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FLIGHT EVALUATION OF SOME EFFECTS OF THE PRESENT AIR TRAFFIC CONTROL SYSTEM ON OPERATION OF A SIMULATED SUPERSONIC TRANSPORT

by Donald L. Hughes, Bruce G. Powers, and William H. Dana

Flight Research Center
Edwards, Calif.

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SUMMARY

An exploratory flight program was conducted to investigate the effect of the present Air Traffic Control system on the operation of a simulated supersonic transport in the Los Angeles terminal area. The climb and descent portions of a representative supersonic transport flight profile were flown with an A5A airplane. In addition, en route problems were explored within the speed and altitude capabilities of the test airplane. Airplane velocity, acceleration, and altitude data were obtained, as well as flight-crew opinions and ground-personnel comments.

The results of the investigation indicate that general piloting problems associated with flying the supersonic transport profile appear to be minor, limited primarily to speed and altitude fluctuation during the high speed—high altitude portion of the profile and overshoot tendencies during level-offs from steep portions of the climb. The critical effect of temperature on climb and acceleration performance during the program emphasized the need for including temperature-altitude information in weather forecasts to be used for supersonic transport flight planning. Integration of the single test airplane, used to simulate a supersonic transport, resulted in only minor compatibility problems with the Air Traffic Control system. The problems encountered very likely can be solved with slight changes in the existing structure of control zones and in pilot—controller communications procedures.

INTRODUCTION

It has been anticipated that integrating the supersonic transport (SST) into the Air Traffic Control (ATC) system will pose an operational problem for both the aircrew and the air traffic controller because of the high performance capability of the SST. Of primary concern will be the takeoff, climb, descent, and landing approach. Some of these problems have been investigated with ground-based simulators by the Federal Aviation Agency and the NASA Langley Research Center (refs. 1 and 2). The NASA Flight Research Center at Edwards, Calif., in cooperation with the Federal Aviation Agency, conducted a flight-test program

with an A5A airplane to examine the compatibility of the SST with the present ATC system. The principal objectives of the program were to investigate anticipated problem areas and to evaluate the effect of the present ATC system on the operation of a simulated supersonic transport.

The tests were conducted in the Edwards Air Force Base and the Los Angeles areas using adjacent jet airways, which are heavily traveled by major airlines. In addition, a round-trip cross-country flight was made between Los Angeles and Albuquerque, New Mex., to investigate potential en route problems. The results of these tests are reported in this paper.

SYMBOLS

a_l	longitudinal acceleration, g
a_n	normal acceleration, g
F	frequency of communication, calls/minute
h_p	pressure altitude, ft
M	Mach number
R	range along flight path, nautical miles
t	time, sec
V_i	indicated airspeed, knots
V_t	true airspeed, knots

AIRPLANE AND TEST EQUIPMENT

The A5A airplane used in this investigation was loaned to the Flight Research Center by the U.S. Navy for research on operating problems related to air traffic control. The test airplane is a tandem two-place attack vehicle with swept wings and twin engines. Pertinent physical characteristics are presented in the following tabulation:

Overall length, ft	76.7
Overall span, ft	53
Overall height, ft	19.4
Wing area, sq ft	700
Empty gross weight, lb	34,000
Sea-level maximum static thrust, lb	34,000

The A5A is capable of matching the climb and descent performance of an SST; however, the mass, inertia, volume, and configuration are not representative of an SST. A photograph of the airplane is shown in figure 1.

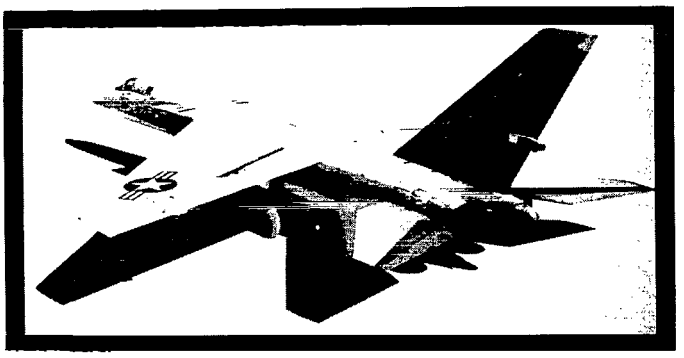


Figure 1.- A5A airplane. E-10555

The aircraft communication-navigation (COM-NAV) gear was augmented to provide capability comparable to that of present civil air transports. The second-station crewman acted as copilot. The disadvantage of the tandem cockpit was overcome to some degree by using the aircraft's intercommunication system and by installing some of the navigation equipment in both cockpits. Figures 2 and 3 show the pilot's and copilot's instrument panels and right-hand and left-hand consoles, respectively.

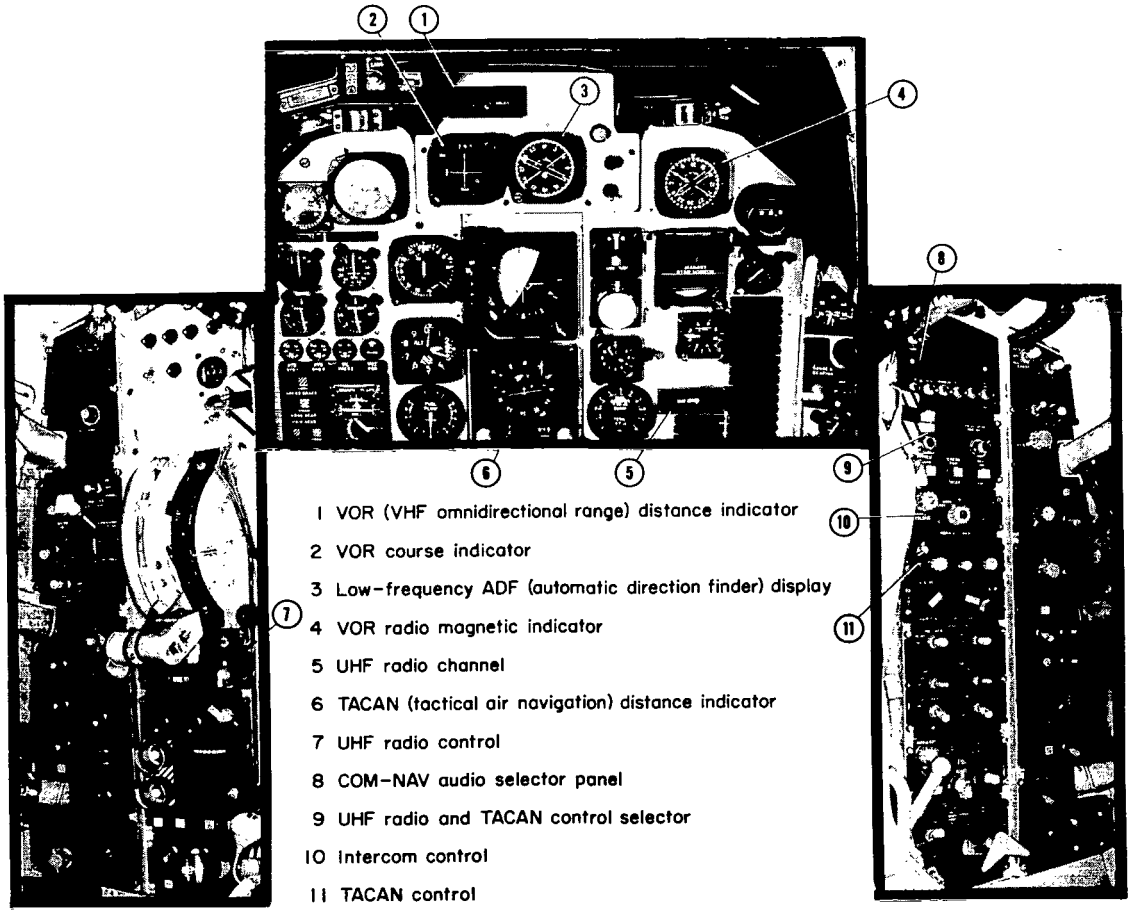
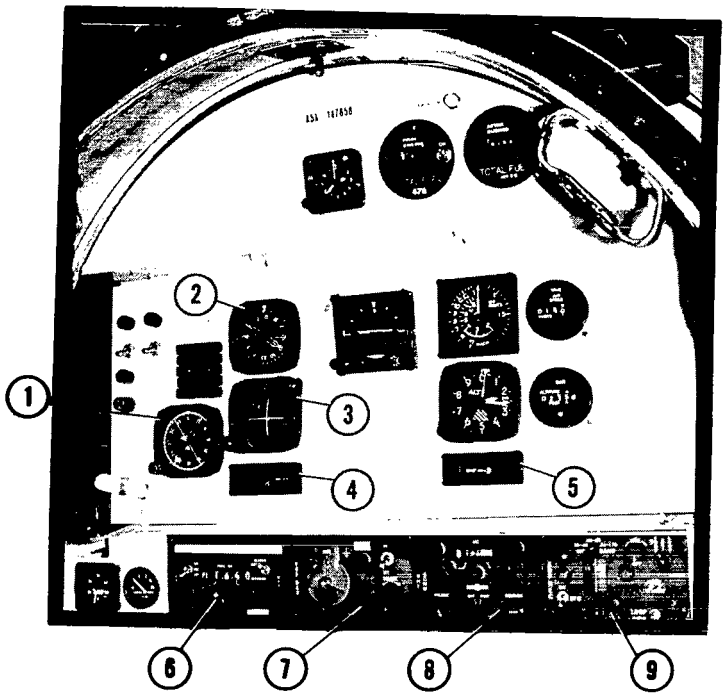


Figure 2.- Pilot's instrument panel and consoles.



1 Low-frequency ADF display

2 TACAN and VOR radio magnetic indicator

3 VOR course indicator

4 VOR distance indicator

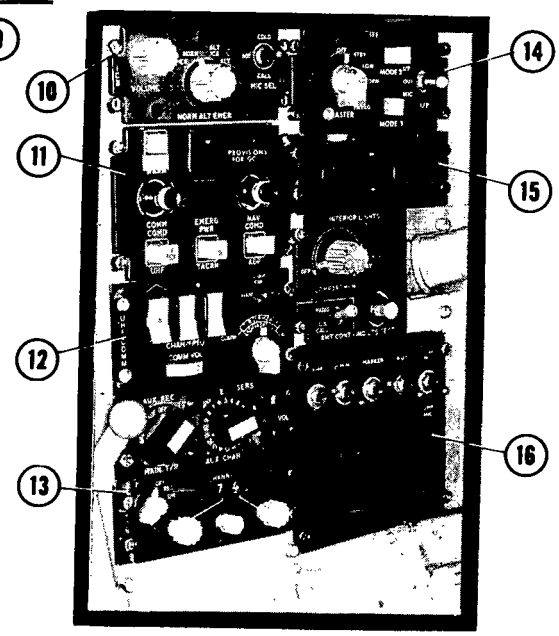
5 UHF radio-channel indicator

6 VOR-DME (distance measuring equipment)

7 VOR control

8 VHF radio control

9 ADF control



10 Intercom control

11 UHF radio and TACAN control selector

12 UHF radio control

13 TACAN control

14 IFF (identification, friend or foe) control

15 SIF (selective identification feature) control

16 COM-NAV audio selector panel

Figure 3.- Co-pilot's instrument panel and consoles.

A standard NACA airspeed head was mounted on the nose boom of the airplane to measure airspeed and altitude. Accelerations were measured in three axes at the airplane's center of gravity. All quantities were internally recorded on film and correlated by a common timer. Communications were recorded on an airborne tape recorder.

PROCEDURES AND TESTS

A representative SST flight profile was derived for this study from the results of numerous supersonic commercial air transport (SCAT) feasibility studies. The profile, a composite of variable-sweep and delta-canard aircraft trajectory profiles, is depicted in figure 4 with the A5A simulation envelope superimposed. The thrust-to-weight ratio of the A5A was adjusted to that predicted for the SST (refs. 3 and 4) so that the climb and descent performance of the SST could be matched to an altitude of approximately 50,000 feet and a Mach number of 1.4. All flights were made with manual controls, using stability augmentation.

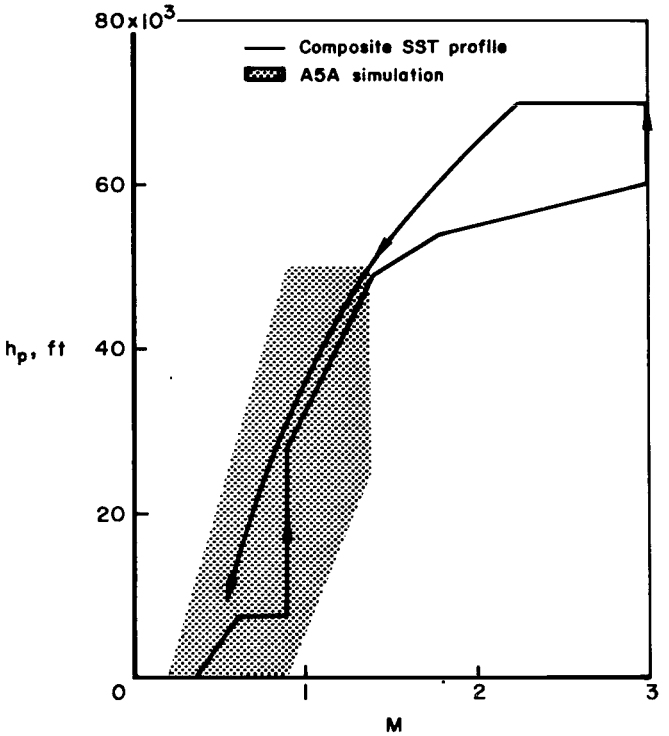


Figure 4.- Portion of typical supersonic-transport climbout and descent profile simulated by the A5A.

The test program was conducted in three phases. For the first phase, Edwards Air Force Base (EAFB) was used as the airport for simulated SST departures and arrivals. In the second phase the airplane was based at Edwards and used Los Angeles International Airport for arrivals and departures, without landing. During the third phase, the A5A operated entirely from Los Angeles International Airport.

EAFB Flights - Phase 1

Initially, individual SCAT profiles and the composite profile shown in figure 4 were flown in the Edwards Air Force Base area. These flights established operational procedures and increased pilot proficiency in reproducing the profile before operation was extended to the high-density air traffic of the Los Angeles area.

Los Angeles Flights - Phase 2

During the arrival and departure phase of the flights in the Los Angeles area, only the composite profile was flown. The air route shown in figure 5 between Tuba City, Los Angeles International Airport, and Palmdale was followed.

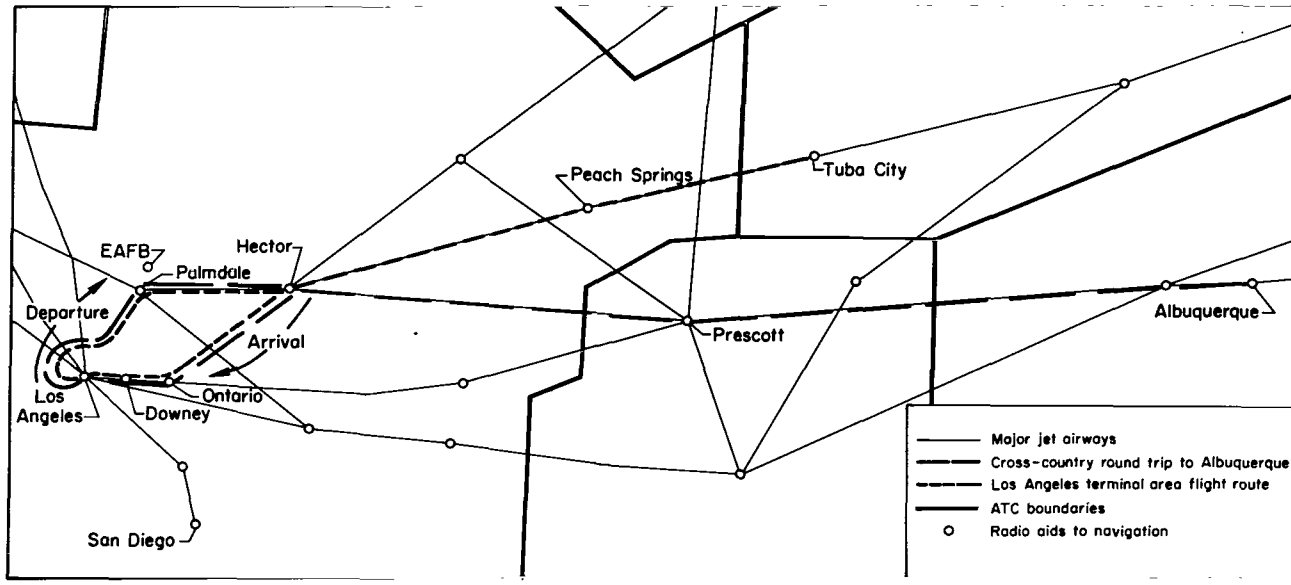


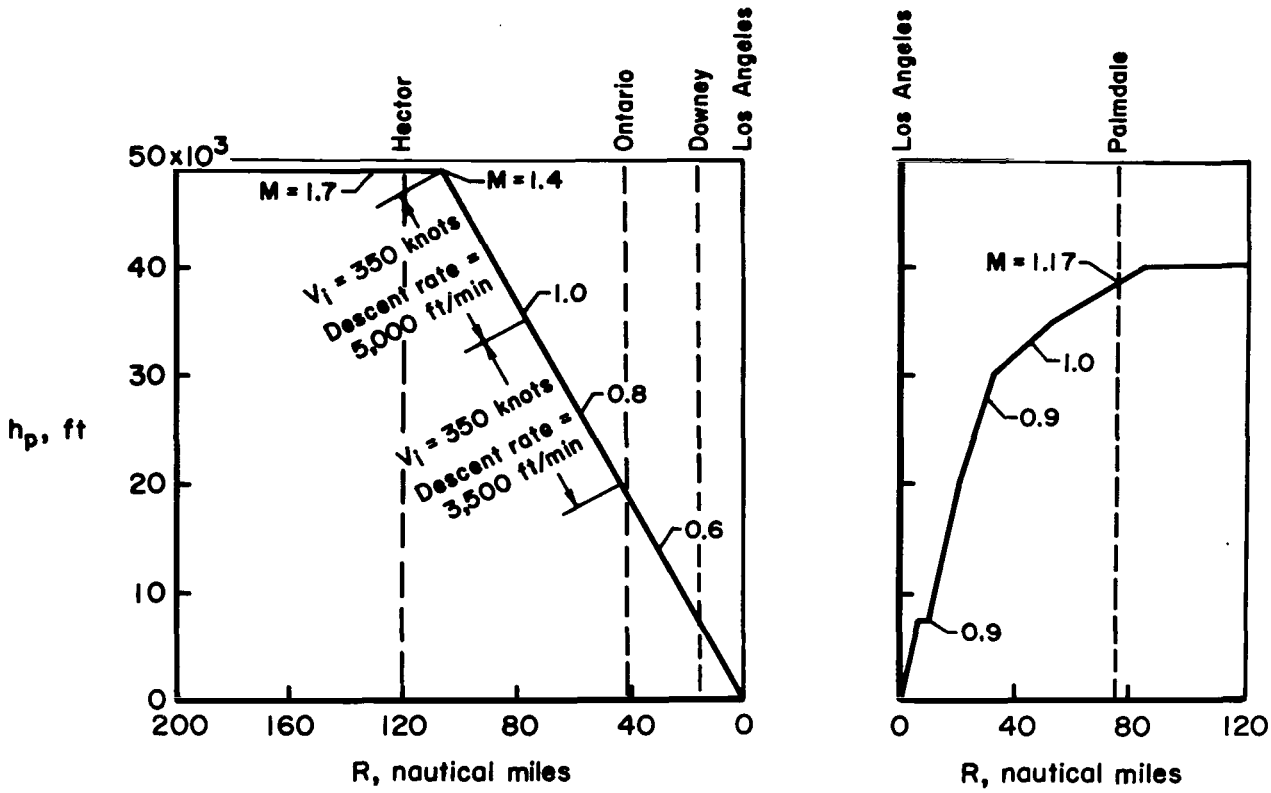
Figure 5.- Routes used in the investigation.

As shown in figure 6(a), the arrival simulation was started 107 nautical miles from Los Angeles at an altitude of 49,000 feet by decelerating the A5A from $M = 1.7$ to $M = 1.4$. It was found that the predicted SST descent parameters could be matched most closely by maintaining a constant indicated airspeed of 350 knots and a constant rate of descent of 5,000 ft/min between 49,000 feet and 35,000 feet altitude, and then reducing the rate of descent to 3,500 ft/min between 35,000 feet and 20,000 feet altitude. The indicated airspeed was reduced to 320 knots at Ontario, and the remainder of the approach was similar to that of a subsonic jet.

The departure simulation, as shown in figure 6(b), started at Los Angeles International Airport and continued to 40,000 feet altitude and a Mach number of 1.17 for 75 nautical miles along the flight path to the vicinity of Palmdale, where the mission terminated. This first group of departures from the Los Angeles area was performed without landing at International Airport. The aircraft took off from Edwards Air Force Base, used the SST arrival profile with a low pass over the Los Angeles International Airport, then climbed out following the SST profile. Special ATC handling was required to clear the low pass over the airport with the subsequent climbout.

Los Angeles Flights - Phase 3

To obtain more realistic departure flights, the A5A was based at Los Angeles International Airport. Flight plans were filed with those of the commercial jet transports, and the A5A taxied into takeoff lineup with the commercial aircraft. When clearance was received, the A5A took off and followed the prescribed climb profile. Several aircraft were overflown on the outbound route between Los Angeles, Hector, and Tuba City.



(a) Arrival.

(b) Departure.

Figure 6.- Arrival and departure profiles used in the Los Angeles area.

During the phase 3 portion of the simulation, a round-trip flight was made between Los Angeles and Albuquerque on the airway shown in figure 5. The en route cruise segment was flown at an altitude of 49,000 feet and a Mach number of 1.5. Both flights were scheduled to coincide with predicted periods of high-density air traffic in the Los Angeles area.

Sonic Boom

No evaluation was made of the sonic-boom problem. The A5A does not represent the mass, volume, or configuration of the SST and, therefore, the consequent ground overpressure signatures are not compatible with those of the SST.

RESULTS AND DISCUSSION

Departure and Climb to Cruise

Altitude hold.- During the departure phase of the simulation, altitude-hold procedures required during the climbout were difficult to perform even though

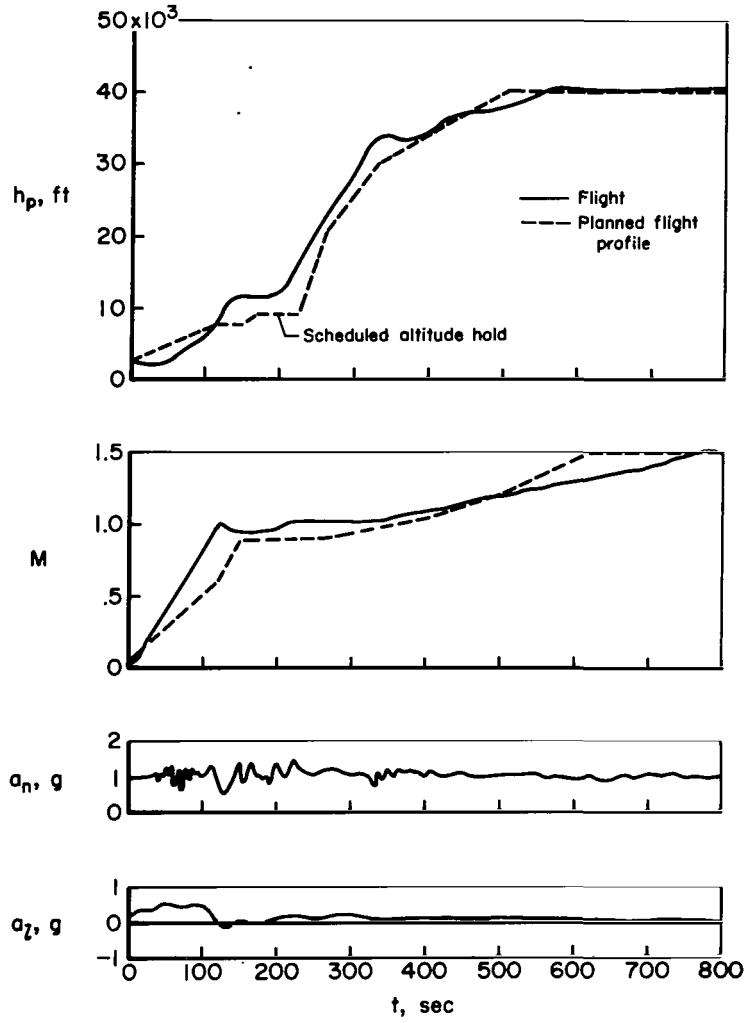


Figure 7.- Time history of a departure with a 1-minute altitude hold.

the pilot received advance warning from the traffic controller. Figure 7 is a typical time history of an attempt to follow the composite SST departure profile. The flight plan specified a level-flight acceleration from $M = 0.6$ to $M = 0.9$ at an altitude of 7,500 feet, followed by a climb at $M = 0.9$ to 9,000 feet where an altitude-hold restriction was to be flown for 1 minute before the climb profile was continued. As shown, the target hold altitude was missed by approximately 2,300 feet. This deviation was attributed to the pilot's attempts to keep the change in load factor to a minimum for passenger comfort and, at the same time, to follow navigation instructions and watch for other aircraft. Instrument lag and poor horizon visibility during the climb and push-over also added to the difficulty of leveling off at the specified altitude. The longitudinal acceleration data at $t = 100$ seconds indicate that the engine thrust was reduced at 7,500 feet; however, the level-off was not established until an altitude of 11,300 feet was reached. During the maneuver, the normal accelerometer indicated an incremental change of 0.8g, which is undesirable for passenger comfort (ref. 5). It should be emphasized, however, that the A5A dynamic characteristics, such as the inertia and maneuverability, are not the same as those predicted for an SST; thus, these accelerations indicate only a potential problem in this area.

Leveling off at an altitude of 40,000 feet for acceleration to cruise Mach number posed a similar piloting problem. Through practice, however, the pilot eliminated altitude overshoots by becoming familiar with the magnitude of anticipation necessary to permit smooth transition from climbing to level flight.

The A5A flights indicate that the SST pilot will require advance warning from the controller at least 4,000 feet to 5,000 feet before the hold altitude is reached to allow time for the throttles to be moved to a lower power setting

and for a gradual push-over to begin. Also, it appears that it will be necessary for the SST pilot to practice level-offs in order to become familiar with the increase in the magnitude of anticipation over that required with subsonic jets.

Temperature effects.- A critical area during departure and climbout for jet aircraft is the deterioration of engine power when the temperature increases over standard day levels as altitude is increased. Figure 8 is a time history of a level-flight acceleration from $M = 0.90$ to $M = 1.7$ at an altitude of 35,000 feet, followed by a constant $M = 1.7$ climb to a cruising altitude of 50,000 feet. Because of the 10.5° C increase in temperature over standard day temperature, the time required to accelerate from $M = 0.95$ to $M = 1.7$ was almost twice as great as predicted. Consequently, the amount of fuel expended was also almost doubled.

Inasmuch as the estimated fuel expenditure for the SST climbout and acceleration to the supersonic cruise Mach number is estimated to be one-third of the total fuel on board, the acceleration phase of the mission will be critical, in that the additional use of fuel may require a reduction in range. For flight-planning purposes, therefore, it will be necessary for weather advisories to include the variation in temperature with altitude for a distance as great as 300 miles from the terminal area along the intended SST flight path.

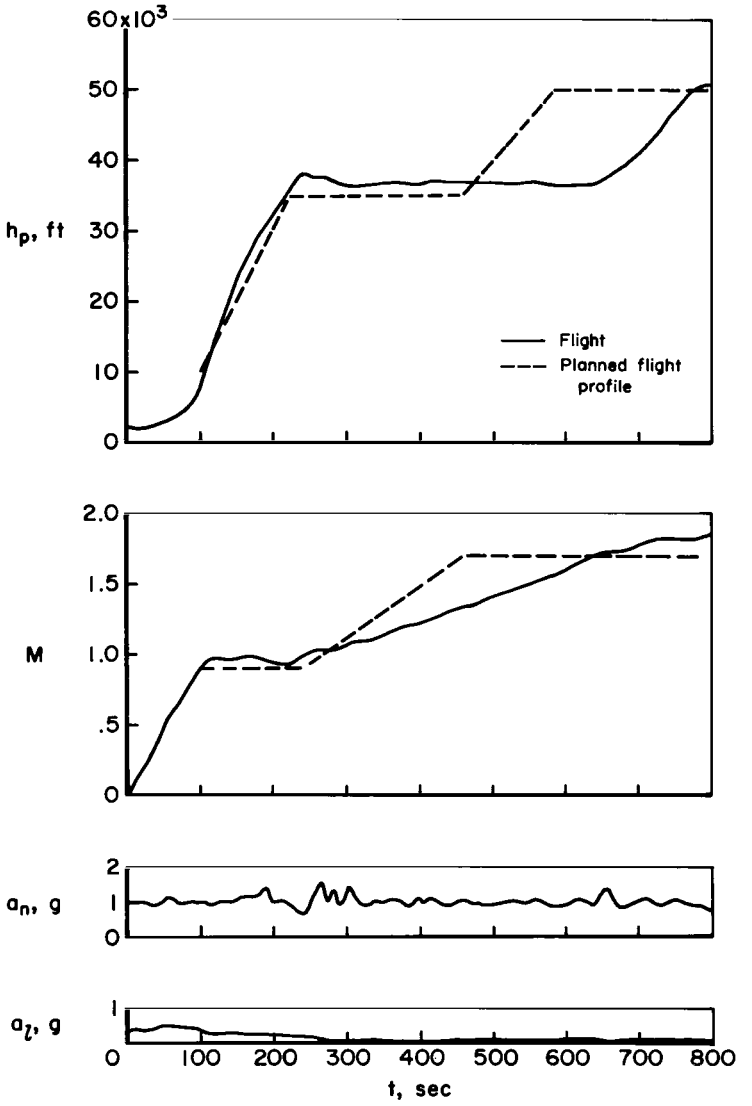


Figure 8.- Effects of an increase in temperature above standard day temperature on a departure with a level-flight acceleration at 35,000 feet.

Departure trajectories.- Arrivals and departures of commercial jets using the same routes as the A5A into and out of Los Angeles International Airport were surveyed to obtain an understanding of ATC problems and to compare the

predicted performance of the SST with the existing subsonic jets. Departures of the two types of aircraft are compared in figure 9; arrivals are compared in figure 10. Shown also in each figure are several of the actual flight profiles.

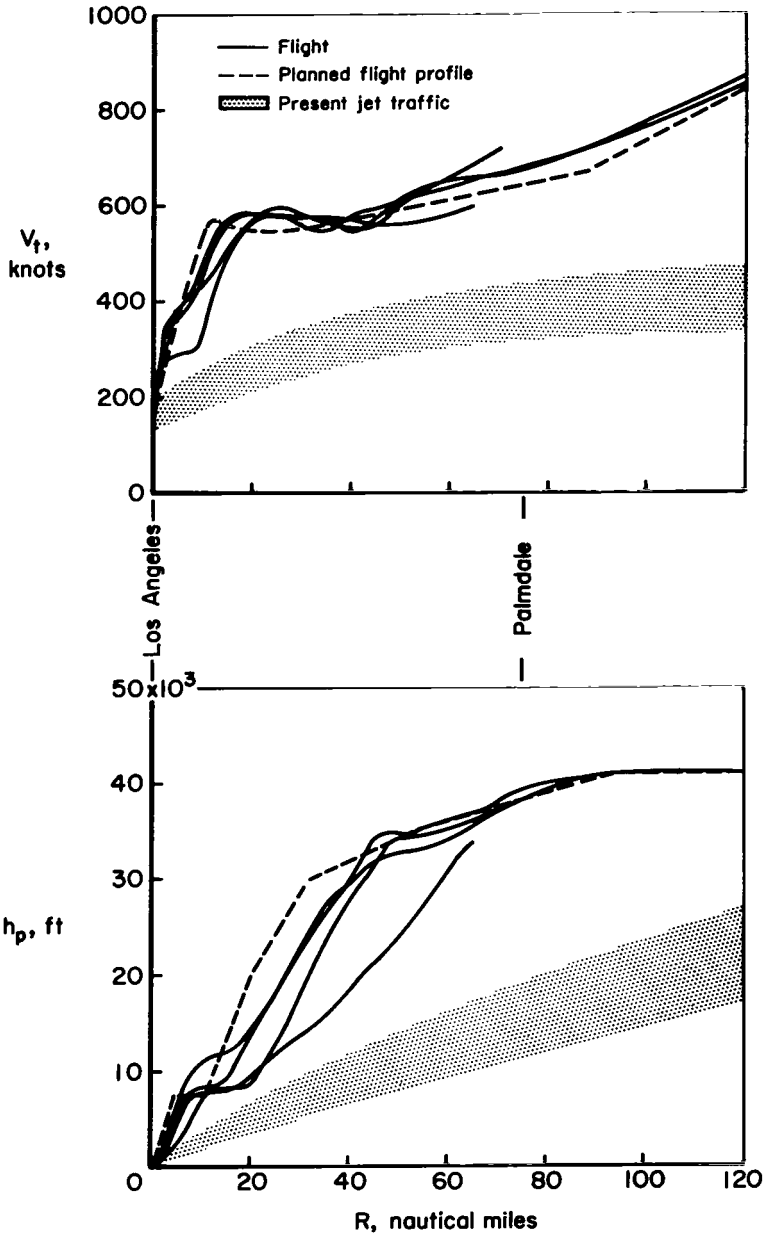


Figure 9.- Comparison of jet-transport departures with simulated SST departures from Los Angeles International Airport.

During the climbout (fig. 9), at approximately 80 nautical miles from the terminal area, the true airspeed of the jet transports is between 320 knots and 450 knots; the predicted SST airspeed is 650 knots. The jet transport altitudes range from 12,000 feet to 20,000 feet; whereas, the SST altitude is 39,000 feet. Since the SST will climb more than twice as fast as present subsonic jets, the over-flight traffic will have to be protected as the SST makes its high-speed climb to cruise altitude.

Another problem associated with the high performance capabilities of the SST occurred on the first simulated departure from Los Angeles. The A5A reached the limit of its clearance at an altitude of 28,000 feet while still in the ATC geographic sector covered by the low-altitude radar controller. Clearance from the high-altitude radar controller had to be obtained for the next sector before the A5A could continue its climb. This problem was alleviated on later flights by advance coordination so that a continuous clearance could be granted before departure. The problem was compounded by the presence of other aircraft in the area; therefore, priority was given to A5A flights by holding back or rerouting the over-flight traffic.

Speed restrictions.- The air traffic controller had difficulty keeping the A5A within the departure controller's sector because of the large turn radius

resulting from the high climbout speed. A 1-minute speed restriction of 250 knots was necessary to enable radar surveillance to be maintained and to allow the airplane to be vectored to the Palmdale departure route without exceeding departure control area bounds. The speed restriction allowed the A5A to make a much shorter turn radius and, thus, travel a shorter distance to reach Palmdale. The restriction also moved the sonic-boom problem farther down the flight path. Pertinent aspects of the restricted and nonrestricted departures are compared in the following table:

	No speed restriction	1-minute speed restriction
Time from takeoff to Palmdale, sec	518	495
Distance traveled to Palmdale, nautical miles	75	65
Altitude at Palmdale, ft	39,000	34,800
Mach number at Palmdale	1.17	1.14

Ground noise levels and overpressure limitations will dictate the location of the ground track for the departing SST and may even impose speed restrictions until the airplane clears certain areas. These considerations may constitute a problem for airports handling the SST.

Pilot workload.- The pilot's workload during the departure was excessive. The heavy load may have been caused by several factors, such as the difficulty of matching the SST profile and the tandem seating arrangement. It is attributed primarily, however, to the high flight speed through many different control sectors, which required many radio-frequency changes within a short time, as discussed later.

Descent and Arrival in the Terminal Area

Initially, some difficulty was encountered in matching altitude and Mach number against range in the descent profile because of the interdependence of all parameters. This problem was alleviated by establishing a constant rate of descent and a constant indicated airspeed, as shown in figure 6(a). The transition areas at the initial push-over at an altitude of 49,000 feet, the change in rate of descent at 35,000 feet, and the change in the indicated airspeed at 20,000 feet were minor problems associated with this type of descent.

As noted previously, data obtained on arrivals of civil jets into the Los Angeles area are compared in figure 10 with the planned profile of the simulated SST to illustrate the operating regimes of the two types of vehicles. Both the SST and the subsonic jet traffic are descending 100 miles from the airport; the SST is at an altitude of 46,000 feet, the present jet traffic at altitudes of 20,000 feet to 33,000 feet. The true airspeed of the SST is 730 knots; the airspeed of present jet traffic varies from 390 knots to 520 knots. At Ontario (44 nautical miles from the terminal), the SST altitude is 20,000 feet, and the altitude of the commercial jet traffic varies from 9,000 feet to 15,000 feet; the true airspeed of the SST is 425 knots, and the jet speed ranges from 255 knots to 405 knots.

As shown in figure 10, the A5A generally remained above the commercial jet traffic until it reached Downey, approximately 16 nautical miles from the runway. It then intersected the Instrument Landing System (ILS) glide slope between Downey and the outer marker beacon and passed over the outer marker beacon at an altitude of 1,830 feet, 5.4 nautical miles from the approach end of the runway. Initially, the air traffic controller restricted the airspeed of the A5A to 150 knots between Ontario and Los Angeles. This speed was considered to be slower than desirable; thus, an arbitrary minimum approach speed of 170 knots was agreed on by NASA personnel and the approach controllers as a more representative SST approach speed. This restriction was imposed on succeeding flights to maintain current separation distances. The simulation study of ATC procedures reported in reference 1 concluded that the traffic control system will be more sensitive to separation distance than any other factor in the arrival operation. During arrival into Los Angeles International Airport, under VFR conditions and varying amounts of traffic density, no major problems were encountered when speed restrictions were accepted. The entire arrival simulation appeared to be compatible with existing ATC procedures.

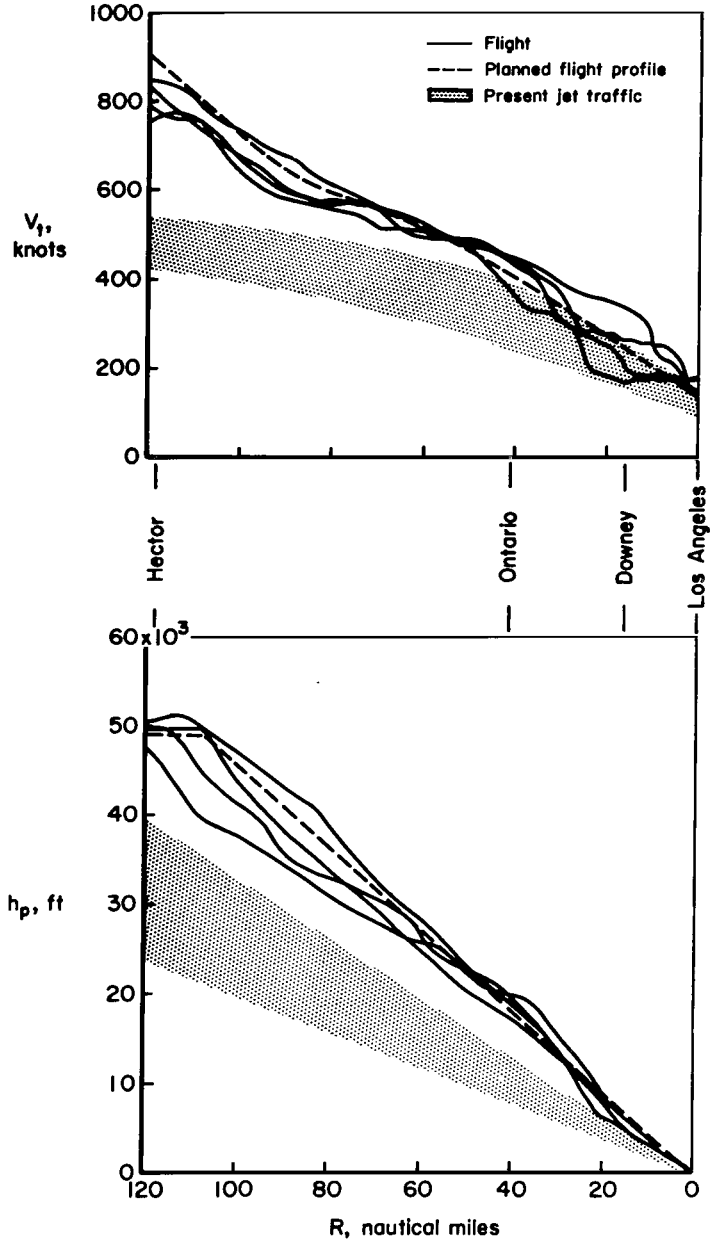


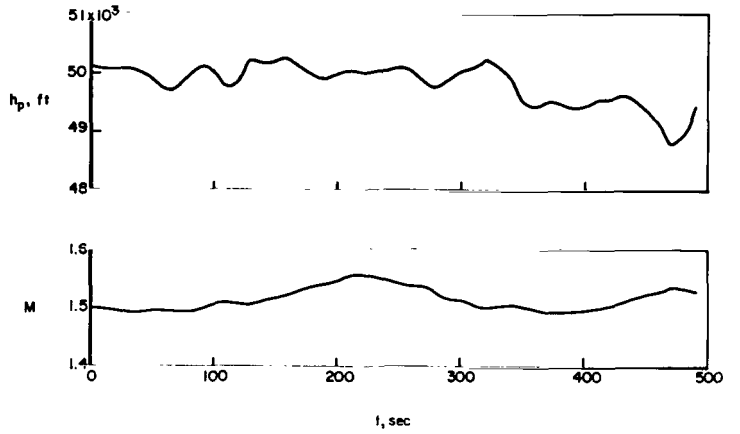
Figure 10.- Comparison of jet-transport arrivals with simulated SST arrivals into Los Angeles International Airport.

En Route Cruise Simulation

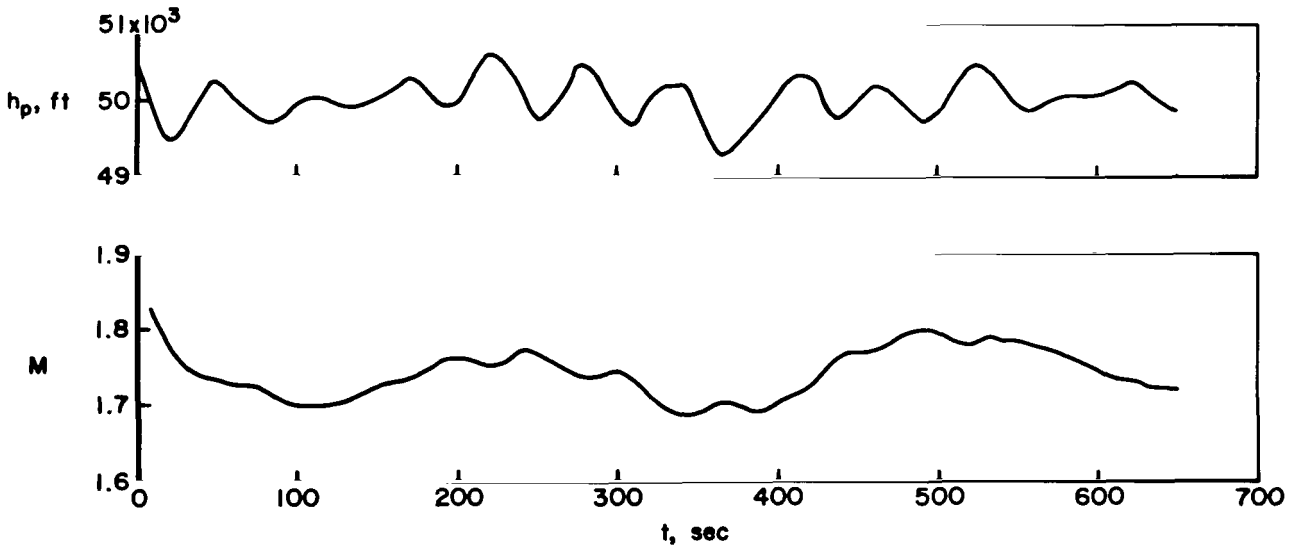
The en route problems that might be associated with supersonic operations were not fully investigated because of the limited range, speed, and altitude capabilities of the A5A. However, some experience was gained on the short en route

supersonic segment of a round-trip flight from Los Angeles to Albuquerque. Each flight was about 640 miles; total time in transit was 1 hour, 6 minutes for each direction of travel; and most of the flight was made at 49,000 feet altitude and a Mach number of 1.5. Although the round trip started during the heavy morning eastbound traffic, there were no significant air traffic control problems. Hand-offs from sector to sector and from center to center were made routinely. The only areas of potential operational difficulty were in maintaining assigned flight-clearance altitude and airspeed, and communications.

Figure 11(a) is a time history of an 8-minute portion of the en route simulation during which the pilot attempted to manually maintain constant airspeed and altitude. Throttle and control-stick adjustments were required continually. Because of the phasing of these adjustments, the altitude varied from 50,300 feet to 48,800 feet and airspeed varied from M = 1.48 to M = 1.55. Figure 11(b) shows the variations in airspeed and altitude that occurred at a higher Mach number over an 11-minute portion of the supersonic cruise. The altitude varied from 50,600 feet to 49,300 feet, and the airspeed varied from M = 1.84 to M = 1.69.



(a) M = 1.5.



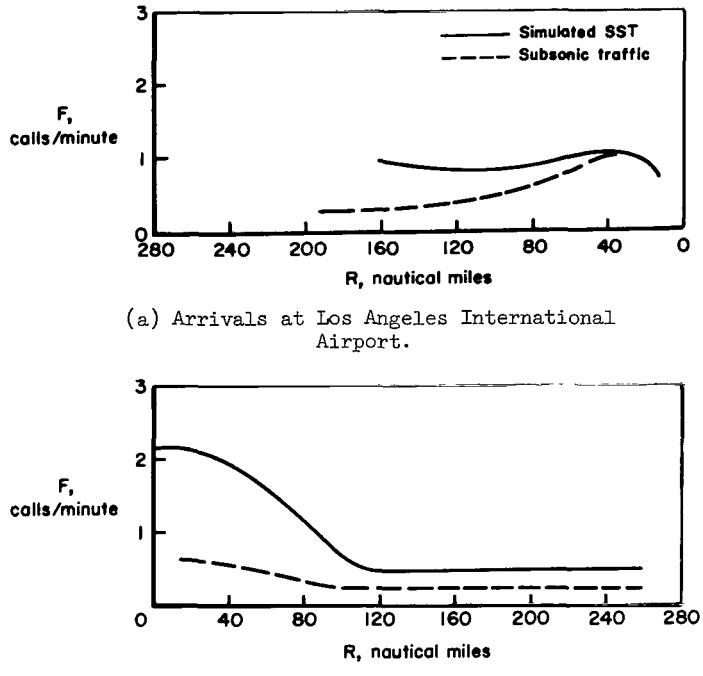
(b) M = 1.7.

Figure 11.- Fluctuations in Mach number and altitude during supersonic en route cruise.

For aircraft traveling at a Mach number of 1.5, a 1° change in pitch attitude causes a 1,500 foot-per-minute altitude change. For the A5A, these variations are related to the inherent short-period and phugoid characteristics, which are not necessarily representative of an SST. However, as indicated also in the simulator studies of reference 6, these variations did occur and could arise in SST operations under similar conditions. Atmospheric conditions could also be contributing factors.

Communications

Communications surveillance added significantly to the pilot's workload. Fourteen radio-frequency changes were required on the flight from Los Angeles to Albuquerque. Seven calls were made during the cruise portion of the flight, with an average of 2.6 transmissions per call. During the departure, 23 calls were made, with an average of 2.8 transmissions per call.



(a) Arrivals at Los Angeles International Airport.

(b) Departures from Los Angeles International Airport.

Figure 12.- Frequency of radio communications for the simulated SST and present subsonic jets.

Figure 12 summarizes the communications workload for the A5A and present subsonic traffic in terms of calls per minute averaged for all the flights of this program. Figure 12(a) shows that the average number of calls per minute was about 1 as the A5A approached Los Angeles, remained above 0.8 during deceleration and descent, rose above 1 just before the turn onto the final ILS approach, and dropped off after the ILS glide slope was established. Approximately 40 nautical miles from the terminal, when the simulated SST and the jet traffic were traveling at approximately the same speed, the number of calls per minute was about the same for both types of aircraft.

During the first 90 nautical miles of the departure, the average number of calls per minute for the A5A was three times the average for the departing subsonic jet (fig. 12(b)). Thus, the communications workload appears to be directly related to the speed of the two types of aircraft as they pass through the various ATC control sectors and centers.

SUMMARY OF RESULTS

Climb and descent portions of a representative SST flight profile were flown with an A5A airplane in a high-density air traffic area to investigate compatibility problems which might arise when the supersonic transport is introduced into the present air traffic control system. The results of the investigation are as follows:

Most of the problems occurred in the departure from the airport. These problems can all be attributed to the increased performance the SST is expected to have over present commercial jets. Several thousand feet of altitude advance warning for an altitude hold during a steep climb were required to allow time for the pilot to move the throttles to a lower power setting and to begin a gradual push-over. Speed restrictions were imposed by the air traffic controller to hold the A5A within the area bounds of the departure controller's jurisdiction. The high-speed flight through the many control sectors caused a heavy increase in communications workload. The critical effect of temperature on climb and acceleration performance emphasized the need for including temperature-altitude information in weather forecasts to be used for SST flight planning.

No major en route problems were encountered, although fluctuations in airspeed and altitude were experienced at high speed and high altitude.

During the initial portion of each arrival simulation, the A5A approached the airport at a much higher altitude than the commercial jets; thus, no problems were encountered. Speed restrictions were imposed, however, during the latter portion of the arrival to permit integration and to maintain aircraft separation distances.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., September 4, 1964.

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