HIGH-SPEED AERONAUTICS

NASA Langley Research Center
Langley Station, Hampton, Va.

Presented at Field Inspection of Advanced Research and Technology

Hampton, Virginia
May 18-22, 1964

HIGH-SPEED AERONAUTICS

INTRODUCTION

You are in the test chamber of the Langley Unitary Plan wind tunnel. This facility has two separate test sections, each 4 feet square, covering a Mach number range from 1.5 to 5. The installed power of this facility totals about 100,000 horsepower.

The purpose of the stop is to discuss the aerodynamic problems associated with high-speed flight, and to acquaint you with recent research advances which are making possible new levels of aerodynamic performance in both military and civil aircraft.

AIRCRAFT PERFORMANCE

Speed is the primary advantage of aircraft. In figure 1 is shown a bar chart depicting the history of aircraft speeds. There has been a spectacular increase in maximum speed from the World War I fighters of approximately 100 miles an hour to values of approximately 2,000 miles an hour (1,700 knots) for current military aircraft and projected supersonic transports. For a number of years, an increase in maximum speed was accompanied by increases in landing speed. However, the limitations of available runway lengths forced a leveling off in further increases in landing speed, as noted in the figure. The limitation in landing speed for high-performance aircraft was accomplished through the development of various wing flaps and high-lift devices. The dramatic Boeing 707-80 flyby illustrated the latest research on applications of a jet flap in reducing minimum aircraft speeds.

VARIABLE-SWEEP WING

A revolutionary concept for improving aircraft performance in both the low-speed as well as the high-speed flight regimes is the variable-sweep wing. The concept of variable sweep is not new. Interest at Langley in variable-sweep aircraft extends back to 1945. Later, the NACA, Air Force, and industry combined in the development of a variable-sweep research aircraft, the X-5, which flew in 1951. For the X-5, however, stability considerations required that the whole wing be translated fore and aft as the wing was swept. The penalty for translation was increased weight and complexity.

Research on the problems of variable sweep was continued in the wind tunnels. In 1959, Langley found a solution to the variable-sweep stability problem such that a structurally simple wing pivot could be used. (No wing translation was required.) This research breakthrough, combined with the urgent need of the military services for a multipurpose aircraft led directly to the concept of the

F-111 fighter-bomber now under procurement. Major wind-tunnel programs in direct support of the variable-sweep F-111 are currently being conducted in this Langley Unitary Plan wind tunnel, as well as other NASA facilities.

The operation of a variable-sweep wing is demonstrated as follows (demonstrate with TAC-8A model): The wings are swept forward for take-off and landing to provide the maximum wing span and flap effectiveness. The wings are then swept to an intermediate angle of sweep of approximately 45° for optimum subsonic cruise, and then to about 70° for maximum efficiency in high-altitude supersonic flight. For high-speed operation "on the deck," where the aerodynamic forces are high and little wing area is required, the wings are folded back on top of the fuselage to minimize the aerodynamic drag and the gust response of the aircraft.

In figure 2 is shown a military mission which utilizes the versatility of a variable-sweep aircraft. This is a simple plot of altitude versus distance. The take-off is made from unimproved fields with runways from 1,500 to 3,000 feet. The aircraft flies at its optimum cruise altitude to the area of penetration. The aircraft then descends to within 500 feet of the ground to escape radar detection and accelerates to supersonic speeds to minimize vulnerability to antiaircraft fire. Bomb release will be from low level. The aircraft then climbs to high altitude to return to its base. Alternate missions might include high-altitude aircraft interceptor missions as well as high-altitude supersonic reconnaissance or bombardment.

MULTIMISSION DEMONSTRATION

A demonstration of an aircraft flying the so-called "Hi-Lo-Hi" mission of figure 2 will now be made. A model that can sweep its wings and actuate its flaps is mounted in front of a movie screen. A movie taken from an aircraft flying the mission of figure 2 will be back-projected on the screen to give a realistic impression as we fly this mission. Imagine you are flying formation above the model shown in front of the screen.

Take-off is made with the wings forward and the flaps down. After take-off the flaps are retracted and the aircraft climbs to altitude and starts its cruise. As the aircraft approaches the general area of the target, the pilot starts his pushover and accelerates to supersonic speeds. Supersonic flight on the deck is made with the wings fully swept. Ground motion corresponds to a flight speed of 1,000 miles per hour. As the aircraft approaches the target, the pilot makes a pull-up and releases his weapon. Return to base is made at high altitude with the wings in the midsweep position. As the aircraft approaches its home base, the wings are swept fully forward and the flaps are lowered for a minimum-length landing.

Thus far, speed and multimission capability have been emphasized; however, there are overriding requirements for increased payload and range. These performance requirements, along with design considerations of aircraft noise and sonic boom, demand an aircraft of the highest possible aerodynamic efficiency.

The trends toward increasing velocity and range are indicated by the Century-series fighters with so-called "dash" supersonic capability; our operational supersonic bombers lie in midrange area; while at the other end of the spectrum, the B-70 and the supersonic transports are shown at Mach numbers near 3 with transoceanic range capability.

Of these aircraft, the supersonic transport is the most demanding. It must be safe, economically sound, and have acceptable noise and sonic boom characteristics. The critical requirement is the level of supersonic cruise efficiency - or more specifically, producing the required lift with a minimum of drag. The attainment of high cruise efficiency serves to reduce the weight of aircraft for a given mission and thereby also serves to reduce the airport noise and level of sonic boom.

Shown on the front panel of the display is a series of configurations evolved in NASA wind tunnels during the last few years to study the aerodynamic problems of the supersonic transport and to establish a level of potential aerodynamic efficiency. They include fixed-wing (SCAT's 4 and 17) as well as variable-sweep configurations (SCAT's 15 and 16) and encompass a wide range of wing planforms, control surfaces, and engine installations. Results from these studies have been utilized by industry in their design proposals relative to the National Supersonic Transport Program.

RESEARCH BACKGROUND

The aerodynamic background which led to these configuration concepts was based on research conducted in the early 1950's. Comprehensive theoretical analyses and extensive wind-tunnel programs have led to the evolution of the following aerodynamic concepts: The famour "area rule" of Dr. Richard T. Whitcomb which provided a procedure for analyzing and minimizing the transonic and supersonic drag (this evolved out of our transonic wind-tunnel research of 10 years ago - illustrate by SCAT 4); the theory of twisted and cambered wings which provided a means for reducing the drag due to lift (theoretical work in this area was initiated by Mr. R. T. Jones, now of Ames Research Center, as early as 1947 - illustrate by twisted and cambered wing); and more recently, the technology of favorable interference which provided a basis for the optimum arrangements of components (illustrate by SCAT 15).

A comprehensive experimental wind-tunnel and flight program was undertaken to check the validity of the basic theories, to establish appropriate restraints, and to provide an insight into new concepts. Modifications to the theories were made to be able to handle the "real" flows involved in a complete configuration. It was found as the aerodynamic efficiency was increased, the ability of the theoretical program to predict the aerodynamic characteristics was correspondingly improved.

Out of this intensive program of experimental and theoretical correlation there gradually evolved a capability to optimize and to predict the aerodynamic characteristics of a broad range of configurations. We have now learned to realize in fact the improvements and gains that theory indicated was there.

Within the last 6 months, the aerodynamic technology that had evolved over the last several years has been programed into high-speed electronic computers. Results on aerodynamic performance can now be available in hours rather than weeks. Thus, the computer programs can now be used as design tools.

APPLICATION OF TECHNOLOGY

Within the last few months, we have employed this new aerodynamic technology to optimize a configuration for high-speed flight. Using the mission requirements of the supersonic transport as a basis, a configuration has been evolved which establishes new levels of aerodynamic efficiency. The resulting configuration has the following characteristics: The fuselage is long and slender and is carefully integrated with the wings; leading edges and trailing edges of the wing are highly swept, while the wing is twisted and cambered to optimize the drag-due-to-lift characteristics; the engine nacelles are attached to the undersurface of the wing behind the point of maximum thickness to provide favorable lift and drag interference effects; the fuselage itself is cambered to optimize the flow for the lifting condition.

The results of this initial program are shown in figure 4. This plot shows the variation of drag and lift-drag ratio with lift. The circular points are taken from wind-tunnel tests of the subject model while the solid lines are the computed theoretical values. Relative to lift-drag ratio, it will be noted that the agreement is excellent, with the experimental values falling just slightly under the theoretical values of lift-drag ratio. Shown for comparison is a band of lift-drag ratios corresponding to the general level attained by the four supersonic transport configuration concepts shown in model form on the right (SCAT's 4, 15, 16, and 17). It is obvious that a substantial improvement has been made.

WIND-TUNNEL DEMONSTRATION

The ultimate check of any calculated procedure must be made in a wind tunnel. The wind tunnel has the further capability of permitting visualization of the flow and therby providing an insight to the physical phenomena involved. To illustrate the powerful effects of nacelle location on the wave drag of a configuration, we have set up a live wind-tunnel demonstration. Mounted in the test section of the Unitary tunnel is a model similar in many respects to a supersonic transport configuration. You can hear the tunnel in the background as it increases speed to Mach number 2.6 (1,700 miles per hour). Figure 5 shows how the wing-body-nacelle combination is mounted in the wind tunnel. The model is sting-supported from the rear, with provision for translation of the nacelle fore and aft relative to the wing. Separate drag balances are located in the wing-body and the nacelle and the output from these balances is indicated on the two dials overhead.

Figure 5 also depicts the shock waves that are characteristic of supersonic flight. It is these shock waves which reach to the ground and produce the sonic boom. In the wind-tunnel demonstration, these shock waves will be made visible by means of a schlieren system, which is an optical technique of flow visualization utilizing changes in air density to make visible the flow field. The shimmer of heat waves is a simple illustration of this phenomena. A colored schlieren system is used to aid in the flow visualization.

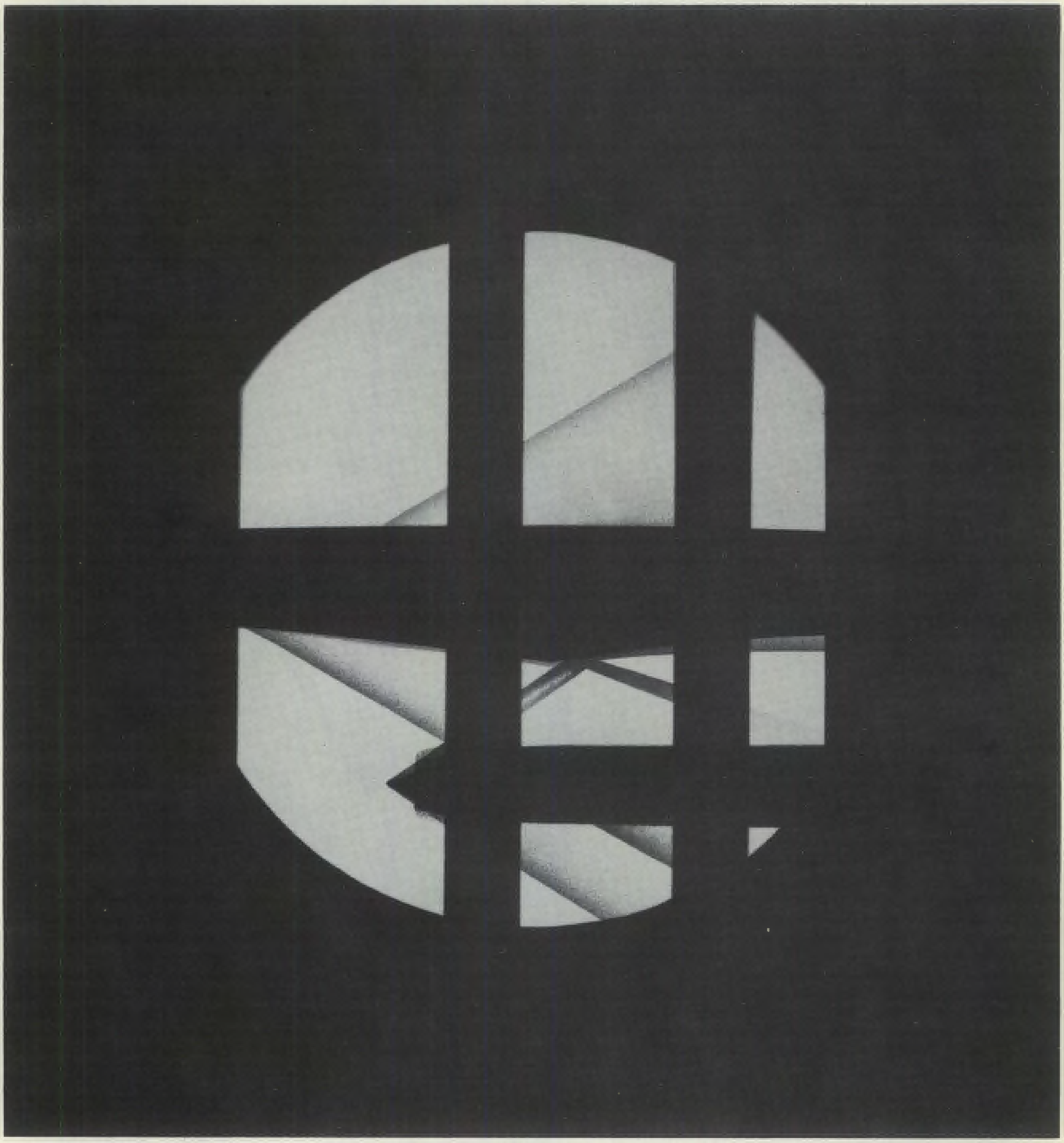
The next figure (fig. 6) shows the portion of the flow field that the schlieren system will make visible. The vertical shadows result from the bars across the windows of the test section wherein the model is supported.

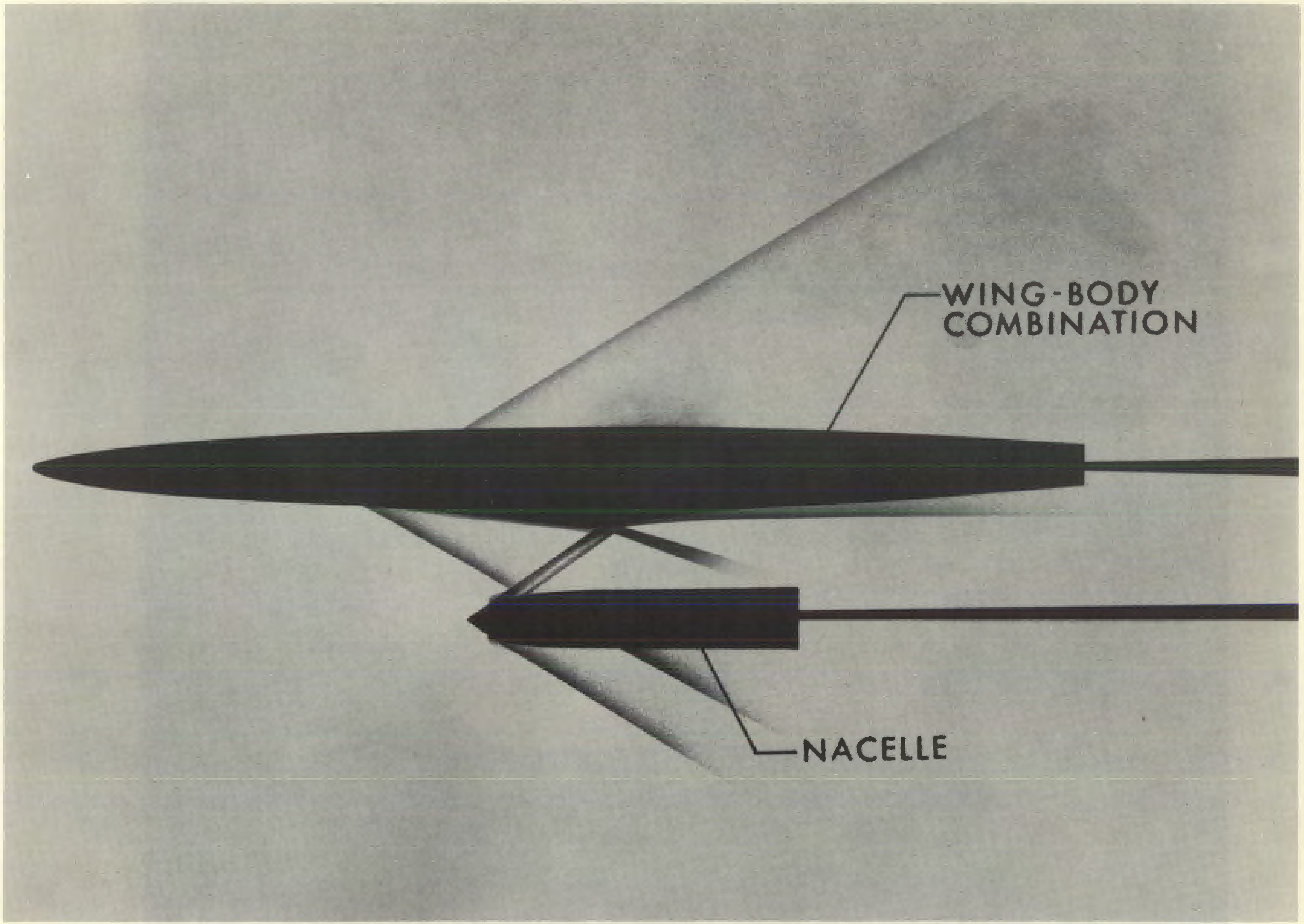
TUNNEL SEQUENCE

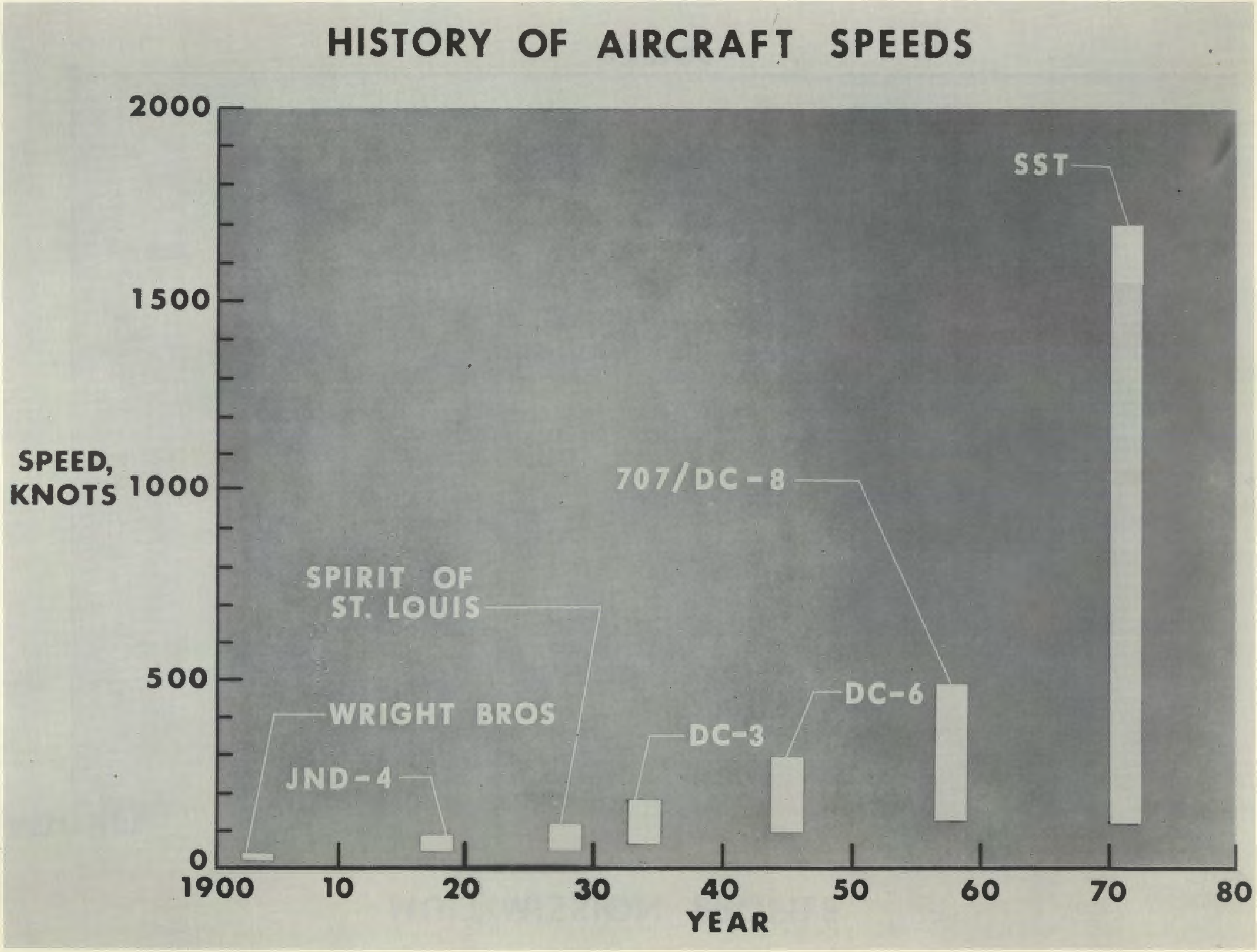
The tunnel is now at $M = 2.6$ (1,700 mph) with the colored schlieren image projected overhead. The nacelle is positioned well aft so that it is riding in an essentially interference-free flow. This can be determined by the fact that the shock waves from the nacelle pass to the rear of the wing. As the nacelle is moved forward and the shock from the nacelle impinges on the lower surface of the wing, the drag of the wing-body combination starts to decrease as indicated by the balance overhead. Note that the drag of the wing-body combination reaches a minimum when the shock waves from the nacelle impinge on the line of maximum thickness of the wing - or the so-called ridge line. As the nacelle is moved farther forward, the drag of the wing-body combination starts to increase. Forward of the ridge line, then, becomes a region of unfavorable interference and should be avoided. Not shown in the demonstration was the favorable effect on lift produced by the underwing nacelle. Had we hooked up the lift components of the balance system, this favorable effect could also have been illustrated.

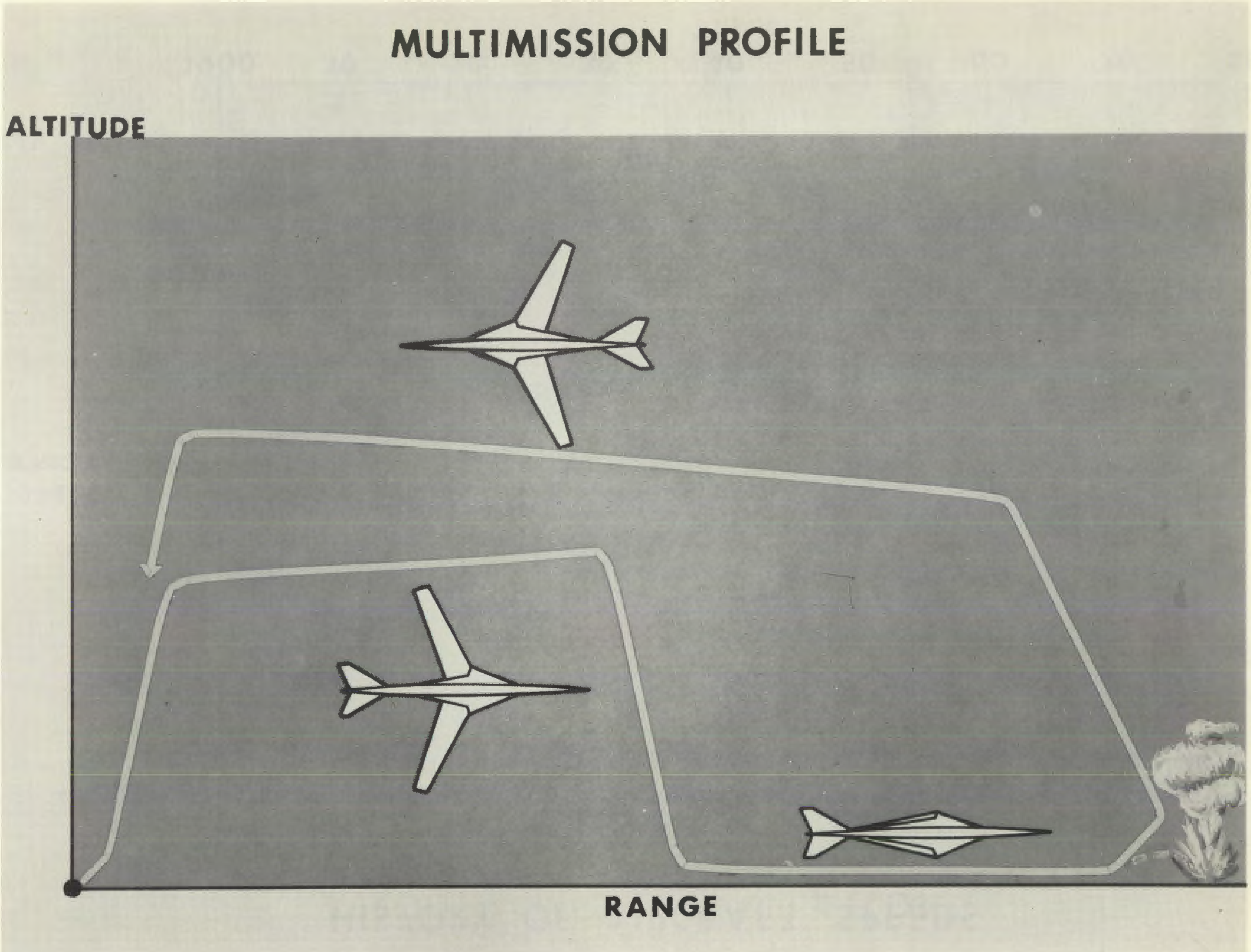
SUMMARY

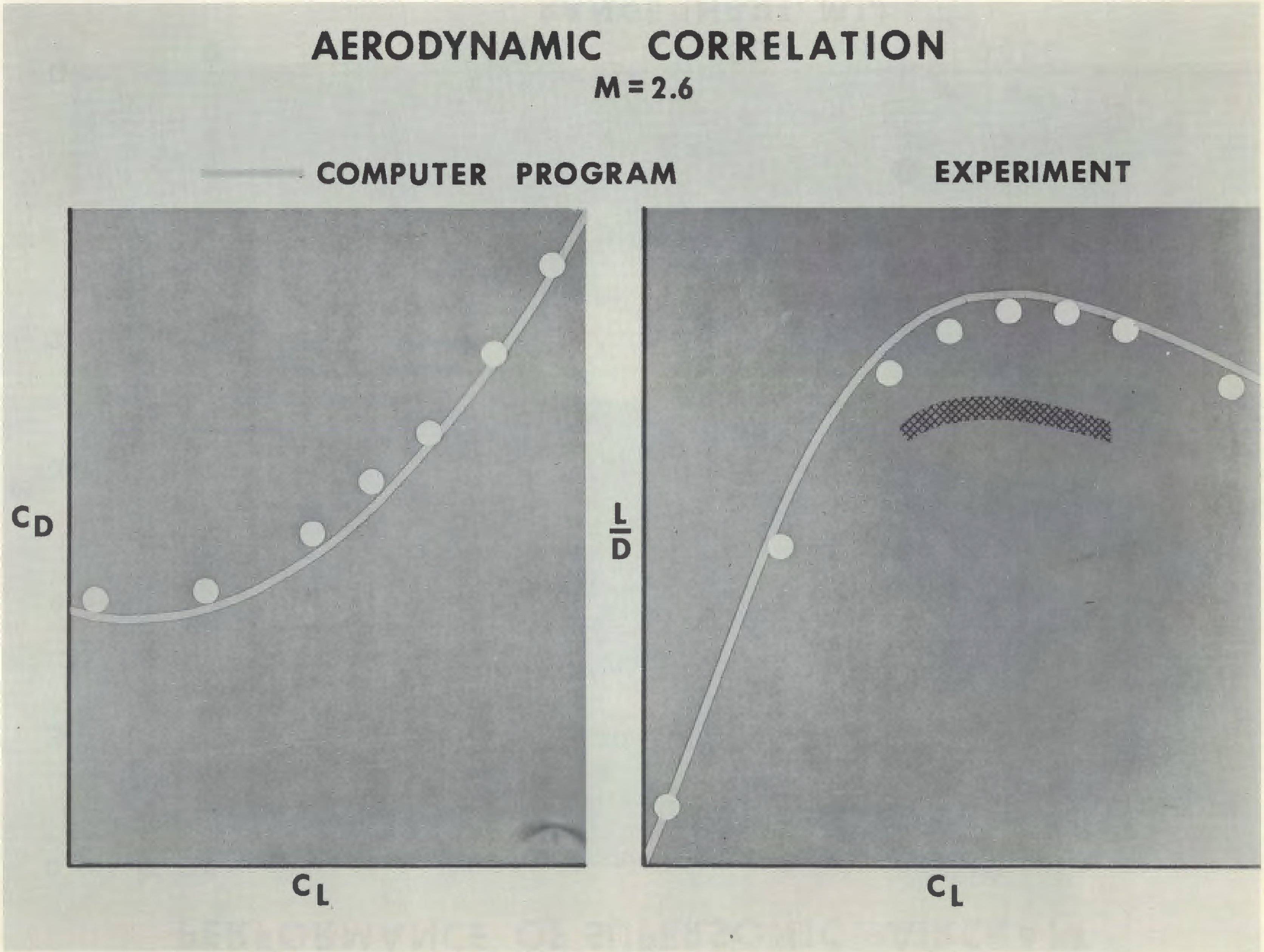
In summary, we have reviewed some of the research that NASA is conducting in the area of high-speed aeronautics. In recent years, the emphasis has changed from merely further increasing of speed to that of increasing the usefulness - in terms of range, speed, payload, and operating flexibility - of this new class of aircraft. One advance used as an illustration of this effort is the research that has made possible the application of the variable-sweep wing principle to practical aircraft such as the F-111. Another example is our research on means for attaining increased flight efficiency in supersonic cruise. This work constitutes a technical breakthrough which will have significant implications relative to the supersonic transport and advanced military aircraft.

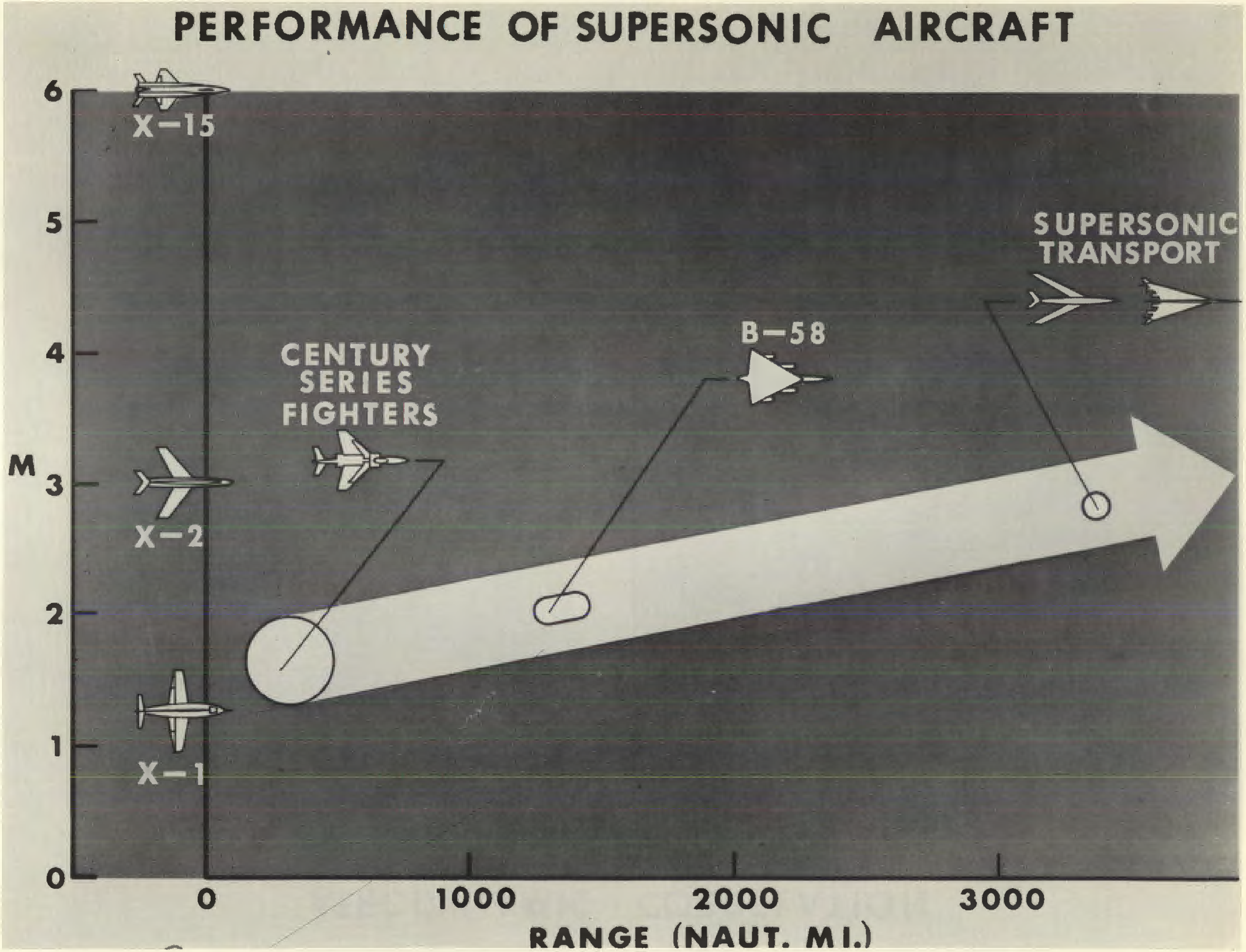



WING-BODY
COMBINATION
NACELLE


HISTORY OF AIRCRAFT SPEEDS
SPEED, KNOTS
2000
1500
1000
500
0
1900
10
20
30
40
50
60
70
80
YEAR
WRIGHT BROS
JND-4
SPIRIT OF ST. LOUIS
DC-3
DC-6
707/DC-8
SST


MULTIMISSION PROFILE
ALTITUDE
RANGE


AERODYNAMIC CORRELATION
M = 2.6
COMPUTER PROGRAM
EXPERIMENT
CD
CL
L/D
CL



NASA-Langley, 1964

NASA
L-64-4876

NASA
L-64-4878