitted, the following changes of the disclosure are suggested:

On page 2, line 1, add "Such bodies may also be used to enclose engines, fuel, landing gears, flap supports, or other equipment." On page 3, line 6, remove "just ahead of". On page 3, line 9, after "local wing sections" add "or between the maximum thickness and the wing leading edge". On page 3, lines 11-13, remove the sentence starting with "The noses . . .". On page 3, line 14, change "20 percent" to "quarter". On page 3, line 17, after "smooth" add "and the maximum longitudinal slopes are not excessive". On page 4, after line 12, add the following paragraph: "The positioning of the noses of the bodies near or just ahead of the maximum thicknesses of the local wing sections usually results in the most effective reductions of shock-induced boundary-layer separation at low lift coefficients. However, extension of the noses forward to regions considerably ahead of the maximum thicknesses provides the greatest reductions of shock-induced separation at high lift coefficients and the lowest drag at speeds below that for the abrupt increases in shock-induced separation. The location of the maximum cross-sectional area of the added bodies
near the wing trailing edge results in the essential elimination of interference of the adverse positive pressure gradient of the aft ends of the bodies on the boundary-layer flow on the wing with a minimum extension of the bodies downstream of the wing. On page 24, line 23, add the sentence "This reduction in separation may also be accomplished by orienting the axes of straight bodies so that they are approximately aligned with the mean direction of the air flow in the region of the bodies".

14. To further clarify the claims, the following changes are suggested: In claim 1, line 2, add "primarily" after "body", substitute "the upper" for "a" ahead of "surface" and in claim 1, line 3, add "and extending generally chordwise thereof" after "panel". In claim 3, line 3, remove "just forward of" and substitute "between" and after "thickness" add "and the wing leading edge". In claim 6, line 1, add "in part" before "circular". In claim 7, line 2, add "essentially" between "in" and "the". In claim 10, line 2, add "primarily" after "body". In claim 10, move the portion starting on line 3 with "A rear" to line 4 after "having". In claim 10, line 6, remove "just". In claim 12, line 2, add "essentially between "in" and "the". In claim 14, line 2, add "primarily" after "body". In claim 14, move the portion starting on line 7 with "a rear" to line 4 after "having". In claim 14, line 5, remove "just". In claim 15, line 3, add "primarily" after "body". In claim 16, line 3, add "primarily" after "body", substitute "the upper surface" for "a" after "on", and after "panel" add "said bodies having a rear tapered portion extending aft of the wing panel trailing edge".

Richard T. Whitcomb
Aeronautical Research Engineer

Enc. Figs. 1 and 2

RTW, amt

ATM

ECD

JS
MEMORANDUM For Associate Director

Subject: Patent Application of Dr. Richard T. Whitcomb for FUSELAGE SHAPING TO REDUCE THE STRENGTH OF THE INITIAL SHOCK WAVE ON LIFTING AIRPLANE WINGS

Reference: Hqs. let. to Lang., April 29, 1958, re Subject application. JAH:ld

1. In answer to the rejection of claim 1 (ref. let.) by the U. S. Patent Office, the following comments are offered: The indentation of the Walker patent is ahead of the wing, while that of the present invention is opposite the wing in the longitudinal direction. The indentation of the Walker patent would not accomplish the objective of the present invention. To clarify claim 1, it is suggested that the word, "longitudinal", be added ahead of "vicinity" in line 3 of the claim.

Richard T. Whitcomb
Aeronautical Research Engineer

RTWamt
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Patents
MEMORANDUM For Associate Director

Subject: Patent application of Richard T. Whitcomb Serial No. 606,176, filed 24 Aug. 1956, for FUSELAGE SHAPING TO REDUCE THE STRENGTH OF SHOCK WAVES ABOUT AIRPLANES AT TRANSONIC AND SUPERSOONIC SPEEDS, Navy Case No. 23315

Reference: NACA Hqtrs. 1st. to Lang., Nov. 14, 1957, re Subject patent application. JAH/cu

1. In answer to the request for comments with regard to the patent office action on the subject application (ref. let.), the following comment is supplied:

In claim 20, the word "area" should be added after the first appearance of the term "cross sectional".

Richard T. Whitcomb
Aeronautical Research Engineer

JS
ECG
ATM
RTW.amt

Patents
MEMORANDUM For Associate Director


Reference: Wash. lst. to Lang., July 30, 1957, re request for subject changes. JAH/DS

1. In answer to the reference letter, the following changes in the subject application are requested of the NACA Patent Council:

Page 1, line 19, after "near" add "or just ahead of".

Page 1, line 20, remove "or just ahead of".

Page 2, after line 27, add "Figure 6 is a partial plan view of a wing with an additional improvement of the invention" (See new figure attached).

"Figure 7 is a cross-sectional view taken along line 7-7 of figure 6" (See new figure attached).

"Figure 8 is a cross-sectional view taken along 8-8 of figure 7" (See new figure attached).

"Figure 9 is a side view of a special fuselage used with the present invention" (See new figure attached).

Page 2, line 31, insert "near or" after "are".

Page 3, line 2, substitute "near" for "somewhat ahead".

Page 3, line 3, after "edge," add "(The noses are usually at least one quarter of the local chord length rearward of the leading edge.)" Also, remove sentence starting "The noses . . . " Substitute "For the greatest effectiveness, the longitudinal development of cross-sectional area for roughly the forward 20 percent of the body lengths are approximately the same as for a cone."

Page 3, line 7, insert after "shapes." "One such alternate shape is described later in the disclosure."

Page 3, line 26, add "The adverse gradients of increasing pressure associated with the aft portions of the added bodies are primarily downstream of the trailing edge of the wing, and thus, have little effect on the separation on the wing."
Page 5, after line 14, add new paragraphs:

"The effectiveness of the added bodies in reducing boundary-layer separation is improved by the special shaping of the forward portions 26 of the bodies shown in figures 6, 7, and 8. The cross sections of the bodies are spread spanwise in these regions so that the forward portions of the bodies form wedges with gradually increasing thickness as shown in figure 7. The contours of the bodies fair smoothly from this wedge to a cross-sectional shape roughly the same as that shown in figure 1 near the wing trailing edge. When used with a sweptback wing, the leading edge of the wedge is obliquely inclined at approximately the angle of the wing sweep. The deceleration disturbances produced by the noses of adjacent bodies intersect between the bodies as shown at 32 in figure 1. These disturbances augment one another in these regions causing relatively large increases of pressure. With the noses of the bodies pointed as shown in figure 1, the streamwise rates of increase of pressure in these local regions is sufficiently great to cause boundary-layer separation for many speed and lift conditions. The rates of increase of pressure and the associated separation in these regions are significantly reduced when the noses of the bodies are wedge shaped as shown in figures 6, 7, and 8.

The value of the bodies added on the wing is significantly improved when these bodies are used in combination with a fuselage shaped as described in my co-pending application, Serial No. 606,176. Such fuselage shapes result in airplanes in which the cross-sectional area in planes generally perpendicular to the longitudinal axis has only a substantially decreasing rate of change from near the nose until the rate of change is zero and has only a substantially negative increasing rate of change rearward of the zero rate of change point. A side view of an airplane incorporating a fuselage with the special version of such a shape, described in my co-pending application entitled, "Fuselage Shaping to Reduce the Strength of the Initial Shock Wave on Lifting Airplane Wings," is shown in figure 9. The top of the fuselage 27 is contoured longitudinally with a concave curvature 29 in the vicinity of the leading edge of the wing-fuselage juncture 28, a downward slope 30 in the region of the forward portion of the juncture, a concave curvature 31 in the vicinity of the middle region of the juncture, and a longitudinal extending region of substantially constant cross-sectional area downstream of 31. One of the important practical results of adding the bodies to the wing is that the Mach number at which a significant increase in drag occurs is delayed. It has been found experimentally that the delay associated with the bodies is increased significantly when the bodies are utilized in combination with a fuselage shaped as shown in figure 9. Further, it has been determined experimentally that the adverse drag increment at lower speeds caused by the bodies is substantially reduced when the fuselage is shaped as shown."

In Claim 4, line 3, substitute "near" for "ahead of".

In Claim 10, line 4, substitute "nose with a longitudinal development of cross-sectional area approximately the same as that of a cone" for "generally conical nose."
In Claim 10, line 6, substitute "near" for "ahead of."
Also, claims for the new disclosures should be added.
The designation 32 should be added, as shown, on figure 1.

Richard T. Whitcomb
Aeronautical Research Engineer
MEMORANDUM For Associate Director

Subject: Idea of patentable nature

1. Richard T. Whitcomb of the 5-foot transonic tunnels staff has conceived an idea for inducing the combustible components into the cylinder of an internal combustion engine whereby the thermal efficiency for the engine should be significantly improved. The idea provides for producing a swirl in the combustion chamber in which a rich mixture rotates around the outside of a lean mixture. The idea is described more completely on the accompanying form NAVEXOS-2375. No plans have been made for reducing this invention to practice other than to apply for a patent.

2. The invention was not conceived during working hours, no contribution of Government facilities, equipment, materials, funds, or information or of time or services of other Government employees on official duty were used for the invention. The invention bears no direct relation to and was not made in consequence of the official duties of the inventor.

Axel T. Mattson
Head, 5-foot transonic tunnels section

Enc. Executed Forms Relating to Patentable Idea

Patents