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TERMINAL AREA PROB[redacted]

SST OPERATIONS

By Richard H. Sawyer

NASA Langley Research Center
Langley Station, Hampton, Va.

Presented at the RTCA 1966 Annual Assembly Meeting

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INTRODUCTION

The problems regarding SST operations in the terminal area described in this paper are problems which have been noted during a joint NASA-FAA research program. This program consists of a simulation study involving terminal area operations of projected designs of the SST in a real-time traffic situation. In these studies, the SST simulator is operated by airline crews and the ATC facility simulator is operated by experienced air traffic controllers. In keeping with the theme of the meeting, the problems are only identified and described. For those interested, results from the research program to date are summarized in the articles referenced at the end of this paper.

VERTICAL FLIGHT PATH CONTROL

Climbout

Because of economic mission requirements, the SST during climbout will be required to operate as closely as possible to maximum allowable operating speed and sonic boom overpressure limitation boundaries of the nature shown in figure 1. In order to operate near these boundaries, there is a need for vertical flight path guidance and speed control because of the following problems:

1. At subsonic speeds, a high degree of susceptibility to overspeeding exists because of the high acceleration-climb capability in this regime. This

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problem is especially acute during the leveling portion of step-climb operations required in tunneling under arrival traffic, and during climbing turns required in being radar vectored to the airways system. Since the SST will probably be manually flown particularly during the lower altitude portion, a means of speed control such as autothrottle appears desirable.

2. At supersonic speeds, the difficulty of following the sonic boom overpressure limitation boundary exists since there is no flight parameter which is constant along this boundary. Development of a climb schedule mode for the autopilot based on a Mach number-altitude schedule with monitoring capability on the flight director appears to be a requirement. It should be noted that in the transonic range, flight path control can be effected only through the interchange of altitude and speed, since changes in engine power are not feasible because of the limited excess thrust capability in this region.

3. The transition from climbing flight into cruise flight without overshooting or undershooting altitude and/or speed is difficult because of the high acceleration-climb capability at near cruise conditions and because of the large power reduction required. Further, the transition must be anticipated sooner than at subsonic speeds and is more difficult to control because of the slower rate at which flight path angle changes can be made when passenger acceleration tolerance levels are observed. The level-off maneuver may require of the order of 6000 feet anticipation in order to prevent overshoot. Development of both automatic altitude capture and hold modes for the autopilot and a cruise Mach number capture and hold capability through autothrottle appear to be extremely desirable features. To cover autopilot failure cases, flight director guidance for the flare from climb into cruise conditions should be provided. The seriousness of this problem is illustrated by the fact that if power reduction is carried out too soon during the flare into cruise altitude, the aircraft may slow to the point where it cannot be reaccelerated even with full afterburning power because of the loss in ram thrust. Under such conditions only by descending can the SST be accelerated.

Descent

From a cruise operational standpoint, the descent of the SST is most easily accomplished by a slowup from cruise speed at cruise altitude to an airspeed at which descent can be made within the prescribed sonic boom overpressure limits (fig. 1). Because of the large speed and altitude changes involved in the descent operations, the descent time (including slowup) is of the order of 30-35 minutes, an increase of 50 percent, or more, over that for the subsonic jet transports. Expediting the descent is limited particularly at supersonic speeds by passenger comfort limitations and lack of drag producing devices suitable for airline operation. The basic problem in accomplishing a minimum time descent is in timing the initiation of slowup in order to arrive over a given fix at a prescribed altitude. The SST is much more sensitive to an error in initiation time than the subsonic jet transport as is shown in figure 2. An error of 1 minute in execution of, or ATC clearance for, start of descent procedures for the SST results in about a 7-minute increase in time spent proceeding at 250 knots to the fix for undershoots or in orbiting down at the fix for overshoots.

The descent problem for the SST is further complicated by the hand-off required from a hi-hi altitude sector controller (altitudes above about FL 430) to the high-altitude sector controller (altitudes from FL 180 to FL 420). Because of the difficulties of integrating the rapidly descending SST into the stream of subsonic traffic, it appears that the descent of the SST may have to be interrupted at times at about FL 430 in the hand-off. Such an altitude restriction is, of course, detrimental through increasing the time required for descent. Also, since at this altitude the SST is operating at slightly above sonic speed, the timing involved in the integration problem is complicated because the SST must be temporarily slowed to subsonic speed during the level-off as it would not be practical to maintain transonic speed for an appreciable period. A somewhat more drastic problem exists at higher altitudes on the descent profile where, if the SST is leveled because of an altitude restriction, insufficient thrust is available to maintain speed, with the result that the SST may approach low-speed flight limit boundaries within several minutes.

Pitch Attitude Control

For the purpose of controlling and adjusting the vertical flight path, the pilot makes use of the pitch attitude indicator on the artificial horizon. Control of the vertical flight path has been found to be difficult at supersonic speeds, both in flight tests of military aircraft and in simulation tests of proposed designs of the SST. This difficulty results from a number of factors including differences in the longitudinal dynamic characteristics and longitudinal control characteristics between subsonic and supersonic speeds. The basic problem, however, stems from the increased sensitivity with which aircraft attitude must be set to hold or adjust the vertical speed of the aircraft. This effect is illustrated in figure 3 which shows the pitch attitude angle change required to make a given change in vertical speed as a function of Mach number. It can be seen that the pitch attitude change required to make a given change in vertical speed at SST cruise speed is less than one-third of the change required at subsonic jet cruise speed. From simulation tests, it appears necessary to develop a pitch attitude display of increased sensitivity (of the order of 5:1) than used on the conventional artificial horizons for use at supersonic speeds. Preliminary indications are that a sensitive mode on the artificial horizon for use at supersonic speeds is preferable to a separate display. However, it should be noted that in providing a choice of normal and sensitive modes on the artificial horizon, consideration must be given to the loss of horizon reference which occurs if the sensitive mode is inadvertently used at high-attitude conditions. Further, a question exists as to a possible loss of attitude reference and loss of control in use of the sensitive mode under turbulent air conditions.

Navigation

For the SST, the main problem of navigating in the terminal area centers around any requirement for making turns at transonic and supersonic speeds. Turns at these speeds are highly undesirable because of their effect on climbout performance and amplification of the sonic boom level. For example, for turns such as those required at just above sonic speed as shown in figure 4, use of a bank angle of 25° (nominal practice) can reduce the climb capability to zero. Use of a lower bank angle, while not affecting the performance as much, results in extension of time at transonic speeds and excess fuel usage. Such turns are also undesirable because the sonic boom level is amplified due to the focusing effect of the turn. In tests with fighter aircraft, amplification factors of from 2 to 4 have been recorded.

It would appear that elimination of turns at transonic speeds in the terminal area could be accomplished by providing the SST with climbout and descent corridors. Consideration of forecasted traffic levels for the SST in the New York area, restricted airspace problems, and the effects of such priority on traffic delays for other traffic and reduction of airport handling rate that have been shown in simulation tests appear to preclude such an approach. The problem therefore exists of designing a compromise system in which the turns at transonic and supersonic speeds for the SST will be minimized with a minimum effect on the overall traffic-handling ability.

From a piloting standpoint, the problem of turning at supersonic speeds is illustrated in figure 5. It can be seen that for a given bank angle, the radius of turn at Mach 2 is more than 5 times greater than that for a subsonic jet at cruise conditions, and at Mach 3 is over 12 times greater. Further, as is shown in figure 6, the time required to make a given change in heading for the SST at cruise speed is greatly increased over that for the subsonic jet at cruise speed. Both of these factors increase the difficulty of manually making heading changes at supersonic speeds. In particular, because of the large turn radii at supersonic speeds, lead-type turns must be used to prevent large overshoots and difficulty in attaining the outbound heading as is illustrated in figure 7. The amount of lead distance required is a function of heading change required, speed, bank angle, and in terms of slant-range distance, the aircraft altitude. Development of a lead-turn capability for the navigation system and autopilot to relieve the crew of determining lead-distance data, and of manually performing long turn maneuvers appears to be a desirable goal.

Another navigation problem which apparently must be considered in the design of overland departure routings for the SST is the superboom. The superboom is the amplified sonic boom which occurs during transonic acceleration due to focusing of the shock waves. The nominal value of the sonic boom has been shown in tests of a fighter aircraft to be amplified from 2 to 4 times during transonic acceleration. In order to eliminate possible structural damage to buildings and excessive complaints from residents, it appears necessary to adjust the climbout schedule and routing for the SST in order to pinpoint the superboom on a desolate area. Consideration must be given to providing a straight track segment during the transonic acceleration phase in order to control placement of the superboom. Provision of more than one area on each departure route appears to be necessary in order to allow for delays in transonic acceleration required because of weather conditions.

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2. O'Brien, Joseph P.: Supersonic Transport Effects on Air-Traffic Control. Astronautics and Aeronautics, August 1966.

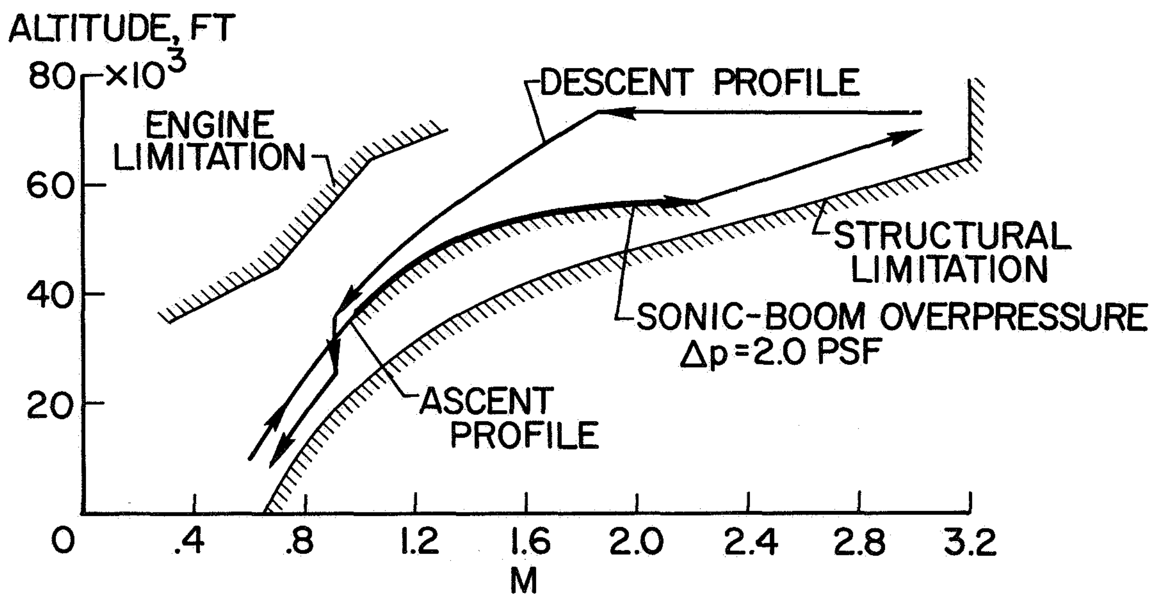

Figure 1.- Profiles and limitations.

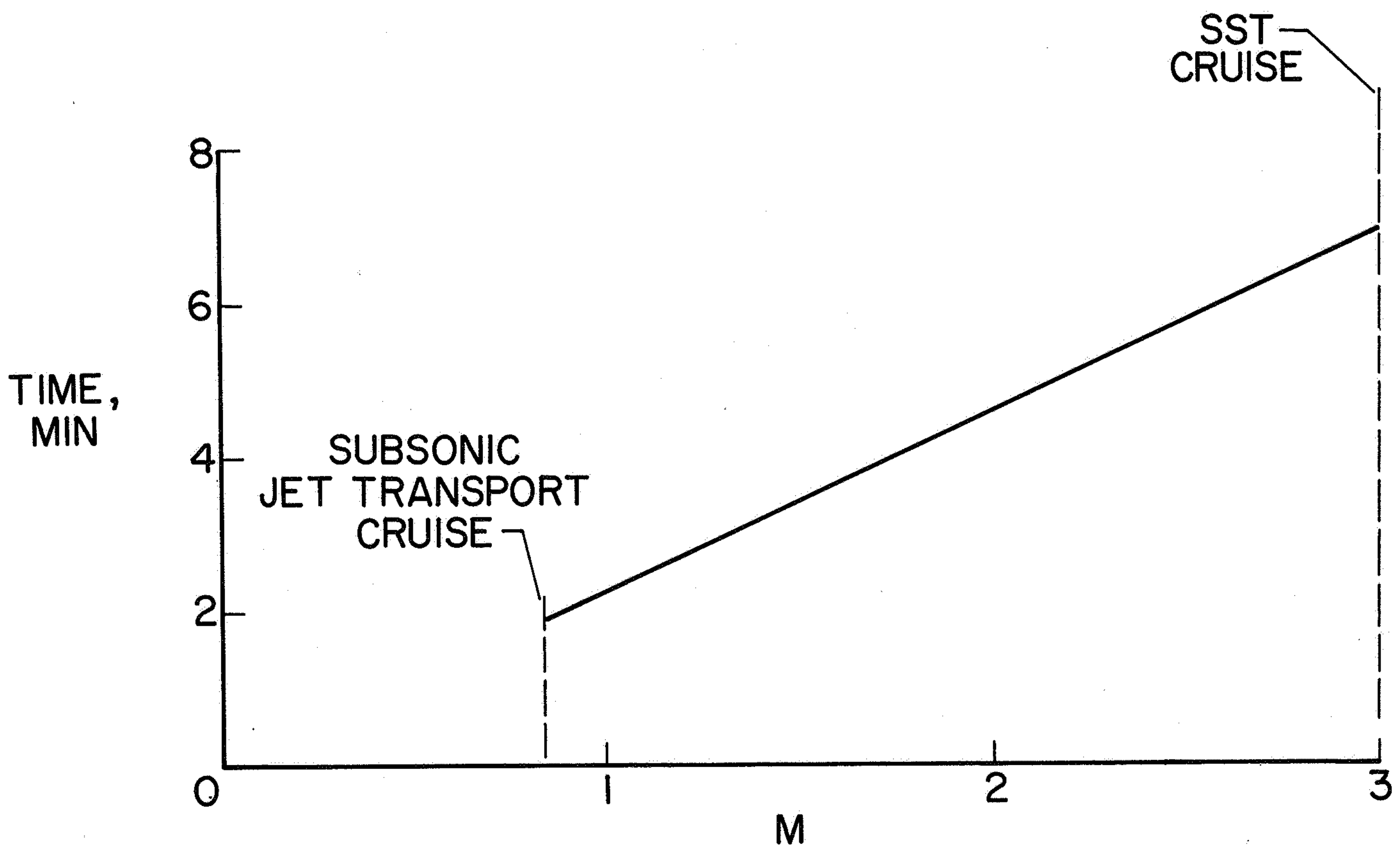

Figure 2.- Additional flight time at 250 knots for each minute error in initiation of descent procedures for the SST and the subsonic jet transport.

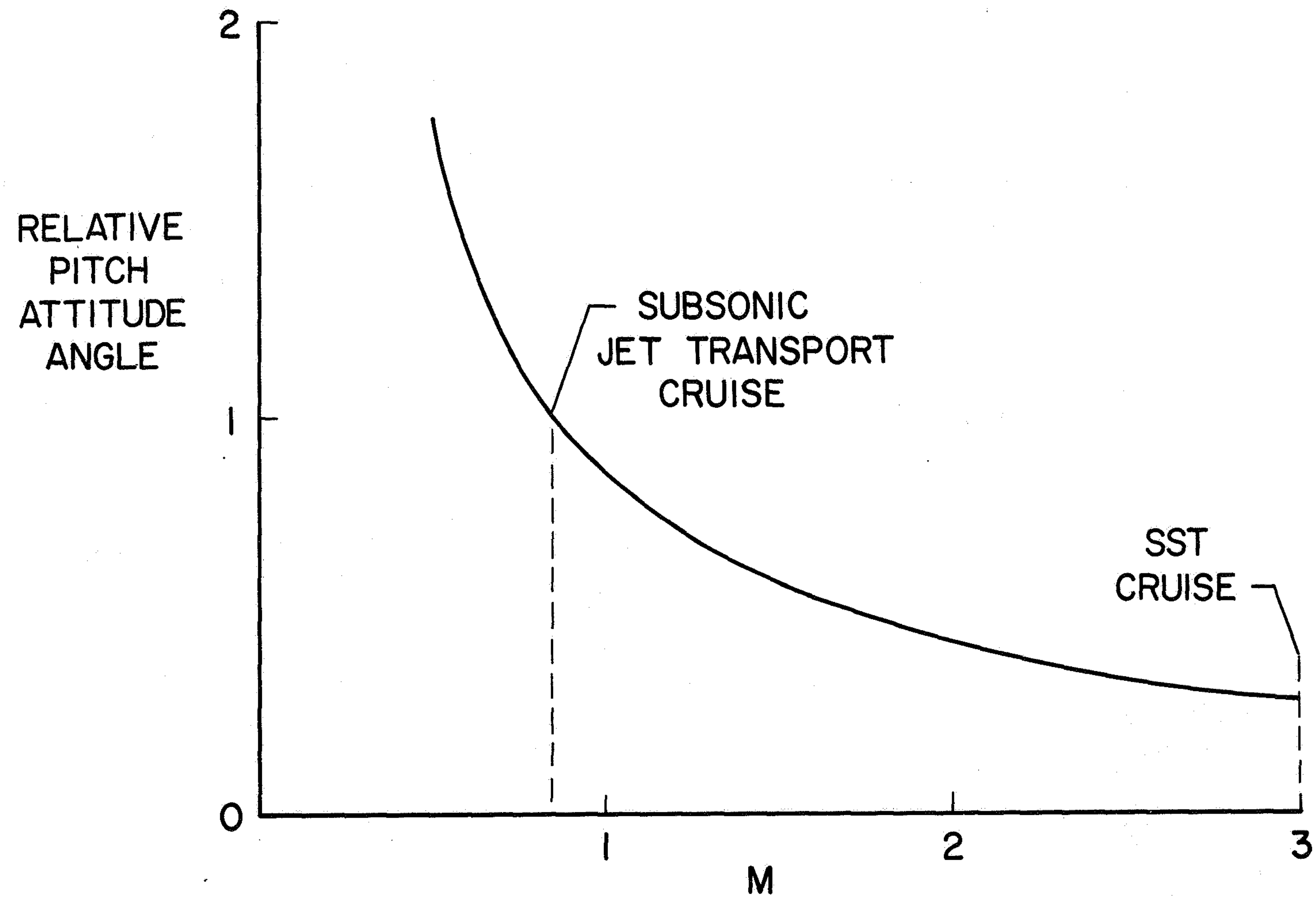

Figure 3.- Relative pitch angle change required to make a given change in vertical speed for the SST and the subsonic jet transport.

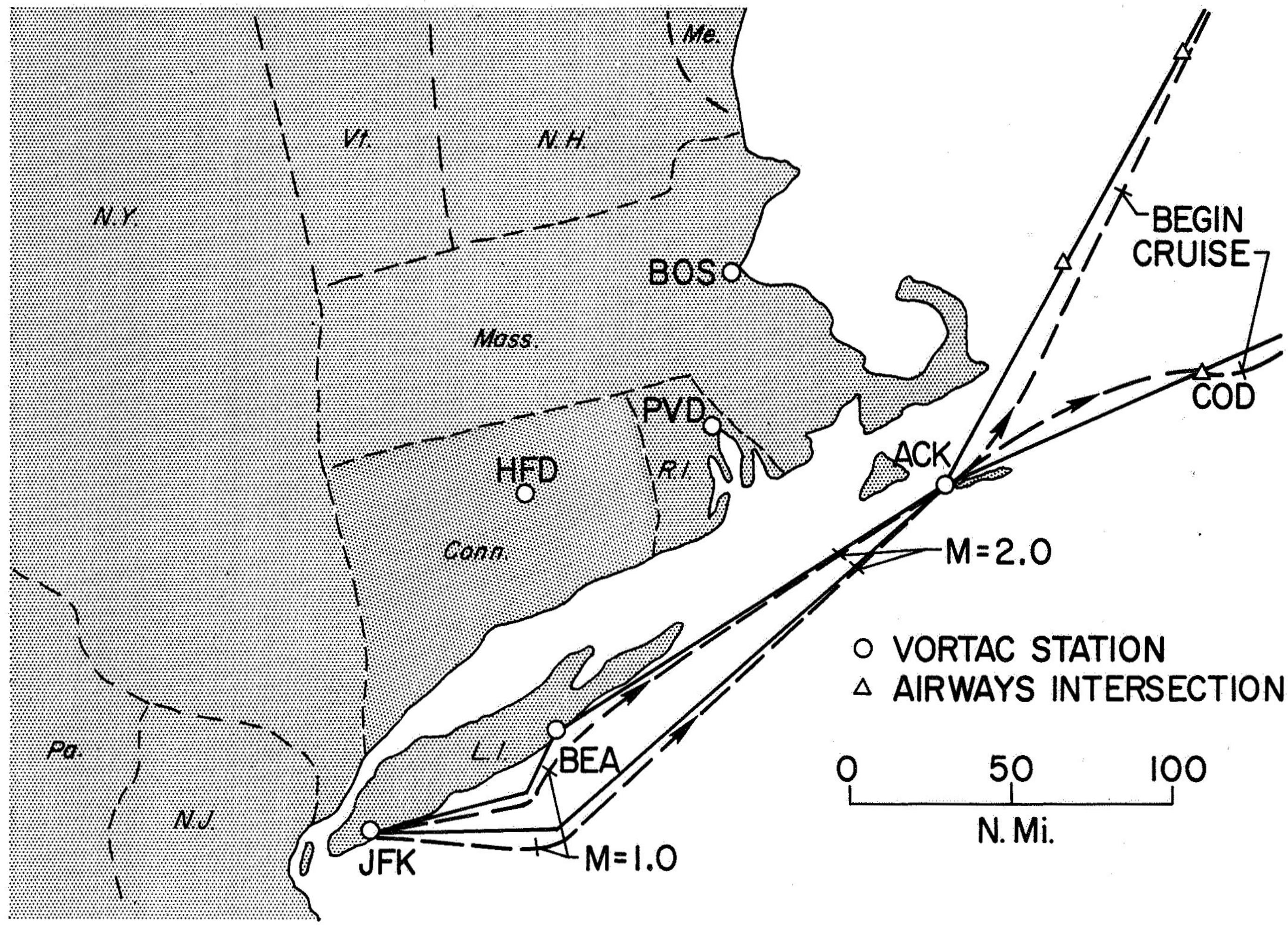

Figure 4.- Oceanic departure routes.

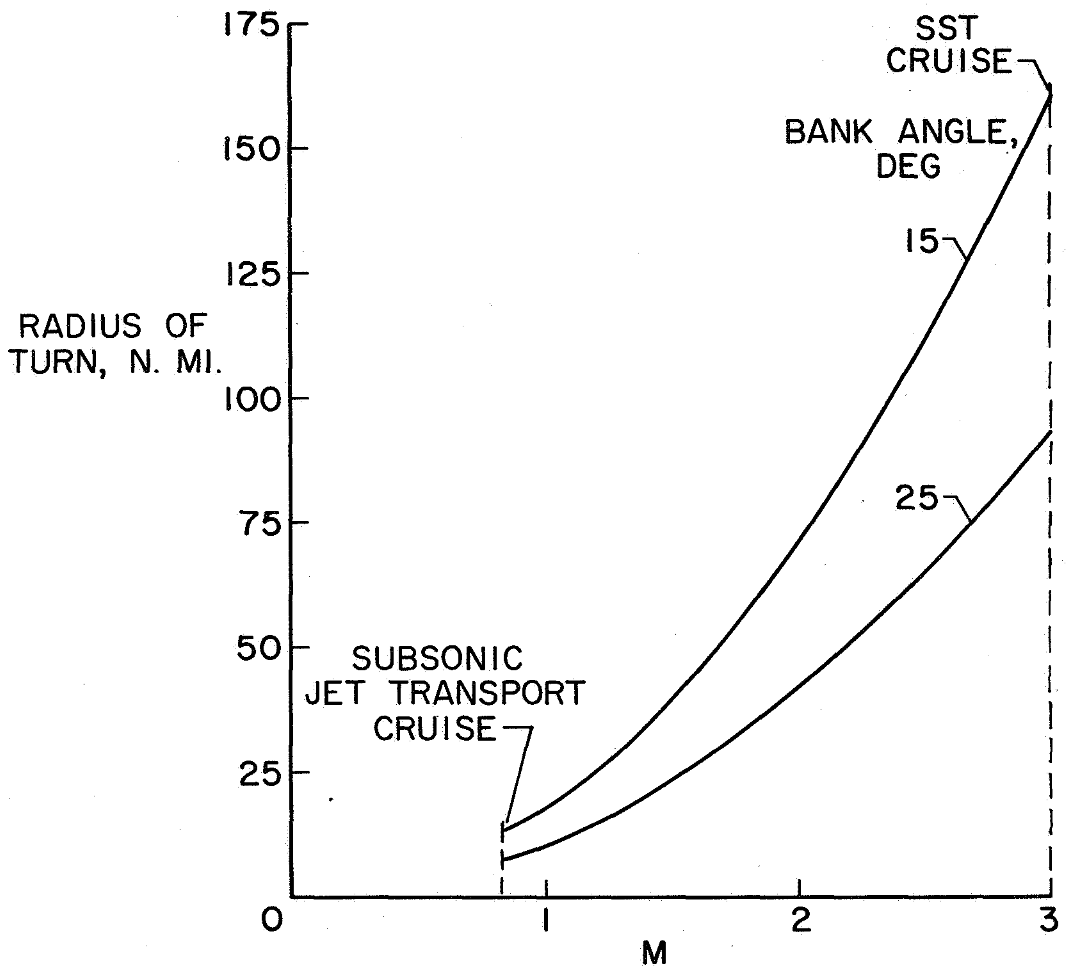

Figure 5.- Radius of turn information.

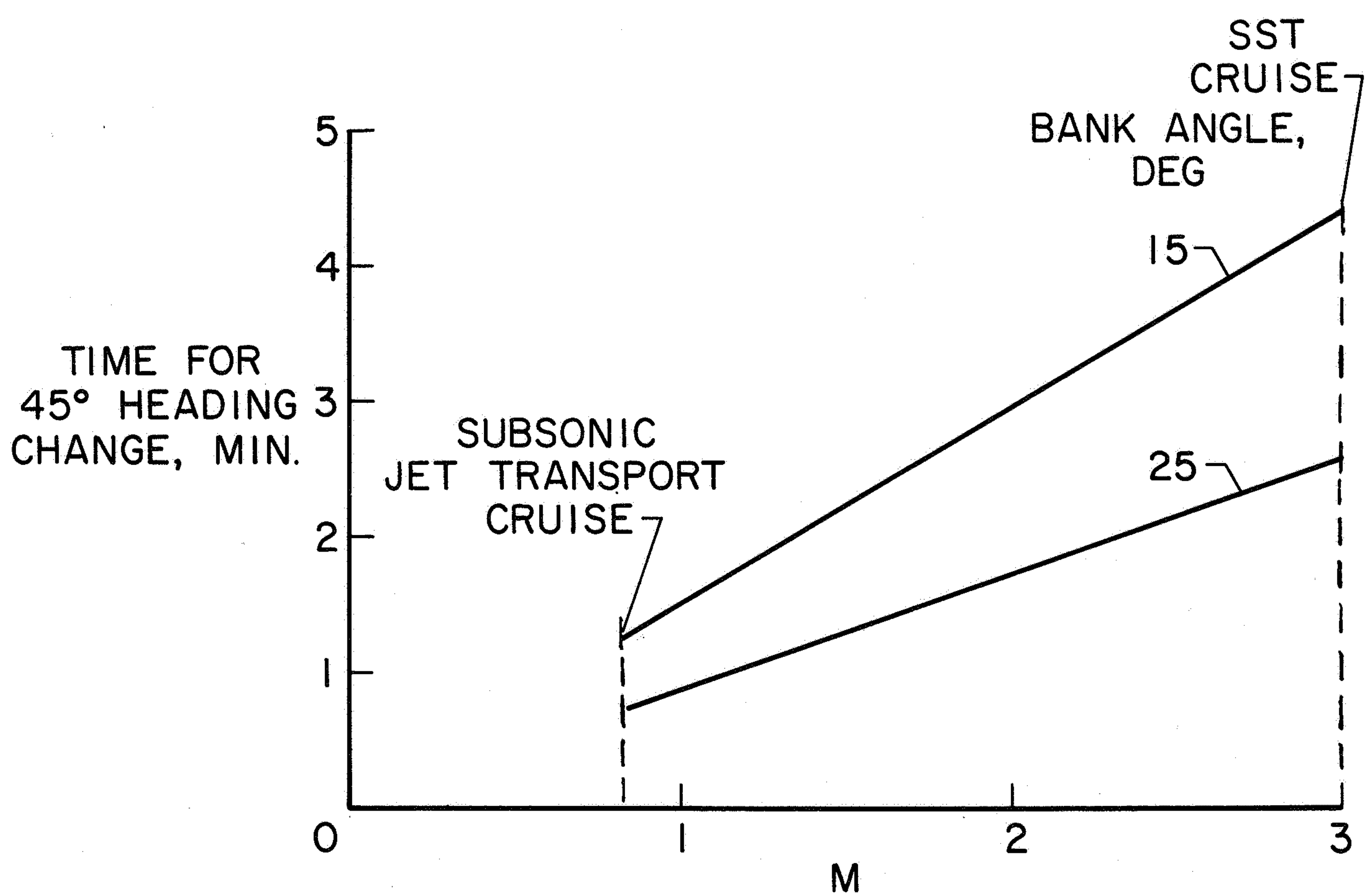

Figure 6.- Time for heading change.

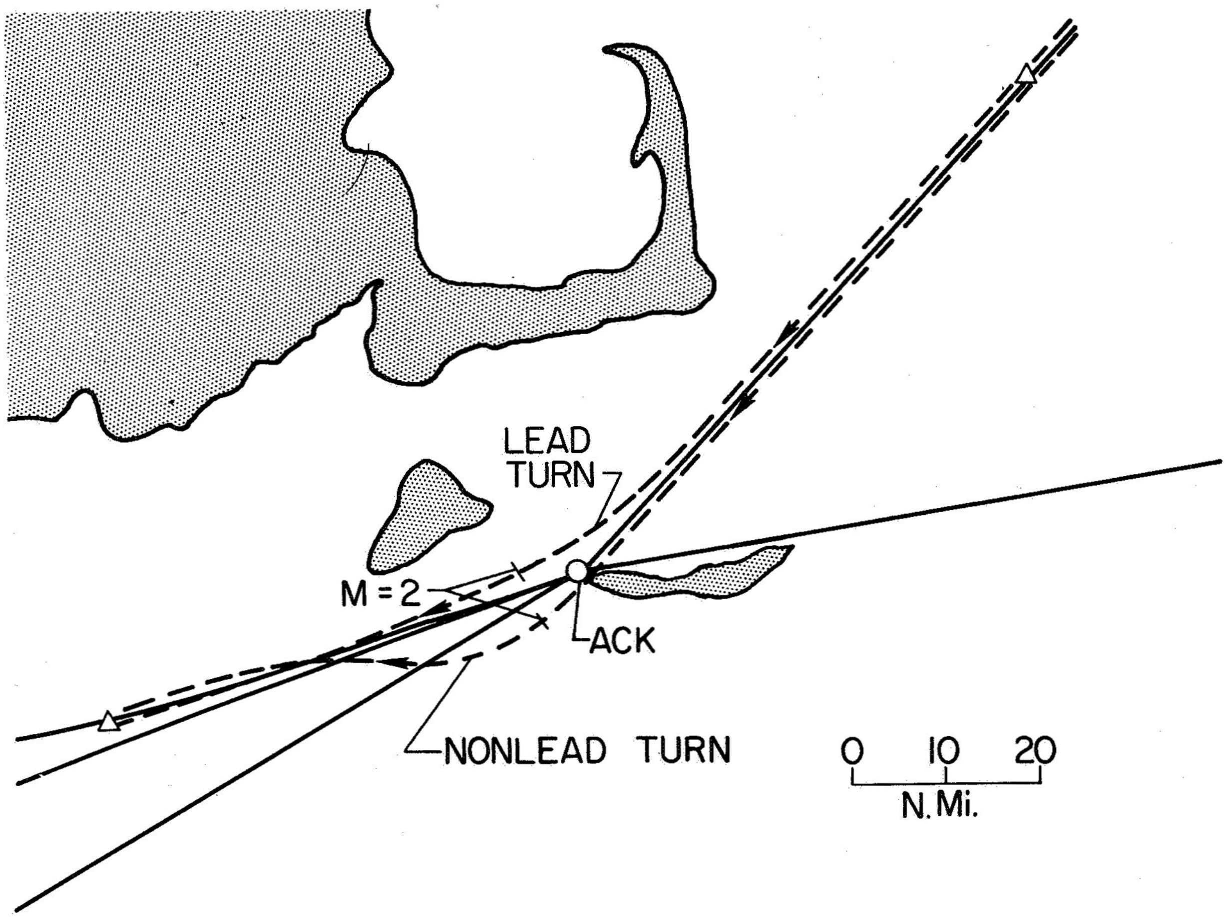

Figure 7.- Supersonic turns.

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