NACA Formula Eases Supersonic Flight

By David A. Anderton

Washington—A revolutionary concept in supersonic aircraft design that is increasing speeds of U. S. military aircraft by as much as 25% was revealed today by the National Advisory Committee for Aeronautics.

Known as the area rule and developed by Richard T. Whitcomb of NACA’s Langley Aeronautical Laboratory, this concept reduces the once-complicated procedure for determining minimum aircraft drag configuration to a simple graphical procedure.

The NACA area rule has been dramatically confirmed in supersonic flight testing of the following new fighters:

- Convair F-102A Delta all-weather interceptor now in production for USAF at San Diego.
- Grumman F11F-1 carrier-based interceptor now in production for the Navy at Bethpage and Peconic River, Long Island.
- Chance Vought F8U-1 carrier-based interceptors scheduled to go into production soon at Dallas, Tex.

The area rule was discovered by Whitcomb and his co-workers in the NACA eight-ft. transonic tunnel at Langley Field during 1951 and later verified by rocket-powered model tests at NACA’s Pilotless Aircraft Research Station at Wallops Island, Va. Area rule data was made available to the aircraft industry in 1952 on a secret basis. The first prototype aircraft incorporating it flew during 1954. Area rule data was kept under tight military security until today—nearly 21 months after Aviation Week first learned of the concept.

Whitcomb’s concept says that basi-
Area Rule and Coke Bottle

It's unfortunate that the phrase "Coke Bottle" was given to the fuselage shape derived from the Whitcomb area rule, because the two are not the same.

During World War 2, the German aerodynamicist Kuehmann made flow studies over the wing root of a swept-back wing and fuselage combination. He found that the flow turned in toward the fuselage, then turned out again; his reasoning was that the interference of wing and fuselage at the root would be minimized if the fuselage were contoured to match the flow.

American intelligence teams discovered the development and tagged it with the name of "Kuehmann Coke-Bottle." As far as is known, Kuehmann did not extend his ideas to any other wing form than the swept Whitcomb's area rule applies to any general shape. While the two applications on a swept wing can look alike, in reality they differ because Kuehmann's is tailored to the local streamlines of flow and Whitcomb's is contoured to maintain an area equivalence based on the entire stream tube.

cally the interference drag—the major drag component at transonic speed—depends almost entirely on the distribution of the airplane's total cross-sectional area along the direction of flight. Interference drag is caused by the interaction of wings, fuselage, tail and other airplane components. To combat this Whitcomb found that the lowest drag in the transonic range was recorded for a theoretically optimum body of revolution—a streamlined shape that resembled bombs without fins. The next step was the discovery that drag in this speed range decreased in proportion to how closely the cross-sectional area of a winged body resembled that of the optimum body of revolution.

The four steps confronting a designer in applying the area rule to a new aircraft are:
- First, the designer plots the cross-section areas of his first layouts against the overall lengths.
- Second, he compares the shape of those curves with the area distributions for an "ideal" shaped body of revolution. The "ideal" shapes have been derived mathematically; one recent NACA Technical Note (TN 3478: On Battail Bodies of Revolution Having Minimum Wave Drag; by Keith C. Harder and Conrad Rennemann, Jr., LMAL) gives some specific shapes. The slimmness—or fineness ratio—is limited by design considerations. Grumman's Tiger was length-limited by carrier elevator dimensions; its diameter of the Tiger was determined by size of the
CONVAIR F-102 model (left) in its original aerodynamic guise ready for launching. Modified version (right) resulting from area rule.

Wright-built J65 turbojet.

• Third, he reworks the airplane area distribution until it agrees as closely as practicable with the “ideal” shape. Compromises may be forced by such factors as visibility requirements from the cockpit, or provision for addition of an afterburner at some later date.

• Fourth, he converts the new area distribution plot back to airplane cross-sections, subtracting wing, tail and other component areas from the fuselage cross-section at each station. That area reduction may be made by a uniform change in fuselage radius, or it may be made by local changes on the fuselage side, as in the Tiger.

The result: an optimum layout for minimum transonic drag.

The final shape can show the curious indentation of the fuselage at the wing, which has erroneously been called the “Coke bottle,” familiar now because of the Tiger and the F-102A. In both designs, fuselage cross-sections have been reduced locally in the region of the wing by the amount of the wing cross-sections.

But it's not always necessary to take away area—and therefore usable volume—from the space-limited designer. Sometimes, it's necessary to add area. One example is: The tail blister on the Convair F-102A, added by scientists at Wright Air Development Center as part of the major fix required for that airplane to fill in the area diagram to make it match the ideal shape more closely. The extended nose of the F-102A and the F11F-I also improves the drag by increasing the fineness ratio and as a side benefit, they produce more useful volume.

Application of the area rule to the Vought F6U resulted in gains of valuable volume around and aft of the powerplant, a space used to great advantage by the designer.

That's all there is to applying the area rule to an airplane for the case of zero-lift drag at transonic speed. But behind this simple plotting stretches a long line of ideas, calculations and tests firmly tied to the development of the transonic tunnel.

The area rule, like many other aeronautical advances, originated in one of NACA's fundamental research programs. No goal was set up; instead, the scientists were merely curious to know what transonic flow looked like and how transonic drag was produced.

What was the shock pattern on simple wing shapes and body forms? Why did the drag rise occur?

How could airplane drag be computed; could component drag simply be added together?

The answers had to wait for the availability of the transonic tunnel.

This unique tool was developed by John Stack, Assistant Director of Langley, and won for him the Collier Trophy for 1951. Whitcomb directed this study, which included many pressure distributions and Schlieren photographs.

The Schlierens were startling; they showed the existence of a strong normal shock behind the trailing edge of the wing-fuselage intersection, in addition to the normal shock near the nose. This shock extended way out into the stream so that its geometry was large compared to the size of the wing-body combination. This was Whitcomb's first clue: The transonic drag rise was caused by losses from that shock.

Other clues followed from the study of the results of the first test. The shock formations and the drag rise at zero lift for the wing-body were similar to the expected shape of shocks around a modified body of revolution. That body had a swelling around its middle, like the egg sack of an earthworm; the swelling represented the additional cross-sectional area of a wing, wrapped uniformly around the body. Thus, the
area change from nose to tail of a wing-body combination was duplicated from the nose to tail by the comparable body of revolution.

While those results were being studied, a different series of tests was being made in the transonic tunnel. It was planned to evaluate the magnitude of the transonic interference drag, and the tests were made with swept, unswept, and deflected wing plus bodies with differing curvature at the wing.

This set of tests showed three major facts about interference drag:

- **Wing-fuselage interference effects** are greatest at transonic speed and may be as large as the wing drag alone.
- **Fuselage shape changes**—even small ones—produced large variations in wing and interference drag.
- **Wing-body combinations** must be treated as an aerodynamic system with the component drag mutually dependent. Total drag can't be computed by simple addition of the drag of wing, fuselage, tail and other items.

With these conclusions and those of his own studies as a basis, Whitcomb reasoned that the interference drag was the source of the largest portion of the transonic drag rise. Reduce the interference drag, and the transonic rise is hewn, not whittled, down. Then he went back to the flow studies for a second look at transonic flow.

**Flow Review**

This is the point at which Whitcomb had to "see" the air in order to better understand its flow patterns. Others before him had tried a similar attack on the drag problem; one had an answer within his grasp, but concluded that there was no practical value in pursuing the idea any further. Perhaps the others never grasped completely the transonic flow picture because their approaches were mathematical. They tried to analyze the flow without also visualizing what happened.

The aerodynamicist works with different volumes of air, with streamlines and stream tubes. The differential volume is, as the name indicates, an infinitesimally small unit of air. It moves along a flow line called a streamline, an imaginary line that is not disturbed by the streamline. The streamline is straight. If the air flows around a wing or body, the streamline curves, displaced by the intrusion of the surface in its path.

A bundle of these streamlines is called a stream tube. A common approach to the theoretical analysis of airflow problems is to isolate a stream tube which contains the object under study.

That's what Whitcomb did; he visualized two stream tubes. One contained the wing-body combination he had been studying; the other held a comparable body of revolution.

He chose to observe at a circular section, with the circumference outside the wingtips of the wing-body combination. Then he mentally looked at the flow from station to station along the length of the bodies. First, the streamlines deviated around the nose, then along the cylindrical body, and over the wing or the middle bump. Then the streamlines closed down again over the rear of the body and eventually back to the normal path down stream. All this variation from the straight line pattern of streamlines produces flow distortions in any plane normal to the centerline of the body. But two factors work to smooth these distortions rapidly.

- **Pressure changes along the circumference** of any stream tube at any plane normal to the centerline. These changes, caused by the relative speeds of adjacent streamlines distorted by the surface, tend to smooth out the bumps quickly by influencing the flow, around the circumference.
- **Rigidity of the outer streamtubes** acting like the walls of a wind tunnel, these outer streamlines resist displacement, and consequently tend to smooth out radial deviations in the flow.

Both the circumferential and the radial flow changes are quickly lost as the flow gets away from the immediate vicinity of the body. Whitcomb found that the two kinds of flow—over the wing-body and over the equivalent body—were almost identical at only a short distance from the body.

This was the basis for the area rule. In March, 1952, shortly after determining the rule, Whitcomb presented his whole program to the Langley Laboratory's research department. He had no proof of his ideas, but the research group agreed with his conjectures with few reservations. They suggested experimental verification.

Tests of simple wing-body combinations and their equivalent bodies began in April. By this time, Whitcomb had postulated a corollary to his original theorem of area equivalence. The corollary said, in effect, that a wing-body combination could be made to have the same area distribution as a new, over-draged ideal body, and would therefore have minimum drag. Doing this was simple: The body was merely robbed of enough of its cross-section area to compensate for the extra area added by the wing. This produced an indented body.

The tests were the final proof; all Whitcomb's reasoning was justified in the pressure distributions, Schlieren photographs and drag curves that came out of the transonic tunnel. From now on, the wing could get a free ride.

The magnitude of the drag saving was enormous. For an unswept triangular wing and for a delta wing, the drag rise of the wing was reduced by 60 percent. For a swept wing, the drag rise was eliminated completely at Mach numbers up to 1.04. Above that mark, the effect of the indentations wore off for zero-lift conditions.

**Two Airplanes**

By August 1952, things looked black for the Convair F-102. Intended as a supersonic airplane, it was stuck at Mach .9. There were rumors that USAF would cancel the contract.

Transonic tests at NASA's 8-ft. tunnel showed the drag hump at sonic speed was above the capability of the airplane. Convair and Langley engineers met at Langley and decided that salvation lay in the area rule. The Convair engineers returned to San Diego, taking their model for rework.

In October, a delegation from Grumman came down, wanting to know more about the area rule. They were coming up with a new fighter on which a lot of Grumman's future was riding. By February 1953, they had made layouts for Design 98, Grumman's designation for the F9F-9, later to be called the F11F-1. Whitcomb visited Grumman and helped work out the Tiger's final lines.

Right after this, a modified model of Convair's F-102 went into the transonic tunnel for evaluation, and again Whitcomb made the trek to a manufacturer to discuss final lines with the engineers. By July 1953, the layout of the F-102A was completed.

In the meantime, the transonic tunnel had been busy testing the Grumman Design 98 model. The results were good; the Tiger was going to have relatively low transonic drag. By August the tests were completed.

Two months later, the F-102A tests had ended. The final results said what Convair engineers wanted to hear: The airplane would be supersonic. All that was necessary now were the flight tests.

As it happened, Grumman got there first. One year after the tests in the tunnel had stopped, the flashi white Tiger breezed through sonic speed in level flight without the use of an afterburner. The first time this had been done. Grumman pilot C. H. "Corky" Meyer handled the flights and the impressive public demonstration of the Tiger (AW Aug. 16, 1954, p. 381) which followed after the first test runs.

A few months later Convair's Richard L. Johnson flew the F-102A out of Edwards AFB and went past Mach 1 while still climbing.

Other designs have since followed, their bodies indented or bulged by the area rule for better performance. New bomber designs are also using the area rule.

Whitcomb's brilliant conjecture and thoughtful experiments are paying off in a dramatic way in the performance of the next generation of fighting planes.
One of the most significant military scientific breakthroughs since the atomic bomb has been contributed to the American aviation industry by the National Advisory Committee for Aeronautics’ discovery and development of the area rule for supersonic aircraft design. The first technically accurate and complete story on this concept appears on page 12 of this issue written by David Anderton, assistant managing editor (technical).

The true significance of the NACA area rule lies in its across the board application to supersonic aircraft of all types—extremely simple in the critical transonic range and more complex in the truly supersonic area around Mach 2. The so-called “Coke bottle” or “Marilyn Monroe” fuselage is merely one type of area rule application. Area rule discovery and development were particularly timely because they occurred at the very moment that virtually all USAF and Navy fighters aimed at sustained level supersonic flight were apparently doomed to remain just below Mach 1 because the contemporary crop of jet engines available lacked sufficient power to push these designs through the tremendous drag rise that then existed in the transonic range between Mach 0.9 and Mach 1.04.

In addition to providing a major scientific breakthrough at the very moment when the technological race with Russian airpower was becoming hottest, the NACA area rule development will give military and congressional leaders who are concerned over military security problems an object lesson in how a major military scientific secret can be kept effectively to gain a time advantage over international competitors.

First word that something radically new was brewing in supersonic aircraft design first reached AVIATION WEEK in the closing days of 1953. During the early months of 1954 considerable data was accumulated on the “Coke bottle” fuselage, “Marilyn Monroe” supersonic shape, and the “Whitcomb theory” —all loose designations for what was actually the area rule. Since all our data pointed to NACA as the source of what appeared to be a revolutionary new concept in supersonic aircraft design we consulted Dr. Hugh L. Dryden, director of NACA, who in addition to his scientific ability is a man of integrity. After this conference we wrote Dr. Dryden on April 15, 1954 as follows:

“As a result of your very helpful briefing on the security problems involved in the widespread military application of a new development in high speed aerodynamics we have made a policy decision to refrain from any mention of this in AVIATION WEEK until prototype aircraft embodying this principle are open to public view. This decision was made despite the fact that our reporters unearthed the basic facts on the development and its application from a wide variety of technical sources.

“As you pointed out this is too important a matter with which to trifle...We appreciate your counsel in these matters because it helps us to avoid inadvertent disclosures of genuine aeronautical security matters and thus benefits our country.”

Dr. Dryden replied on April 20:

“Thank you for your letter of the 15th and the assurances it contained. I think your decision to withhold from public attention the information you have obtained about new developments in aeronautics properly falls in the category of a real public service to the nation.”

The real root of the security problem in cloaking the significance of the area rule lay in the fact that there were several earlier theoretical investigations in this field that had been published in this country and in England without any security classification. Wallace D. Hayes, then of North American Aviation, and two Britons, G. N. Ward of the University of Manchester and W. T. Lord of the Royal Aeronautical Establishment, had all taken a mathematical approach to the problem beginning as early as 1946 but without the research tool of the transonic tunnel available then, they all concluded that there was not much promise to this channel of effort. The real security in the area rule lay not so much in the indented “Coke bottle” shapes of the fuselage on new fighter prototypes (the Kuchemann Coke bottle design was well known in the United States, Europe and Russia as a result of captured German documents and bears no resemblance to the area rule) as in the fact that Hayes, Lord and Ward were on the right track in their wing-body relationship studies and that many clues could be found in their unclassified publications.

After AVIATION WEEK established its security policy on the area rule with NACA, other publications began to get the same information and after talking with NACA agreed to follow the precedent established by AVIATION WEEK. When the Grumman F11F-1 prototype appeared the fuselage indentations were labeled only as a “drag reducing” feature which was accurate as far as it went. But no mention of NACA, area rule or the application of a basic new principle appeared in the American or foreign press.

In September 1954 the editor of Aero Digest violated that magazine’s written commitment to NACA by publishing a fragment of the area rule application to the Grumman Tiger. AVIATION WEEK again consulted with Dr. Dryden on the grounds that if security had been breached we should publish the full story without further ado. Dr. Dryden pointed out that since the published story had appeared in a magazine of limited aeronautical readership it might easily pass unnoticed if it was not picked up and magnified by an aviation magazine well known for its technical accuracy. The missing link to the unclassified data of Hayes, Lord and Ward was still secure as was the scope of the widespread applications to new military aircraft.

AVIATION WEEK decided to continue its area rule security policy unaltered. We wrote to Dr. Dryden on Oct. 5, 1954:

“After our conversation this morning I consulted Bob Martin our publisher. We agreed unanimously to continue our policy of not printing information on this important aeronautical development until such time as there is a general agreement that its security value has diminished to an extremely low value.”

Dr. Dryden replied:

“I believe AVIATION WEEK is performing a valuable public service by its decision to continue its policy of not publishing information on this important aeronautical development until such time as there is general agreement that its security value has diminished to an extremely low value. I realize, at least in part, how seriously your publication must have considered this point in view of the recent publication elsewhere of the information about the development in question.”

Now that official military security has been lifted on the NACA area rule AVIATION WEEK has brought its readers the first technically accurate and complete story on this subject and honored its security agreements to the letter.

—Robert Hotz