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TALOS AERODYNAMICS

During development of the aerodynamic configuration for the Talos missile, several technological constraints and problems existed whose solutions added significantly to the body of design principles used in subsequent missile designs.

STATE OF THE ART IN 1945

The small group of aerodynamicists associated with the Bumblebee Program who initiated aerodynamic investigations of supersonic missiles in 1945, had limited experience in supersonic aerodynamics; their experience had been primarily with subsonic aircraft before and during World War II. The status of supersonic aerodynamics at that time was assessed at a symposium held at APL on December 6 and 7, 1945 that was attended by representatives from 49 organizations. A survey of the field revealed progress in fundamental theory, which included shock-wave theory, expansion theory, cone theory, and a method of characteristics for two-dimensional flow. For the vehicle designer there existed linear theories for bodies of revolution, for thin finite-span wings, and for ducted bodies, as well as linear and second-order theories for two-dimensional wings.

Some experimental data on projectile aerodynamics were available from the spark photography ranges of the Ballistics Research Laboratory at Aberdeen Proving Ground, Md. There were also some limited test data on small models in the two operating supersonic wind tunnels in the United States, one at the Guggenheim Aeronautical Laboratory in Pasadena, Calif., and one at the National Advisory Committee for Aeronautics, Langley Field, Va. In 1945, these were the only wind tunnels in the United States in which models could be tested at supersonic speeds, but they were too small to be of significant value for designing large guided missiles. A somewhat larger facility was available at the Ballistics Research Laboratory, but it was not yet operational. Thus, a decision was made to develop a wind-tunnel facility of sufficient size to permit testing models of approximately 1/10 scale, a size that would permit testing of relatively complicated models at desirably large Reynolds numbers. This decision led to the development of the Ordnance Aerophysics Laboratory at Daingerfield, Tex., for both aerodynamic and engine testing (Fig. 1). The aerodynamic wind tunnel eventually covered a test range of Mach numbers from 1.25 to 2.75 in a 19 × 27.5 inch test section. It proved to be the principal aerodynamics ground-test facility for the Talos program and for many other missile programs until it was closed in 1958.

Only limited flight test data were available to aerodynamicists because most supersonic testing was related to the ballistics of shells rather than to the aerodynamics of missiles. Early in the Talos program, high-velocity aircraft rockets were used as missile models for acquiring information on base pressure, drag, wing pressures, and missile accelerations attainable through deflections of movable wings. Most of the aerodynamic flight testing was carried out at the Naval Ordnance Test Station, China Lake, Calif., and later at White Sands Missile Range, N.M.

A team of associate contractors from industry and the universities was formed to assist APL in carrying out research and development in several aerodynamics areas related to the design of guided missiles. Their activities were guided by a panel of experts (known as the Bumblebee Aerodynamics Panel) whose charter was to provide broad planning of the aerodynamics program and whose goals were (a) to develop prototype information for defining an early design, (b) to develop information to improve the prototype's range and maneuverability, and (c) to foster basic research.

CONSTRAINTS IMPOSED BY OTHER TECHNOLOGIES

Low Angle of Attack for Engine

Since a key element in the development of the long-range missile was the ramjet engine, it was essential to operate the engine as efficiently as possible. This led to the decision to fly the missile at a low angle of attack, which would permit optimum engine performance, and to depend on movable wings to provide the desired maneuverability. Thus, the missile would be maintained at a small angle to the oncoming airflow while the wings would be deflected by an amount sufficient to provide the necessary lift to achieve the desired maneuverability.

Skid-to-Turn Steering

The original choice of beamriding guidance with commanded maneuvers in two orthogonal planes dictated a cruciform arrangement of wings and tail stabilizers. In addition, the wings served as control surfaces to steer the missile in pitch or yaw through de-

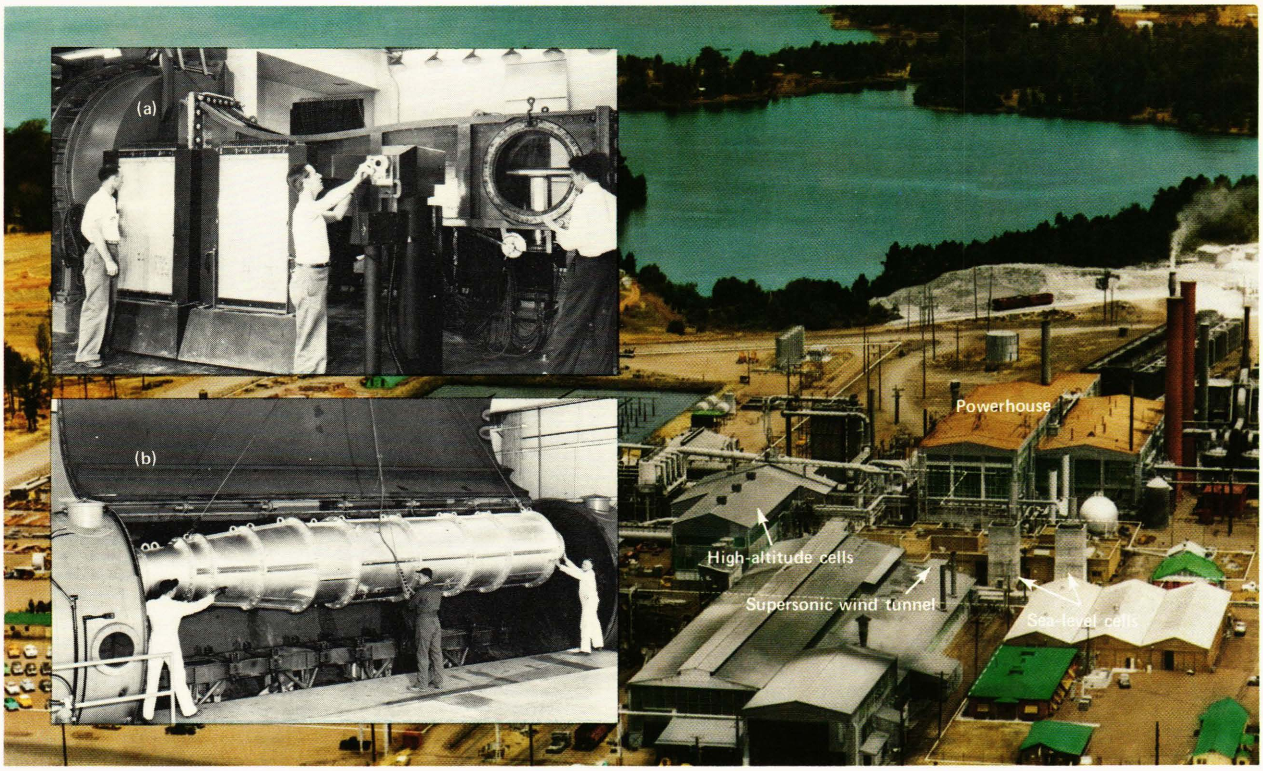

Figure 1 — The Ordnance Aerophysics Laboratory used blast-furnace blowers available at the adjacent steel plant to supply large volumes of high-pressure air for operation of a wind tunnel and burner facility. (a) Test section of the wind tunnel, where airflow from Mach 1.25 to 2.75 was available at a test section of 19 × 27.5 inches. (b) Test cell for full-scale combustor tests, where maximum air capacity was 15,000 pounds of air per minute at a pressure of 45 pounds per square inch absolute or 7500 pounds of air per minute at a pressure of 124 pounds per square inch absolute.

flections of pairs of wing panels and to stabilize it in roll through differential deflection of all four panels.

Minimum Space for Control Servos

Because the ramjet engine required a central air duct, the servos needed for operating the wing control system had to be housed in the annular region of the body around the central duct where space was limited. This restriction led to a study of wing planform shapes to find one that would result in the smallest hinge moments required to deflect the wings over the full range of operating Mach numbers and angles of attack. The planform finally selected became known as the Bumblebee planform.

Boost Phase Control

Another important factor in ramjet engine design is the need for a secondary propulsion system to boost the missile to the ramjet "take-over" speed. Thus, two aerodynamic configurations must be considered, one consisting of the missile alone and the other consisting of the missile combined with the attached rocket booster, which must fly stably until it attains the speed at which the booster can be dropped and the ramjet engine ignited for its climb to cruise altitude. The missile's relatively large wings, necessary to provide the desired maneuverability, posed a problem as a destabilizing aerodynamic surface well ahead of the center of gravity of the missile-booster combination during the boost phase. This situation required large stabilizing fins to be placed on the booster or, since space in a shipboard system is at a premium, some type of control that could permit a reduction in the size of the booster fins.

SIGNIFICANT PROBLEMS AND PHENOMENA, AND THEIR SOLUTIONS

Wing Design

A design decision was made to achieve lift primarily from the deflected wings (Fig. 2). Consideration had to be given to the problem of maximizing lift while minimizing drag, to structural requirements, and to the need for minimizing servo requirements for deflecting the wings. A combination of aerodynamic and structural considerations led to the choice of a double circular arc (biconvex) wing cross section because of its low drag per unit stress. During the subsequent production engineering phase, a modified double-wedge section was chosen, with minimum loss in aerodynamic or structural efficiency. Taper in both thickness and chord was used primarily for reasons of structural design and weight reduction. A tip rake appropriate for the Mach number regime was chosen to minimize the losses in lift associated with the tip, thus providing a more nearly two-dimensional wing lift, except for the root portion. Force testing on this so-called Bumblebee

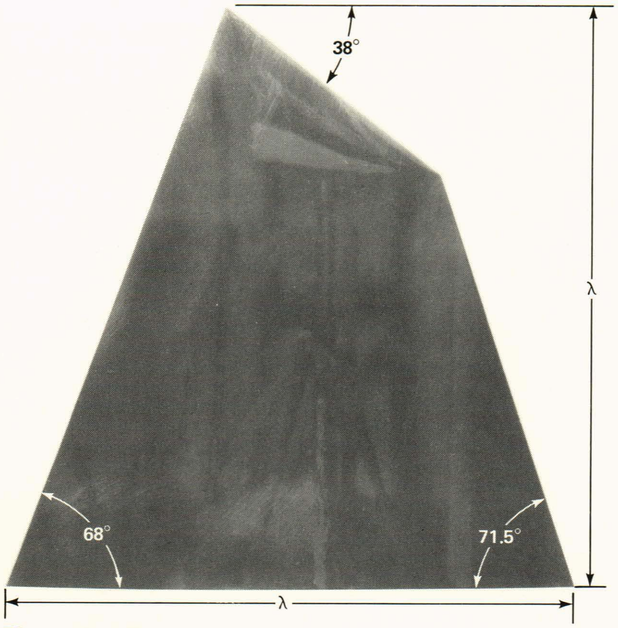

Figure 2 — The unique planform shape of the wings became known as the Bumblebee planform (from the name of the program itself). Its special shape minimized torque requirements on the servos that drove the wing controls.

planform showed rather small variations in chordwise center of pressure over the operating ranges of Mach numbers, angles of attack, and wing incidence so that it was possible to select a hinge line that minimized the design hinge moments. This particular planform shape exhibited very favorable characteristics over an extended Mach number range and has been used in nearly all other Navy surface-to-air missiles and in several non-U.S. missiles.

Roll Reversal (Tail Redesign)

Because the missile was to be roll-stabilized, it was necessary to have a roll-control system in addition to the control systems for pitch and yaw. At first, differential deflection of wings was considered for producing a roll torque and was tried in supersonic test vehicles. In flight, however, the roll obtained on the vehicle was opposite that expected from the torque produced by the wings. Because flow interaction was suspected, a research program to find the cause of the problem was established. Meanwhile, an immediate solution was to provide roll control by small flippers at the tips of the tail-stabilizing fins. Later, when the phenomena associated with this reverse roll were better understood and their effects were quantified, the tail planform was redesigned and the wings were again used to control all angular motion.

Since three angular motions (pitch, yaw, and roll) were to be controlled by four deflected panels, the choice of deflections was made definite by the use of a so-called "squeeze mode" on the wings, which required that deflections would be chosen that would minimize drag. The development of three-axis control by the wings during the missile's sustain phase led naturally to the introduction of the concept of wing control during boost.

Stabilization During Boost (Wing Control)

The early test vehicles were stabilized during boost with large booster fins that were necessitated by the presence of large wings ahead of the center of gravity of the missile-booster combination. However, the limitations of stowage and launcher space stimulated consideration of reducing the size of the booster fins by active control of the missile during the boost phase. The missile control system was designed to operate during boost as well as during sustained flight. Thus, it was possible to reduce the size (and weight) of the fins with only a small additional demand on the control system.

Duct Resonance (Exhaust Vents)

A problem that had to be faced during the flight testing program was the occurrence of resonance of the air column in the diffuser duct and combustion chamber during the boost phase when the air column was blocked by the tandem booster. Flight tests revealed a severe pressure oscillation in the duct ("organ pipe effect") that produced two problems: the pressure oscillation caused the inlet innerbody, which housed the warhead, to oscillate violently; it also prevented a clean separation of the booster from the missile, allowing the booster to recontact and damage the missile during a low point in the pressure oscillation.

The problems were solved by providing exhaust vents near the aft end of the missile to relieve the pressure buildup in the duct during boost. Because those vents were near the center of gravity of the configuration and did not alter the booster fin's effectiveness in stability, no special problems in the aerodynamic behavior of the missile were introduced.

Aeroelastic Phenomena

Because the nose-inlet ramjet engine is truly a "flying stovepipe," (i.e., a body with a large void along the center), it was expected that the design would have to account for the deflection of the missile under load and to establish the aerodynamic characteristics of the distorted configuration. Such quasi-static corrections to aerodynamics are usually needed only when the principal air load (the wing load) is applied at a point and the mass is distributed uniformly, resulting in a banana-shaped body, depending on its rigidity. For the Talos missile, it was found that at low altitudes the flexibility of the structure caused a considerable reduction in the maneuverability achievable per unit deflection of the wings (Fig. 3). The forward portion of the missile (diffuser ducting section) was less rigid than the aft portion (combustion chamber section). However, for a given maneuver, the angle of attack and control incidence increased with altitude, and these angles caused a redistribution of air loads, which must balance the fixed inertia loads. Thus, at high altitudes (such as 60,000 feet) that redistribution of loads caused the body to behave more like a rigid body.

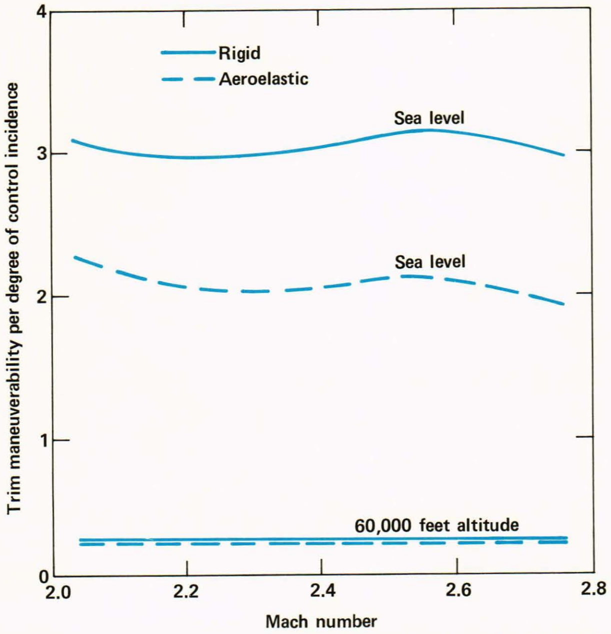

Figure 3 — The aeroelasticity of the missile under the high loading at sea level reduces the attainable maneuverability for a given wing incidence to two-thirds of that available for a rigid missile. At higher altitudes, the effect is negligible.

Effects on Later Missile Programs

As noted earlier, the modified double-wedge cross section for the wing with the tapered planform and raked tip (i.e., the Bumblebee planform) was found to have desirably low hinge-moment characteristics. The planform has been used over a wide range of Mach numbers for control surfaces of many other missiles, including the Terrier, Tartar, and Standard missiles of the United States, the French Masurca, the Italian Indigo, and the British Bloodhound. A somewhat similar planform appears on the British Sea Dart and the Russian Atoll and Gainful.

The procedure followed in the Talos program to account for the effects of elasticity of the missile on the static aerodynamics was also applied to the nose-inlet, wing-tip-controlled Long Range Typhon missile of the early 1960's. On the basis of previous Talos experience, it was decided to vent the diffuser pressure during boost of the Long Range Typhon missile through openings in the adapter section between the missile and the booster to avoid the ''organ-pipe'' oscillations in the duct. In addition, as further experience was gained in operating the inlets at higher angles of attack, it became evident that the restriction to low angles of attack (requiring wing incidence for lift) could be partially removed. In fact, the Long Range Typhon test vehicle used large fixed wings with wing-tip controls and achieved maneuverability through body angle of attack with satisfactory engine performance.

Thus, the Talos aerodynamic program, lacking an adequate supersonic aerodynamics data base, had to embark on a course that generated a new body of aerodynamic data and design principles. These were in the fields of aerodynamic stability, forward surface control, wing-body and wing-tail interference, aeroelastic effects on static aerodynamics, and inlet effects on aerodynamics. A control surface shape, the well-known Bumblebee planform, was developed that minimized center-of-pressure travel.