FEDERAL AVIATION AGENCY
BUREAU OF RESEARCH AND DEVELOPMENT
SYSTEMS ENGINEERING DIVISION

METEOROLOGICAL REQUIREMENTS FOR SUPERSONIC TRANSPORT AIRCRAFT

by

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I INTRODUCTION

The Federal Aviation Agency in its mission to modernize the national airway system, manage and regulate the national air traffic and provide for maximum safety of the navigable airspace, is planning to expend a major effort in the development of the supersonic transport by providing fiscal support and program leadership

An important part of this program is the determination of the necessary meteorological support for supersonic transport operations and its implementation In a recent study[1] the FAA has established the requirements for Weather Information and Weather Services of the airspace users in the period to 1975 This study identifies the supersonic transport as one of the new types of aircraft to be in operation within this period with an estimated target date of 1970 To insure its safe operation at the expected elevated speeds and altitudes adequate meteorological support must be provided and must be planned for at an early stage

The supersonic transport represents a major increase in complexity compared to the present subsonic jet airliners. Its development will involve a number of revolutionary concepts in basic design configuration, as well as in the design of such subsystems as propulsion, cooling, pressurization and navigation equipment Its complexity and advanced performance, requiring a one billion dollar development effort according to latest estimates, will make it mandatory that aside from participation by the aircraft manufacturers and the air carriers, the government will have to assume a major role in the management and implementation of such a project, and in the furnishing of adequate weather support

The high supersonic flight speeds with the accompanying aerodynamic heating of the skin require accurate knowledge of the ambient temperatures over the entire flight profile Operation at extremely high altitudes necessitates more frequent and more accurate coverage of the meteorological conditions and parameters at these altitudes Considerations of fuel economy and attenuation of the sonic boom make it imperative to have a clear picture of inversions and the location of the tropopause within the climb-out region

This report outlines requirements for weather information for the supersonic transport intended to serve as a basis in the formulation, implementation and operation of an adequate weather support program In order

1 "Analysis of National Aviation Meteorological Requirements through 1975" Contract FAA/BRD-139, Borg-Warner Controls, Santa Barbara, California, August 1, 1961

to establish the boundaries of the physical environment, a brief description of the operational limits of supersonic aircraft regarding speed and altitude is presented Subsequently a typical supersonic airliner with specifications covering weight, size, and performance is described The estimated total number of transports to satisfy world travel needs are then presented in tabulated form

In order to identify the specific needs of the supersonic transport for meteorological support the various stages of its performance are described, corresponding to current estimates of its mission profile At the same time the pertinent meteorological parameters are identified and enlarged upon as to their effect on supersonic transport operations

In summary, a table is presented listing the main meteorological parameters and the performance phases to which they apply along with the region of validity of the parameter and the time period during which the information is desired

The first part of an appendix, which is added to this report, establishes an operational profile for the supersonic transport beginning with "Ground Operations" and ending with "Approach and Landing" at the termination of flight The second part is presented in table form, linking the decisions to be made within the operations profile with the meteorological information required

II DESCRIPTION

The environment in which the supersonic transport will operate can best be depicted by a graph showing maximum altitudes for given speeds, Figure 1 The graph is based on the assumption that the aircraft's weight per unit wing area, the wing loading, will be an average of 50 pounds/square foot and that high altitude flight will be accomplished with an average lift coefficient of 0 3

It is seen that at a flight speed of Mach = 1, corresponding to approximately 580 knots, the maximum altitude is 50, 000 feet Altitude limits increase as speeds go up until at Mach = 4 the maximum altitude has become 110, 000 feet At this speed the temperatures generated by air friction are on the order of 800 degrees F, high enough to have an effect on the fatigue strength of currently envisioned materials for supersonic transports This point therefore, may be considered as an upper altitude and speed barrier Briefly, the altitude limits at the various supersonic speeds are

H = 50, 000 feet at Mach = 1
H = 80, 000 feet at Mach = 2
H = 100, 000 feet at Mach = 3
H = 110, 000 feet at Mach = 4
H = 120, 000 feet at Mach = 5

The advent of the supersonic airliner and its operational use can be reasonably projected to the period around 1970 Its technical feasibility corresponds entirely to the state-of-the-art from the standpoint of aircraft configuration, heat resistant materials, pressurization systems and the availability of high thrust jet engines The timing will depend primarily on such factors as financial considerations, national prestige and the role of the government in the development of the aircraft, since the development costs by far exceed the financial capability of one or even a group of the major aircraft manufacturers The Federal Aviation Agency has recently been designated to assume a major share of the planning and administrative work involved in the development of the supersonic transport

As a typical basis for the estimation of such a time table, the development of the present subsonic jet transports may be cited here Aided by the research and engineering effort spent on such military jet bombers as the B-47 and the B-52, the design of the Boeing 707 turbojet transport was started in 1952 Two years later, in 1954 the first prototypes were flight tested During the subsequent period of four years, flight test and development work continued until in the fall of 1958 the first operational jet transports were delivered to the airlines Thus, a period of six years elapsed from the initial design to the operational stage of the subsonic turbojet passenger aircraft

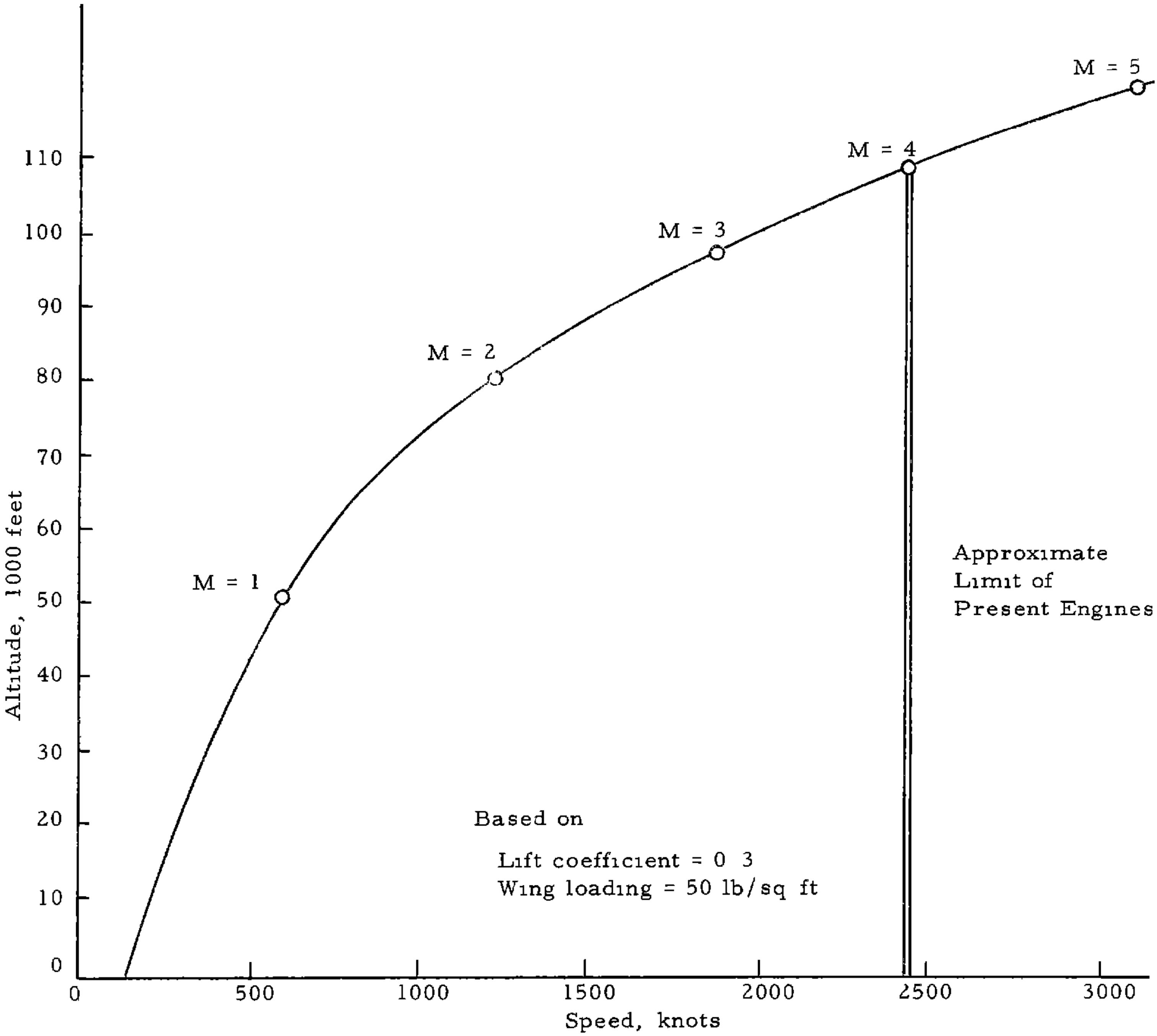

Figure 1 Operational Limits for Supersonic Transports

Applying this time table to the supersonic airliner and taking into account the fact that a considerable amount of technical data from current supersonic military aircraft will be available, a period of eight years for the operational readiness of the airplane appears to be a reasonable estimate If the start of development work is placed in the 1962-63 period the United States could have supersonic transports in operation by 1970

A typical specification of the supersonic transport, based on present estimates, is as follows

Design configuration	Canard type
Over-all length·	200 to 240 feet
Wing span	100 to 120 feet
Gross weight	400, 000 to 500, 000 pounds
Empty weight	200, 000 to 250, 000 pounds
Maximum thrust	150, 000 to 180, 000 pounds
Number of engines	Six to eight
Usable fuel weight	160, 000 to 180, 000 pounds
Number of passengers	130 to 150
Maximum runway length required	8, 000 to 10, 000 feet
Range Minimum	2000 miles
Maximum	4000 miles
Cruising speed	Mach 2-3 (1200-1700 knots)
Cruising altitude	60, 000 to 80, 000 feet

It is difficult at this stage to make accurate predictions concerning the total number of supersonic transports required to satisfy the increasing air traffic demands on United States continental routes and intercontinental flights Since this number to some extent determines the meteorological coverage of supersonic transport operations, a table is presented here listing the estimated domestic and foreign requirements, based on 1975 traffic estimates

The table shows the traffic densities of the major air routes as of 1959 The number of supersonic transports has been computed from the number of flights per week, distance flown, and the passengers transported, on the various routes The resulting numbers are adjusted for the official FAA estimates of traffic increases in the 1975 period The total number of 170-210 aircraft appears to be a reasonable estimate based on the foregoing considerations, which is also in line with current estimates from other sources

Table 1 Estimated Number of Supersonic Airliners Required by 1975

Main Routes	Status as of 1959: Number of Airlines	Status as of 1959: Number of Flights per Week	Estimated Number of Supersonic Transports Required
U S Transcontinental Run	5	473	17
Trans-Atlantic Run	14	217	8
N E United States to Florida Run	3	401	8
California-Hawaii Run	7	82	4
Orient, South America and others	6-10	104	15
Total Estimated U S Requirements, 1959			52
Total Estimated U S Requirements, 1975 Traffic			130-150
Estimated Foreign Requirements, 1975 Traffic			40-60
Total Estimated Requirements for Supersonic Transports in 1975			170-210

III PERFORMANCE AND EFFECTS OF METEOROLOGICAL PARAMETERS

Several features of the supersonic transport aircraft, expected to be in operation in the period around 1970, make it more sensitive to enroute meteorological parameters than conventional aircraft Such features as acceleration through the speed of sound with the resulting sonic booms, supersonic flight speeds which cause problems in aerodynamic heating, extreme cruising altitudes to 80,000 feet, and the short time periods in which long distances are covered, impose new requirements on the complex of meteorological information supplied to the airspace users The following discussions will deal in some detail with these features In addition, the chief meteorological parameters as they affect the various performance stages of the aircraft will be treated together with a projected performance profile

A GENERAL CONSIDERATIONS

Acceleration through the speed of sound is accomplished prior to reaching cruising altitude and supersonic cruising speed of Mach 2-3 The shock wave which is formed at and above Mach = 1 extends from the aircraft to the ground, travels with the aircraft throughout its supersonic flight phase, and produces the so called "sonic boom" on the ground The intensity of this boom can vary from a barely audible rumble to an explosive shock capable of shattering windows, depending on the speed of the airplane, its physical size and attitude and, most importantly, upon its altitude The graph following, Figure 2, illustrates how altitude affects the intensity of the boom produced by a typical supersonic aircraft (1) The curve labeled "popular theory", which has had long time acceptance, accounts for the disturbance created by the volume of the airplane and neglects the effect of airplane lift The other curve is the result of recent research

Shocks producing a pressure rise up to 1 lb/ft^2 constitute the limit of the tolerable level,they are felt as a distant explosion or thunder The graph shows that this level is exceeded until an average altitude of 35,000-40,000 feet is reached At lower altitudes, supersonic flight will produce higher intensity pressure shock waves reaching a pressure of 30 lb/ft^2 at sea level

On the ground, the sonic boom travels with the speed of the airplane The area of maximum intensity is directly underneath the flight path of the aircraft It decreases with lateral distance from the flight path until it disappears due to atmospheric refraction This "boom area" can be displaced laterally by crosswinds but its width and intensity will not be

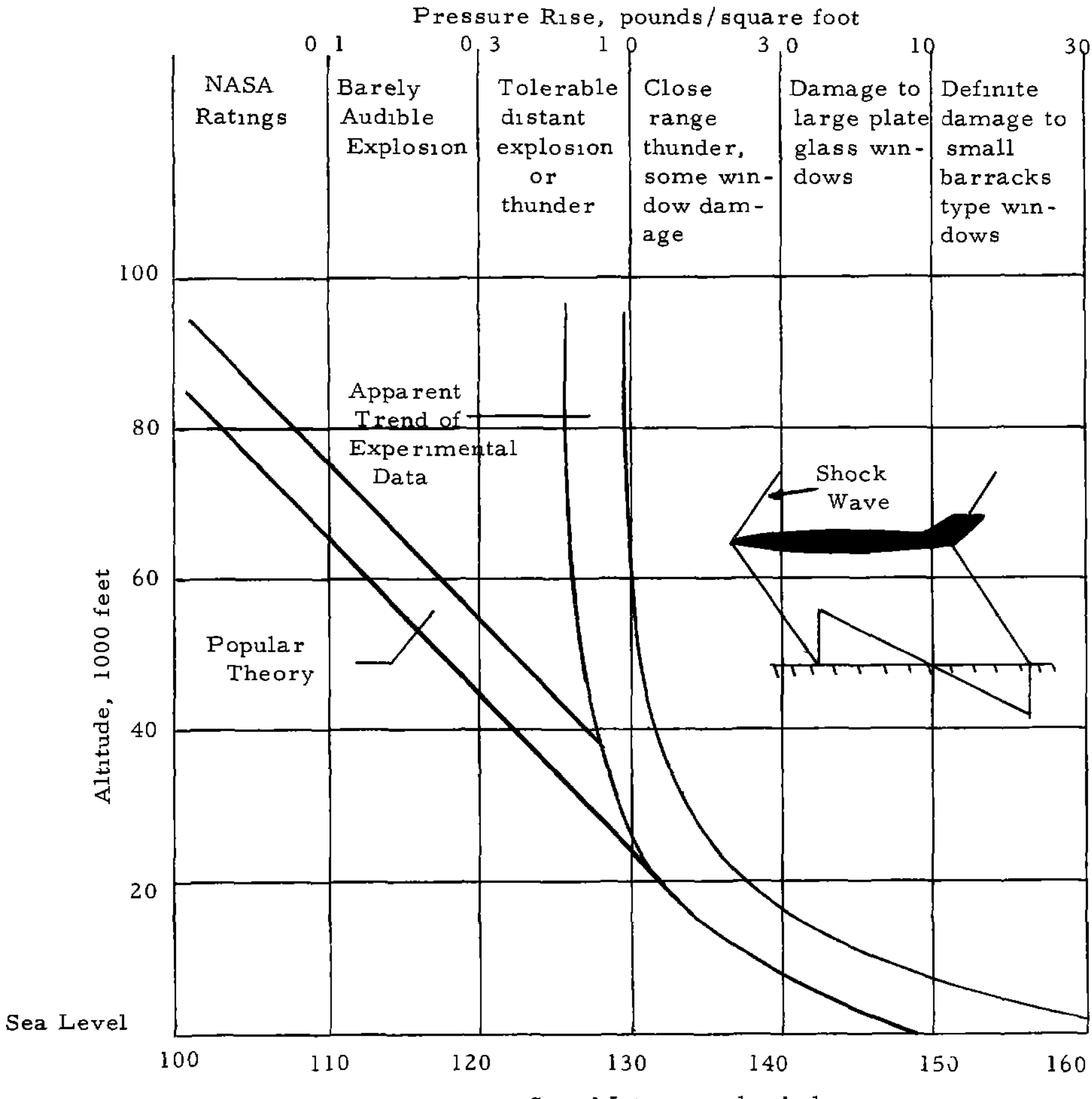

Figure 2 Sonic Boom Intensity vs Altitude

materially affected by winds An aircraft cruising at Mach 3 at 70,000 feet produces a "boom area" of about 70 miles in width As mentioned before, the boom intensity also depends partly upon the airplane's attitude Thus a shallow climb at supersonic speeds increases the intensity of the boom, since it causes the shock to reach the ground at a more acute angle In a similar manner, steep climb angles lessen the effect of the shock Temperature inversions introduce similar effects in that a refraction of the shock wave takes place in these regions

Supersonic speed of the aircraft results in increased skin friction which leads to increased aerodynamic heating, causing skin temperatures to rise from 200 degrees F at Mach 2 to 500 degrees F at Mach 3 Since skin friction is greatly affected by atmospheric density which varies with temperature, it is imperative to have an accurate knowledge of temperature profiles along the entire route Figure 3 shows structural temperatures encountered by supersonic aircraft flying at 70, 000 feet altitude Temperature also affects the thrust and fuel consumption of the engine

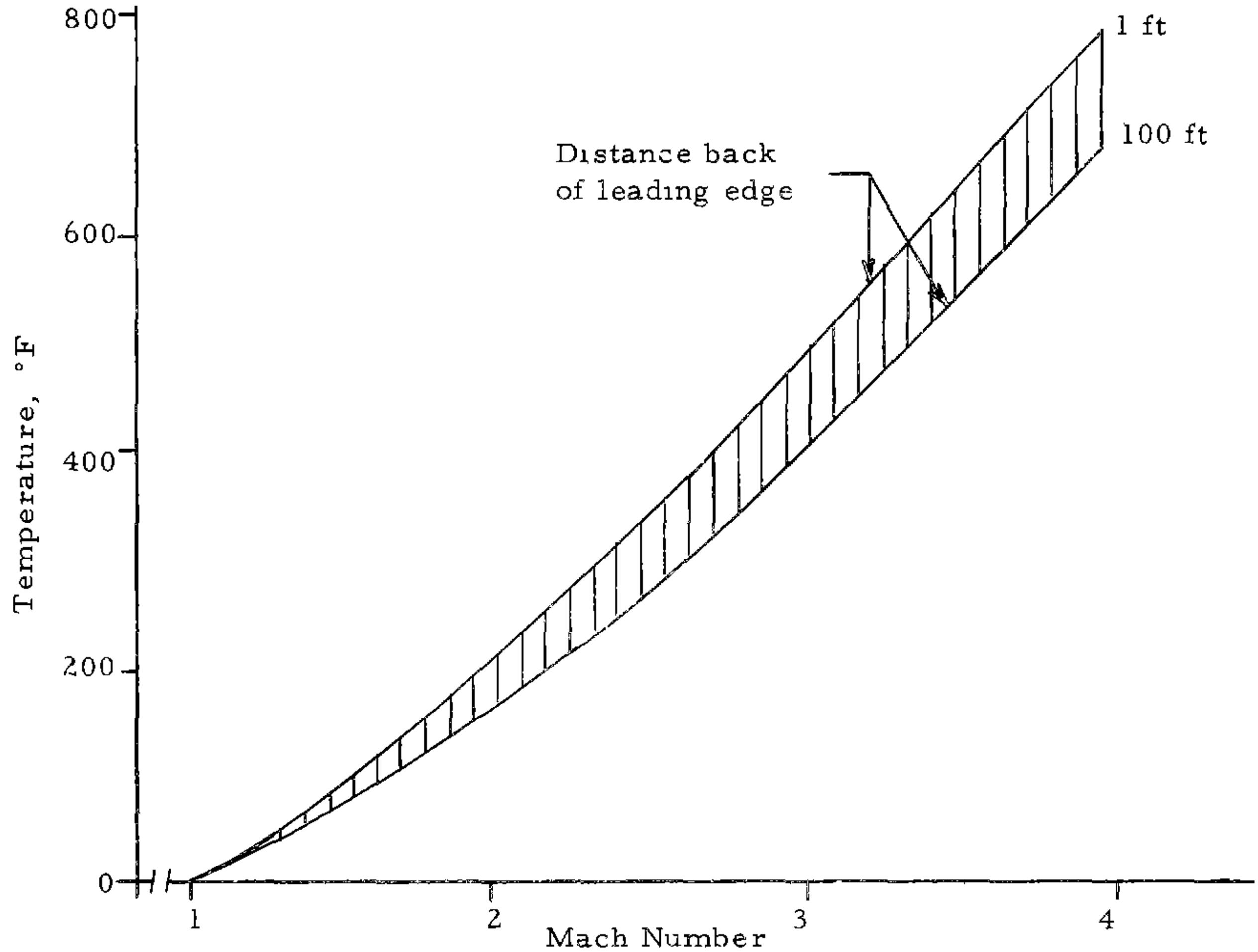

Figure 3 Structural Temperatures for Supersonic Transports, Altitude 70, 000 feet (NASA Technical Note D-423)

Flight at higher than standard temperatures can reduce the range by as much as 15% because of increased specific fuel consumption and decreased thrust There is considerable truth in the statement that the supersonic transport may be flown more by temperature than by air speed

Acceleration from subsonic to supersonic speeds is most efficiently accomplished at the tropopause or the altitude of lowest temperature with its associated high density This region can vary from 20, 000 to 80, 000 feet depending on the latitude and season of the year In the middle latitudes the tropopause is usually found between 25, 000 and 50, 000 feet (2)

Since the fuel flow rate during acceleration through M = 1 becomes from 4 to 5 times higher than during cruise flight, it is of paramount importance to the pilot to have accurate forecasts of the location of the tropopause, in order to avoid excessive use of fuel during this phase of the flight profile Errors or uncertainties in determining the tropopause may lead to a reduction in range of up to 200 miles or a decrease in useful load of from 3000 to 5000 pounds

A typical example of the variation of specific fuel consumption and total fuel used by a supersonic, Mach 3, airliner on a 3400 mile flight is shown in Figure 4 (3) It is seen that for the short time period during the climb and acceleration phase, covering the first 300 miles of the flight, hourly fuel consumption reaches a peak of 220,000 pounds/hour This drops to 50,000 pounds/hour during the cruise phase and reaches a low of 5000 pounds/hour during the final approach at minimum engine RPM Almost 40% of the entire fuel load is consumed during the climb and acceleration phase This graphically illustrates the necessity for following the most efficient climb and acceleration procedure for which accurate

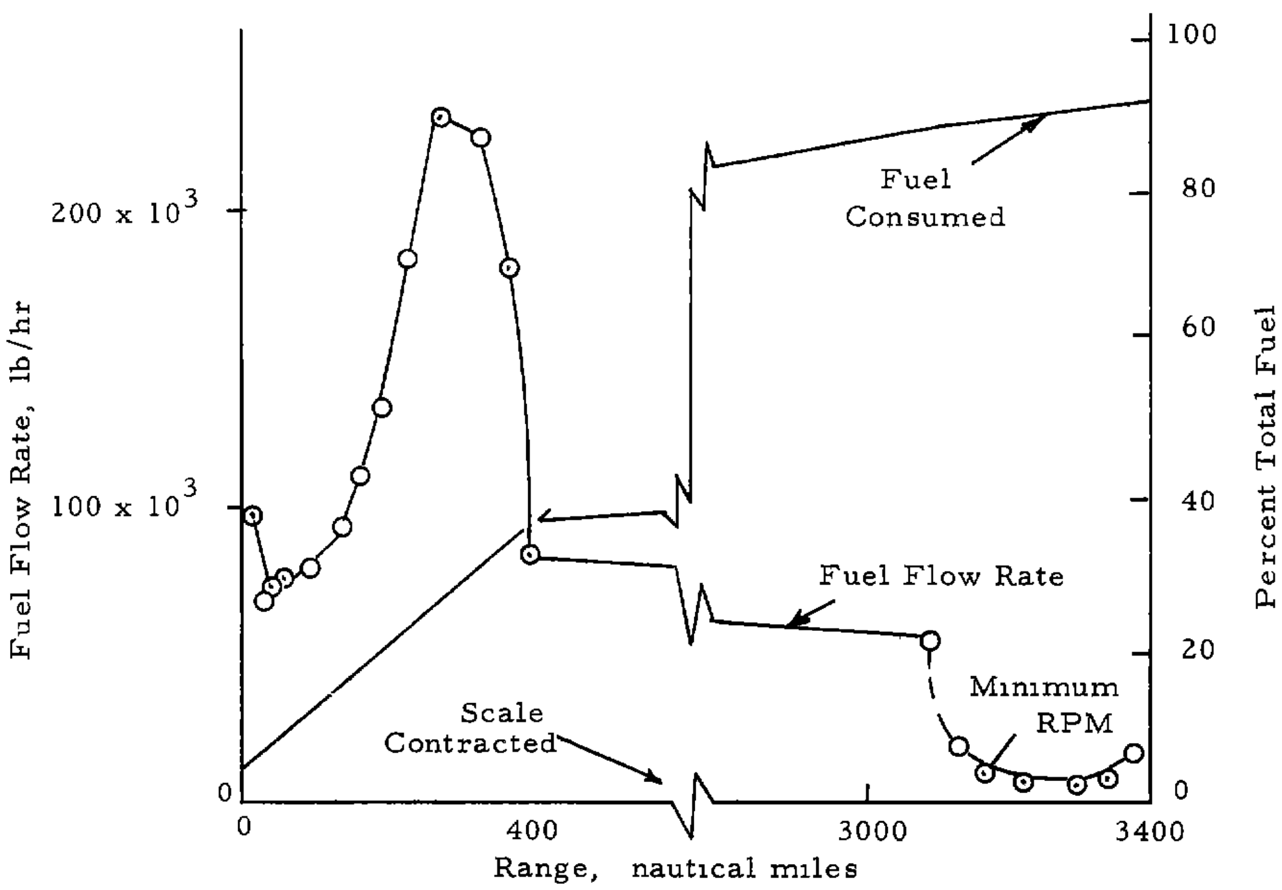

Figure 4 Typical Supersonic Transport Fuel Requirements

knowledge of temperature is a primary requirement

Among the other unconventional characteristics of the supersonic transport are its extremely high cruising altitudes, 60,000 to 80,000 feet, and the relatively short time in which long ranges on the order of 3000-4000 miles can be covered The high altitude performance emphasizes the necessity for more upper atmosphere information than is presently available, such as turbulence, winds aloft, weather hazards, and ozone Moreover, the high speed and short flight time leaves the pilot little time for decisions based on in-flight weather information He should therefore, have complete weather information along the entire route 2 to 3 hours prior to take-off

In summary, we may quote here from Reference 3: "This airplane appears to function very much like a projectile Once launched it must proceed along a very precisely controlled flight path with little or no delays and with a large degree of dependence on automatic flight control and stabilization systems and rapid automatic traffic control over the entire route The capability of the pilot to assume manual control with the safety, economy, and schedule reliability required of commercial transportation is highly questionable "

B PERFORMANCE AND METEOROLOGICAL EFFECTS

In the following description the performance profile of the supersonic transport is presented together with the effects of its meteorological environment

1 Pre-Take-Off

Prior to a transcontinental trip a complete 0-4 hour forecast must be available covering the entire route, including the terminal area, for the preparation of an accurate flight plan, the determination of payload, of the fuel reserve and the climb-acceleration-cruise pattern At the destination, down time on the ground between flights is to be kept below 45 minutes for maximum utilization of the equipment For the return leg before the aircraft takes off on its round trip, 7 to 8 hour advance forecasts must be available Prior to a trans-Atlantic run, 6 to 8 hour forecasts are required before the trip is started in New York A typical performance profile for the supersonic transport is shown in Figure 5 The various phases of this profile are discussed below

2 Take-Off Run

Runway length requirements of the supersonic transport are not expected to exceed the present FAA limit of 10,500 feet maximum length at

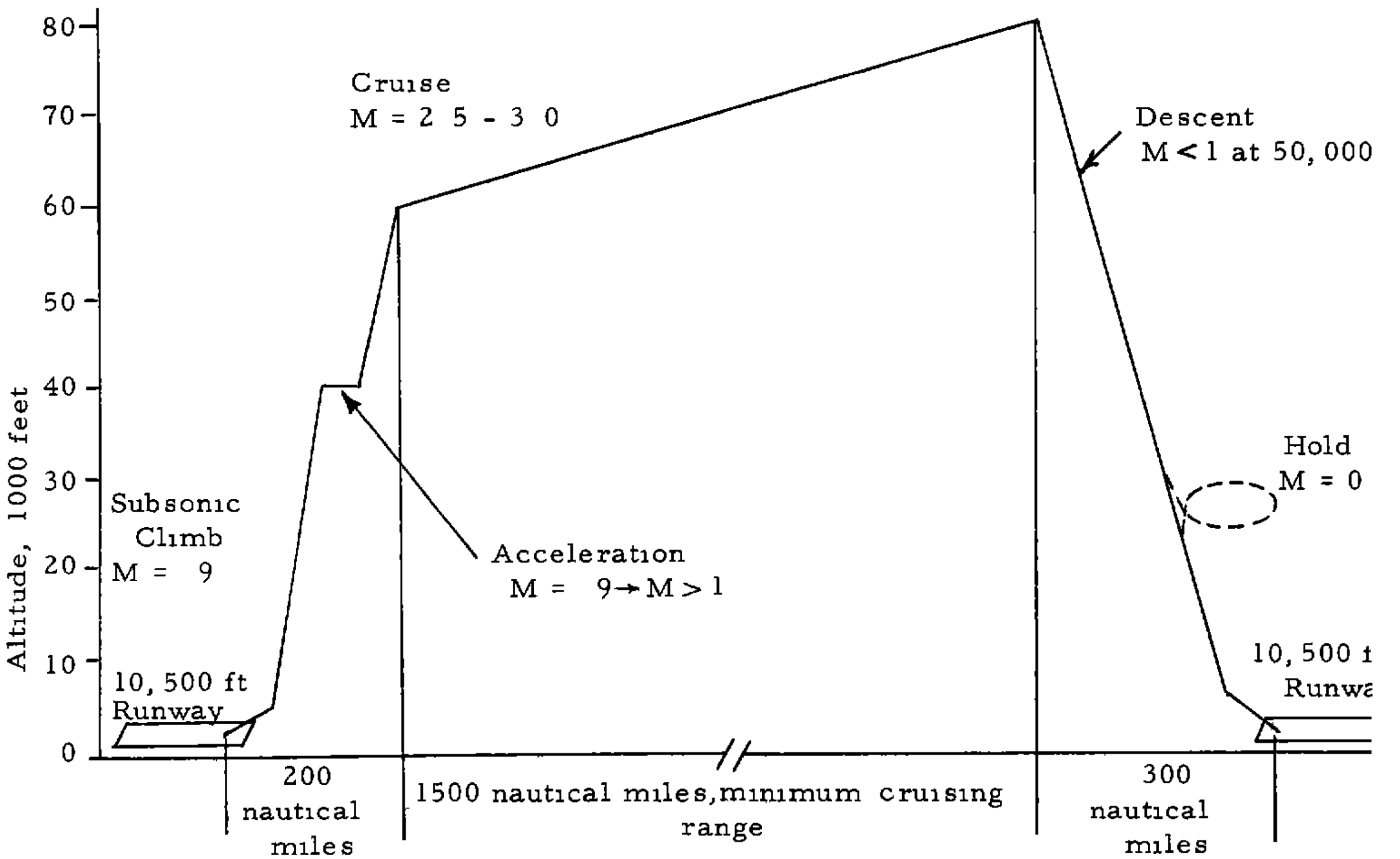

Figure 5 Typical Mission Profile of the M = 3.0 Supersonic Transport

sea level (4). Because the expected thrust/weight ratios of 0 3 - 0 4 are higher than for present subsonic jets, take-off runs will likely be shorter However, the supersonic jet engine is highly sensitive to temperature so that on hot days the limits of 10,500 feet may be exceeded The graph, Figure 6 shows the take-off runway lengths required on a standard hot day (98 degrees F) for subsonic and supersonoc jet transports with thrust/weight ratios ranging from 0 2 to 0 4 Take-off speeds for the supersonic transport are expected to vary from 160 to 190 knots However, current NASA studies indicate the feasibility of the variable aspect ratio wing, where the span is increased on take-off through rotatable wing panels Use of such an arrangement would materially decrease the take-off speed

Temperature affects take-off roll as well as take-off gross weight Figures available on present jet transports indicate that a ±5 degree F deviation from normal would affect gross weight by about 2500

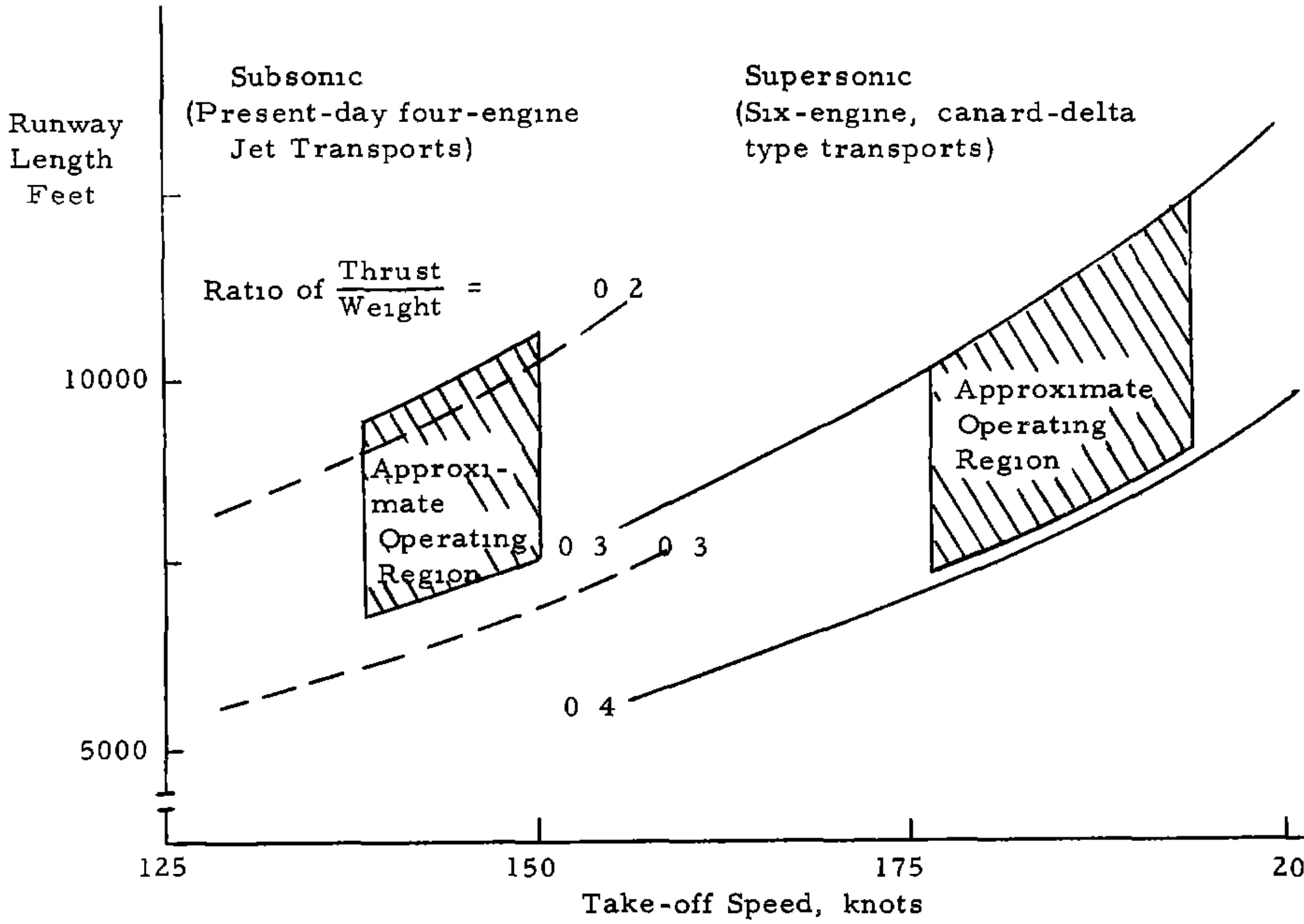

Figure 6 Take-off Runway Length Requirements, Subsonic and Supersonic Jet Transports for Hot Day

pounds Temperature likewise affects the climb angle after take-off Elevated temperatures lead to reduced climb angles which aggravate the noise problem over populated areas

The effect of gusts and cross winds on take-off will be less pronounced than for the present subsonic jets The reason lies in the design configuration of the aircraft The low aspect ratio, delta shaped wing possesses a shallow lift rise reacting more slowly to angle of attack changes than straight, high aspect ratio wings Moreover, the absence of geometric dihedral and the slender, pointed fuselage of the supersonic airliner keep the effective lateral area to a minimum, thus maintaining relatively low lateral forces due to side gusts

3 Climb

For best efficiency, the aircraft will climb at high subsonic speeds, Mach 0 8 to 0 95, to an altitude determined by the height of the tropopause, usually above 35,000 feet It will then level off and accelerate to a supersonic speed of about Mach 1 5 Subsequently, a climb-acceleration pattern is flown until full cruising speed of Mach 2 5 - 3 is reached at 60,000 to 65,000 feet (Figure 5) The entire climb phase will cover a distance of 200-300 miles depending on gross weight of the aircraft Climb angles will be steeper than for subsonic aircraft because of higher engine thrust Average climb angle values of 8-10 degrees are expected to be reached as compared with 5 degrees for subsonic jets In this phase, the danger of property damage from sonic boom effects will be greatest Figure 7 shows two typical climb patterns designed to avoid the damage-producing combination of low altitude and high speed During climb the plane may be exposed to the effects of various meteorological elements The more important parameters are described below

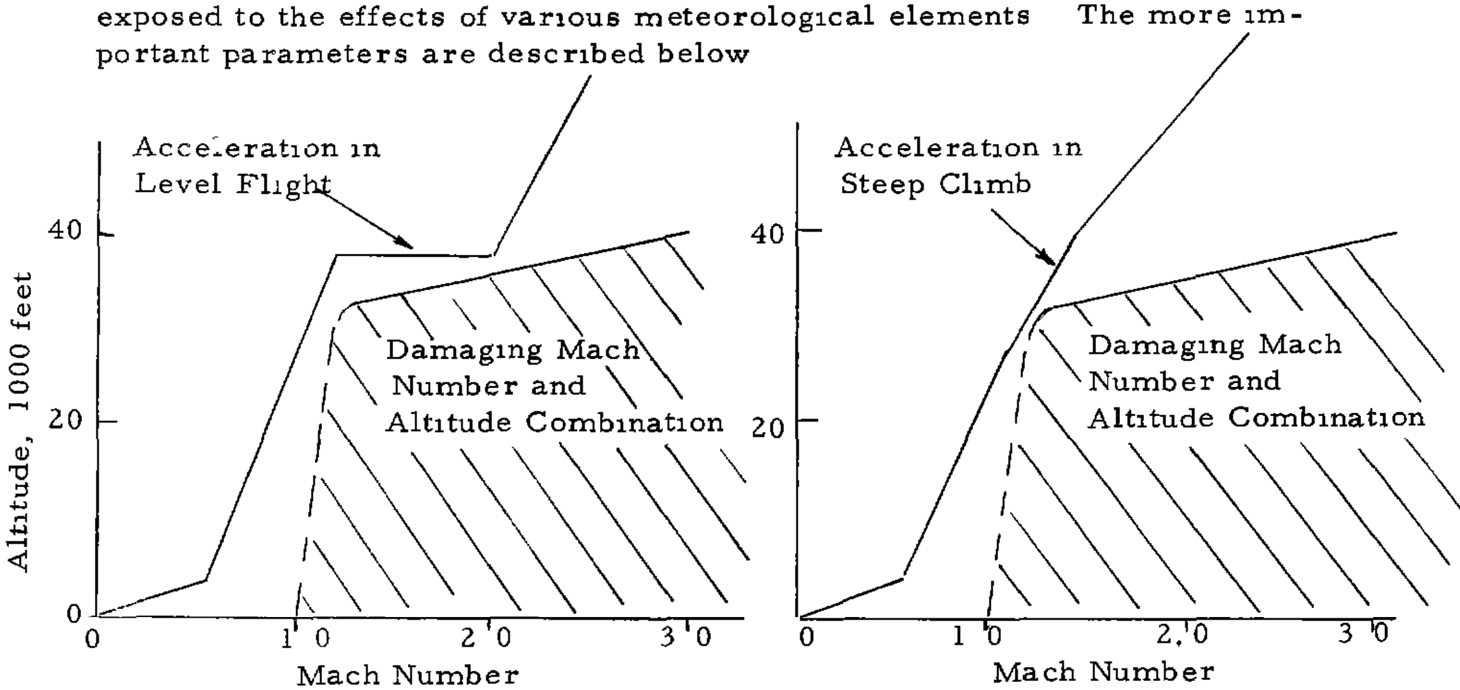

Figure 7 Climb Schedules to Avoid Damage to Property from Supersonic Boom Effects

Icing conditions present a problem, although not a serious one because of the relatively short time required to traverse through the regions of ice formation Only about five minutes are required by the aircraft to reach sonic speed During approximately three minutes after take-off the aircraft may be exposed to icing conditions Experience with military high speed aircraft has shown that no more than a layer of 1/32 inch of ice will form on leading edges and jet intakes under these conditions De-icers on engine intakes, wing and tail surface leading edges, and windshields will be required and accurate information on icing conditions during climb is a requirement

Abrupt changes in the temperature profile will affect climb angle, fuel consumption, noise level and the intensity of the sonic boom They must, therefore, be known to the pilot

Precipitation such as rain, sleet, hail and ice poses a serious problem in supersonic flight The exact intensities and locations of precipitation must be known along the climb path Actual flight experience has shown that rain will destroy the plastic enclosure of the plane's radar, the radome, within 20 minutes at Mach 2 flight speeds, and the erosion time of the radome in the case of hail is zero Moreover, severe damage to the skin has been sustained by military supersonic aircraft flying through hail Thus, precipitation at high speeds must be avoided at all costs and prior knowledge of the distribution along the climb path is essential

Turbulence must be known beforehand and avoided Aside from the passenger comfort factor, exposure to frequent turbulence causes fatigue in the structure, especially at the elevated skin temperatures, and shortens the service life of the aircraft Maximum turbulence levels must be known to the manufacturer to incorporate sufficient safety margins in the structure during the design stage Furthermore, strong turbulence can momentarily alter the angle at which air enters the supersonic engine intakes This may lead to engine flame-outs Advance knowledge of turbulence regions is essential for flight safety and comfort

4 Cruise

Initial cruising altitude of 60, 000 feet is reached approximately ten minutes after take-off and after covering a distance of 200-300 miles The optimum flight pattern for fuel economy is a cruise-climb path starting at 60, 000 feet and reaching an altitude of 80, 000 feet at the destination In this pattern the aircraft will fly at constant indicated airspeed roughly equivalent to an increase from Mach 2 5 at 60, 000 feet to Mach 3 at 80, 000 feet However, in the interest of safety and positive separation, the supersonic airliner will probably be required to fly a level cruise pattern with step climbs to the final 80, 000 feet cruise altitude

The most significant meteorological factor for this phase is temperature A horizontal and vertical temperature profile along the flight path will be required to evaluate the effects of temperature on engine performance, thrust, fuel flow, and aerodynamic heating From present available data on jet airliners a deviation of ±5°C from standard temperature results in a change in fuel flow rate of ±3 5% to ±5% For the transcontinental trip this would amount to an average of ±3000 lbs variation of fuel consumed over that planned In the case of the supersonic airliner, whose fuel flow will be more than five times that of present jet transports, the variation from planned fuel consumption on a transcontinental or transatlatnic trip is conservatively estimated to be about ±7500 lbs This is roughly one third of the entire expected payload This means that either 7500 lbs of fuel more than planned will be consumed or that 7500 lbs of unnecessary fuel must be transported in place of payload Maximum expected temperatures at altitude must be known for the establishment of design criteria A major aircraft manufacturer has used an excess temperature of Δt = 40 degrees F over ICAO standard temperature values in the design of the B-58 supersonic bomber From flight experience with the F-106 and the B-58 in level flight and zoom-ups to extremely high altitudes, it has been ascertained that this is a sufficiently high value to cover most of the recorded deviations from standard temperature Military experience over the continental United States indicates that a maximum increment of 15 degrees F above standard atmosphere values is rarely exceeded If better temperature information becomes available, design limits may be more closely defined and engine performance more accurately determined for better high altitude performance

Clear air turbulence at cruising levels will be troublesome to passengers and the aircraft's structure Both fatigue stresses and wing flutter may result from excessive turbulence, which becomes especially pronounced with the extremely thin airfoil sections required by high supersonic aircraft U-2 pilots report that clear air turbulence at 60,000 foot levels and above has been heavy on many occasions. As yet no satisfactory method has been found to forecast this phenomenon which extends into the cruising altitude level of 60,000-80,000 feet Clear air turbulence is usually found in regions where vertical and horizontal shear are simultaneously present It is also found where high mountain ranges or peaks (such as the high Sierras near Bishop, California, or Telescope Peak in the Panamint Range near Death Valley) produce standing waves in the upper air layers.

Winds aloft will affect the cruise performance of the supersonic transport aircraft to some extent While their effect is not considered to be serious their distribution, magnitude and direction should be known along the route for accurate flight planning and performance calculations

Cloud tops and precipitation in the form of ice crystals are occasionally found at cruising altitudes. They constitute discrete hazards to the aircraft, primarily because of the accompanying turbulence and erosion Avoidance of clouds and precipitation must be considered in advanced planning In flight the aircraft will be unable to turn through even a small angle of bank without producing excessive drag with a resulting loss of speed The turn is costly since the small margin of excess thrust at high altitudes requires subsequent long periods of acceleration to normal cruising speeds with attendant high fuel consumption Moreover, considerable losses in range are involved for even a small diversion on account of the large radius of turn A supersonic aircraft at Mach 3 must turn through a radius of nearly 90 miles to pull a moderate load factor of 0 15 g at a 30 degree bank angle Calculations show that for a cruising speed of Mach 3 and a bank angle of 30 degrees, the initial distance at which a maneuver must be started to provide a one mile lateral separation between two airplanes on a head-on collision course, is 30 miles (3). The time involved is on the order of one minute Such distances are beyond visual range capabilities and the short time involved does not enable the pilot to take corrective action This points out the necessity for closely *monitoring flight hazards from ground radars and forecasting their* location in advance of the flight

Pressure altitude readings and possible errors in altimeter indications pose additional problems to aircraft separation at high altitudes Figure 8 shows the capabilities of pressure altimeters to provide altitude separation Minimum current separation values are shown

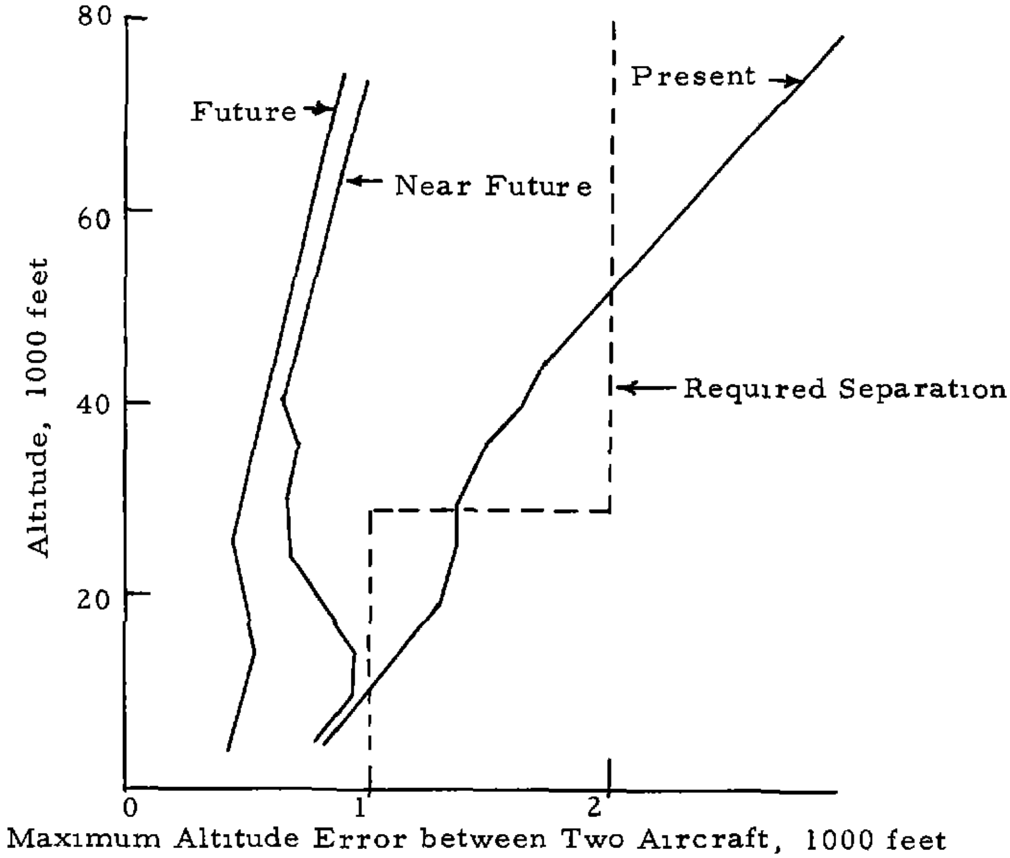

Figure 8 Altimetry Errors of Two Aircraft, 0 3% Probability (NASA Technical Note D-423)

by the dotted line plotted versus cruise altitude Thus, 1000 foot separation is required below 29, 000 feet and a 2000 foot separation above 29, 000 feet. The curve labeled "present" shows separation errors of current pressure altimeters in three out of 1000 cases. There are two altitude ranges where positive separation above the minimums is not provided in these cases They lie in the 11, 000 to 29, 000 feet altitude zone and in the region above 52, 000 feet, where the supersonic transport will cruise. These errors point out the need for improved instrumentation, pressure pick-offs and repeatability of readings Current development work carried out by NASA towards greater precision instrumentation, is expected to provide separation substantially below currently required minimums, as indicated by the curves labeled "near future" and "future"(3)

5 Descent

During descent, the angle at which the sonic boom strikes the ground becomes more acute This leads to an increase in the intensity of the boom effect Thus, immediately upon entering the descent pattern, the sonic boom is felt more strongly on the ground It is mandatory that deceleration to subsonic speeds be initiated at higher altitudes than during the climb phase where climb angle works in the direction of a decrease in boom intensity Current projected performance profiles call for a transition to subsonic speeds above 50,000 feet in order to minimize population annoyance, especially in densely populated terminal areas

For purposes of fuel economy, it is desirable to descend at highest possible subsonic speeds, or around M = 0 95 However, severe turbulence in the lower altitude regions may dictate a reduction to M = 8 or less in order to keep gust loads on the aircraft low Since the engines are designed for optimum fuel flow at high speeds and high altitudes, the descent and approach phase constitutes an off-design condition with relatively poor fuel economy, particularly if holding is required at the 30,000 foot level and at speeds below Mach = 8 Present holding practices of 1/2 hour duration are considered too costly for the supersonic transport For example, holding 30 minutes at M = 0 8 at 35,000 feet will require an additional 20,000 pounds of fuel Currently the FAA, in a research program, is obtaining data on reserve fuel required by the B-58 supersonic bomber under various holding conditions with the object of determining reserve fuel requirements for supersonic transports

Figure 4, depicting total fuel consumption shows that over 1/3 of the fuel is consumed during climb and acceleration, 1/2 on the cruise phase and only 8 percent of the initial fuel remains on landing (3) Thus, the ability to proceed along a precise flight path and to land in a preassigned slot without holding may spell the difference between profit and loss As an example, an economic study conducted by a major aircraft manufacturer showed that a reduction in reserve fuel by only 7500 pounds could cut direct operating costs by a substantial five percent

6 Approach and Landing

During descent and approach, the supersonic transport essentially becomes a subsonic airliner except that sinking speeds will be higher than those of present jets by 10 to 20 percent Thus, ceiling and visibility minimums will probably have to be higher since greater heights and distances are traveled in the same period of time

Temperature in the terminal area and on the runway must be known for glide path performance, touchdown speed and landing run Higher runway temperatures, resulting in reduced air density over the runway approach area, lead to an increase in landing speeds and therefore landing runs of the aircraft. Moreover, they put the point at which the final approach should be started farther ahead of the landing area Also, the aircraft's tires and brakes are affected by temperature and on present supersonic bombers pose a severe heating problem The pilot should have temperature readings ahead of and along the runway in order to determine his glide angle and touchdown speed

The landing runway length requirements of subsonic and supersonic jet transports on a standard hot day are shown in Figure 9

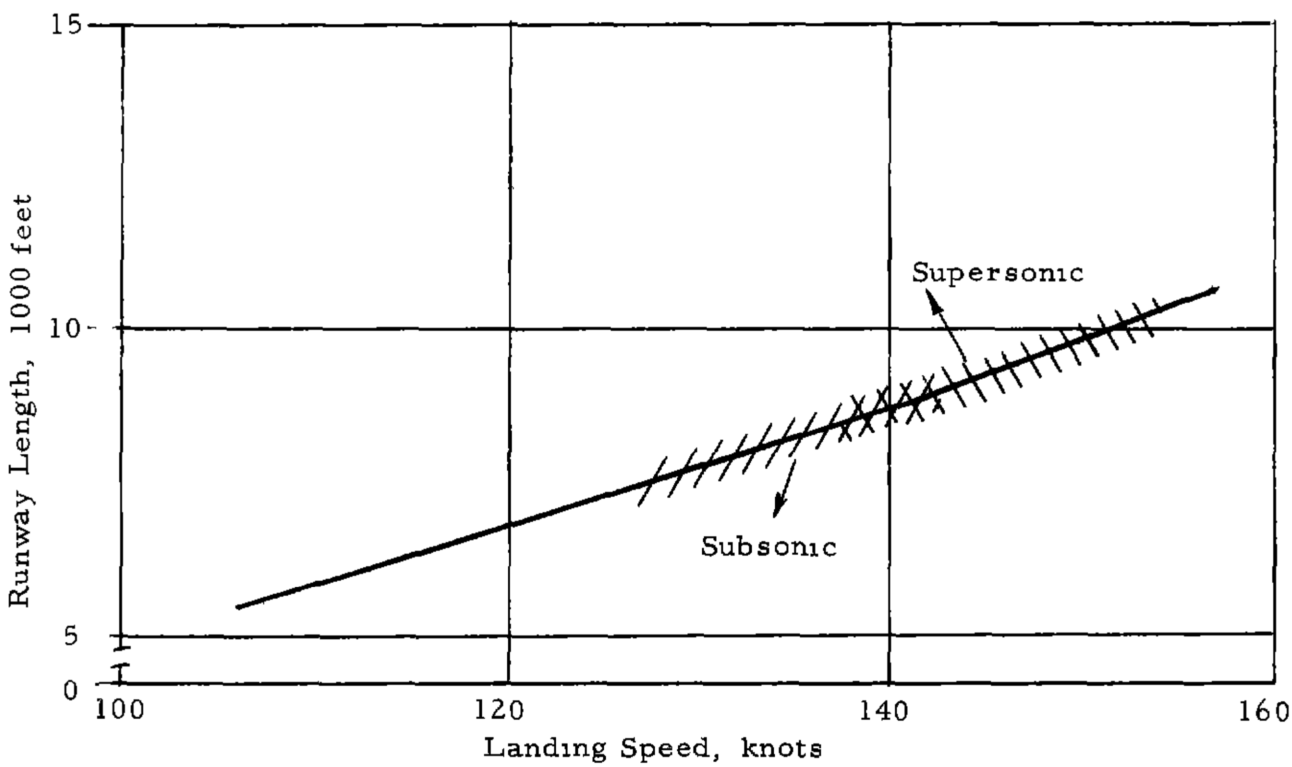

Figure 9 Landing Runway Length Requirements, Subsonic and Supersonic Jet Transports Hot Day

Touchdown speeds of 140-155 knots are reached with landing run length exceeding 10,000 feet These values are considerably higher than those attained by present subsonic jet transports Current airline practice limits the landing speeds of jet transports to 145 knots However, research currently in progress at NASA on variable sweep configurations indicates that they may be the solution to the problem of reducing landing speeds and take-off speeds if the aspect ratio is increased during these phases

Gusts and cross winds on landing will affect the supersonic transport to a lesser degree than present subsonic jets because of its lower aspect ratio and relatively small lateral area as discussed under "take-off" It is expected that present cross wind and gust limits will not require modification

C SUMMARY OF METEOROLOGICAL PARAMETERS

The following tables summarize the meteorological parameters, their region of validity and their sampling frequency as applied to the performance phases of the supersonic transport While the list does not claim to be complete, it presents the major parameters of temperature, winds, gusts, turbulence, precipitation, icing, humidity, ceiling, visibility, cloud tops, and ozone The flight segments listed, are take-off, climb, cruise, descent and landing

Table 2 Meteorological Parameters

Meteorological Parameter	Performance Phase	Region of Validity	Sampling Frequency
Temperature	Take-off	On runway at engine height Several locations along runway and climb path	1/12 hour intervals
	Climb	From sea level to cruise altitudes (60, 000 feet) 300 mile radius around terminal Lapse rates, inversions	1 hour intervals
	Cruise	On course up to 4000 miles distance Altitudes 60, 000 to 80, 000 feet	1 hour intervals
	Descent	Altitude 50, 000 feet to surface 300 mile radius around terminal 10 miles ahead of runway for glide path angle	1 hour intervals
	Landing	Several locations along approach path and runway	1/12 hour intervals
Winds, Gusts	Take-off	Several locations along runway Vertical profile to 500 feet above runway	Continuous monitoring, 10 minute average with gust distribution
	Climb	Wind profile to 60, 000 feet 300 mile radius around terminal	1 hour intervals
	Cruise	Winds aloft 60, 000 feet to 80, 000 feet along course, over distances up to 4000 miles	1 hour intervals
	Descent	50, 000 feet down to surface, 300 mile radius around terminal	1/2 hour intervals
	Landing	10 miles ahead of runway Several locations on runway	Continuous monitoring, 10 minute average with gust distribution
Turbulence	Take-off	------------	-----------
	Climb	Cloud turbulence and clear air turbulence to 60, 000 feet, 300 mi. radius around term	1/2 hour intervals

Table 2 (Continued)

Meteorological Parameter	Performance Phase	Region of Validity	Sampling Frequency
Turbulence (Cont)	Cruise	Clear air turbulence, wind shear, 40,000 to 80,000 feet altitude along course	1 hour intervals
	Descent	50,000 feet altitude down to surface, 300 mile radius around terminal	1/2 hour intervals
	Landing	On approach path, 20 miles ahead of runway	1/2 hour intervals
Precipitation	Take-off	Runway surface conditions water, snow, ice, sleet	1-2 hour intervals
	Climb	Location of precipitation centers on course up to 60,000 feet altitude, 300 mile radius around terminal	Continuous monitoring
	Cruise	60,000-80,000 feet No precipitation expected	---------
	Descent	From 60,000 feet altitude down to surface, 200 mile radius around terminal	Continuous monitoring
	Landing	Precipitation centers on approach path 20 miles ahead of runway	1-2 hour intervals
Icing	Take-off	20 miles around take-off area	1 hour intervals
	Climb	From surface to 20,000 feet, 50 mile radius around terminal	1 hour intervals
	Cruise	Limiting altitudes for icing conditions below cruising altitudes	---------
	Descent	Altitudes 20,000 feet to surface 100 mile radius around terminal	1 hour intervals
	Landing	20 mile radius around terminal	1 hour intervals

Table 2 (Continued)

Meteorological Parameter	Performance Phase	Region of Validity	Sampling Frequency
Humidity	Take-off Climb Cruise Descent Landing	(Humidity affects piston and turbine engine performance unfavorably by decreasing the mass of intake air, since water vapor has a lower molecular weight than dry air On the other hand, precipitation has a favorable effect on engine performance acting somewhat like water injection)	----------
Ceiling, Visibility, Cloud Tops	Take-off	20 mile radius around take-off area	1/12 hour intervals, 10 minute average with ceiling distribution
	Climb	To 5000 feet altitude, 20 mile radius around take-off area	1/2 hour intervals
	Descent	Cloud tops and cloud bases 300 mile radius around terminal	1/2 hour intervals
	Landing	Ceiling and visibility 20 mile radius around terminal	1/12 hour intervals, 10 minute average with ceiling distribution
Ozone	Take-off	-----------	-------------
	Climb Cruise Descent	Ozone content of the atmosphere appears to have produced certain physiological effects on personnel of subsonic trans-Atlantic jet transports The effects become measurable at altitudes above 30,000 feet Supersonic transports cruising at 60,000-80,000 feet altitudes may require ozone filters in the cabin ventilation system for the comfort of passengers and crew The sampling of ozone as a meteorological parameter could therefore become a requirement for flight altitudes above 30,000 feet	
	Landing	-----------	-------------

APPENDIX - PROFILE OF SUPERSONIC TRANSPORT OPERATIONS AND METEOROLOGICAL TABLES

APPENDIX - PROFILE OF SUPERSONIC TRANSPORT OPERATIONS AND METEOROLOGICAL TABLES

A OPERATIONS PROFILE

In order to identify the decisions which are dependent on meteorological information an operations profile was outlined for the supersonic transport This profile consists of six distinct functions Ground Operations, Advanced Planning, Pre-flight Planning, Take-off and Climb, Enroute, and Approach and Landing Within each function, activities were outlined requiring decisions on the part of the crew which are based on meteorological information Specifically the functions with their associated activities are

1 Ground Operations

For aircraft maintenance, schedule major or minor repair of engine, airframe, systems, and support equipment Rescheduling and replanning of maintenance activities may be necessitated by unforecast conditions or unavailability of meteorological information

After determining aircraft parking and storage requirements, provide severe weather protection Inaccurate or lack of information can cause rescheduling of storage or closed facilities Flight replanning or rescheduling may be necessary due to snowed-in parking areas

Determine airport operability Determine usability of runways, taxiways and ramps Advance weather information may be required for repair scheduling

2 Advanced Planning

Determine if destination airport will be at or above IFR minimums

Select or confirm time of flight on the basis of advance meteorological information for the departure, alternate, destination terminal and enroute segment

Plan flight by selecting route and determining check points as well as status of navigational aids Select best cruising altitude (or altitudes) Predict time to climb, select acceleration altitude and predict level off point Predict descent point and time and determine fuel load, allowable gross weight and payload

3 Pre-Flight Planning

Prior to take-off complete pre-flight check and confirm or up-date all calculations on basis of latest meteorological information and alter routing, altitude, weight and balance as required

4 Take-off and Climb

Taxi out and select runway, departure heading and taxi route

Check engine and equipment operation, adjust flaps and trim as required

Confirm take-off minimums

Confirm forecast climb conditions, changes in meteorological conditions may require modifying climb route and speed

5 Enroute

Establish and continue cruise

Monitor outside air temperature for engine temperature limits and skin heating

Re-set altimeter as required and correct indicated altitude after readjusting altimeter setting

Adjust course and speed for winds

Establish descent and continue to a holding fix or facility if required Receive weather reports as required in order to circumnavigate severe weather areas If required, airspeed should be reduced and ground speed recomputed

In holding pattern establish airspeed and altitude to minimize effect of turbulence

Confirm weather information at destination terminal

Determine fuel reserve Change in holding speed, due to turbulence, holding altitude and temperature may require re-evaluation of fuel reserves because of increased fuel consumption

6 Approach and Landing

Establish approach and determine approach pattern and procedure

Obtain latest terminal weather information, active runway, altimeter setting, wind conditions, runway surface conditions

Land and reverse thrust, using brakes according to runway surface and aircraft type

Taxi to parking area

B. TABLES OF METEOROLOGICAL REQUIREMENTS

The tables in this section present the detailed meteorological information requirements as applied to supersonic transport operation Meteorological parameters with the extent of their spatial coverage, their critical limits and accuracies required are listed This is done for each function of the operations profile and associated activities calling for decisions based on weather information The tables do not claim to be complete However, they present weather requirements corresponding to the current estimates of supersonic transport operation and performance

Table 3 Meteorological Requirements of the Supersonic Transport Function -- Ground Operations

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Aircraft maintenance					
Schedule major or minor repair of engine, airframe, systems, and support equipment	Hail, freezing rain, snow	Repair areas	As reported	Size, intensity, accumulation	9 hours
	Surface winds		Storms, tornadoes, hurricanes	±5 knots	9 hours
	Electrical discharge		As reported	Intensity	9 hours
	Blowing sand or dust		As reported	Intensity	9 hours
	Low temperatures		-6°C, -32°C	±1°C	9 hours
Determine aircraft parking and storage requirements					
Provide severe weather protection	Hail, freezing rain, snow	Airport surfaces	As reported	Size, intensity, accumulation	9 hours
	Surface winds		40 knots, 10-knot gusts	±1 knot	9 hours
	Blowing sand/dust		As reported	Intensity	9 hours
	Low temperatures		-6°C	±1°C	9 hours

Table 3 (Continued)
Function -- Ground Operations

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Determine airport conditions					
Estimate operational condition of runways, taxiways and ramps	Precipitation	Airport surfaces ↓	As measured	Intensity, accumulation	9 hours
	Surface winds		40 knots, 10-knot gusts	±1 knot	9 hours
	Blowing sand/dust		As reported	Intensity	9 hours
	Low temperatures		$0^{o}C$	$\pm1^{o}C$	9 hours

Table 3 (Continued)
Function -- Advanced Planning

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Select destination airport					
Determine if airport will be at or above IFR minimums	Ceilings	Landing area	400 feet minimum	±50 feet	4 hours
	Runway visibilities	↓	1 mile minimum	±1/10 mile	4 hours
Plan flight					
Select route	Pressure altitudes	Departure corridors, enroute flight envelopes	Each 10,000 feet to 80,000 feet maximum	±1000 feet	2 hours
		Approach lanes	Each 1000 feet, 10,000 feet to surface	±200 feet	4 hours
	Temperatures	Climb-out	Surface to tropopause, 2000 feet intervals	±1 °C	4 hours
		Enroute flight envelopes	40,000 - 80,000 feet, 5000 feet intervals	±1 °C	4 hours
		Descent corridors	30,000 feet to surface, 2000 feet intervals	±1 °C	4 hours
		Landing runway	At engine intake height	±1 °C	4 hours
	Precipitation - frontal structures	Entire flight envelope	Hail, rain, snow and cloud movements	Hourly positions, ±5 miles	4 hours
	Winds aloft	Enroute flight envelopes	Beam component Head/tail component	±5 knots ±10 knots	4 hours

Table 3 (Continued)
Function -- Advanced Planning

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
	Wind shear, turbulence	Entire flight envelope	2000 feet intervals enroute	±3 knots/1000 feet, ±10 fps/1000 feet	4 hours
Select best cruising altitude or altitudes	Pressure altitudes	Departure corridors, enroute flight envelopes, descent corridors	10,000 feet intervals to 80,000 feet maximum	±1000 feet	2 hours
	Temperatures	Enroute flight envelopes	40,000 - 80,000 feet altitude, 5000 feet intervals	±1 °C	4 hours
	Wind shear, turbulence	Enroute flight envelopes	2000 feet intervals, 60,000 - 80,000 feet altitude	±3 knots/1000 feet, ±10 fps/1000 feet	4 hours
Select alternate (enroute and destination)	Ceilings	Landing areas	400 feet minimum	±50 feet	4 hours
	Visibility	↓	1 mile minimum	±1/10 mile	4 hours
	Surface winds and gusts	↓	40 knots maximum	±1 knot, ±10 degrees	4 hours
Plan acceleration altitude to Mach number greater than 1	Temperatures	30,000 - 40,000 feet altitude	Location of tropopause	±1 °C, ±1000 feet	1 hour
	Pressure altitude	Climb corridors	5000 feet intervals to 40,000 feet	±1000 feet	1 hour

Table 3 (Continued)
Function -- Advanced Planning

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
	Winds aloft	Climb corridors	Beam component Head/tail component	±5 knots ±10 knots	1 hour
	Clear air turbulence	Acceleration altitude	30,000 - 40,000 feet, 2000 feet intervals	±3 knots/1000 feet	1 hour
Plan descent point	Temperature	Descent corridors, approach lanes	50,000 feet altitude to surface, 10,000 feet intervals	±1 °C	3 hours
	Winds aloft	Descent corridors, approach lanes	Beam component Head/tail component	±5 knots ±10 knots	3 hours
Determine fuel load, allowable gross weight, and payload	Information given above is sufficient				

Table 3 (Continued)
Function -- Pre-Flight Planning

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Complete pre-flight check (just prior to take-off)					
Confirm or up-date all calculations on basis of latest meteorological information alter routing, altitude(s), weight and balance, and alternate as required	Ceiling	Departure terminal	400 feet minimum	±50 feet	2 hours
		Destination terminal	400 feet minimum	±50 feet	4 hours
	Temperature	Departure runway	Engine operation	±1 °C	2 hours
		Climb corridor	2000 feet intervals to 40,000 feet	±1 °C	2 hours
		Enroute flight envelopes	5000 feet intervals, 60,000 to 80,000 feet	±1 °C	3 hours
		Descent corridors	2000 feet intervals, 30,000 feet to surface	±1 °C	4 hours
		Landing runway	Occurrence	±1 °C	4 hours
	Visibility	Departure runway	1 mile minimum	±1/10 mile	2 hours
		Destination runway	1 mile minimum	±1/10 mile	4 hours
	Surface winds and gusts	Departure runway	40 knots maximum	±1 knot, ±10 degrees	2 hours
		Destination runway	40 knots maximum	±1 knot, ±10 degrees	4 hours
	Winds aloft	Enroute flight envelopes	Beam component Head/tail component	±5 knots ±10 knots	3 hours

Table 3 (Continued)
Function -- Pre-Flight Planning

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
	Precipitation and frontal structures	Entire flight envelope	Hail, rain, snow, and cloud movements	Hourly positions ±5 miles	2, 4 hours
	Wind shear and turbulence	Enroute flight envelopes	2000 feet intervals, 60,000 to 80,000 feet altitude	±3 knots/1000 feet, ±10 fps/1000 feet	3 hours

Table 3 (Continued)
Function -- Take-Off and Climb

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Taxi to take-off point and prepare for take-off					
Re-assess take-off conditions, select runway and departure heading	Ceiling	Departure terminal	400 feet minimum	±50 feet	1/2 hour
	Visibility	Departure runway	1 mile minimum	±1/10 mile	1/2 hour
	Surface winds and gusts	Departure runway	40 knots maximum	±1 knot, ±10 degrees	1/2 hour
	Temperature	Departure runway	Engine operation	±1°C	1/2 hour
	Precipitation	Departure areas	Runway condition	Intensity or accretion rate	1/2 hour
	Moisture content	↓	Dew point 10°C	±1°C	1/2 hour
Check engine and equipment operation, adjust flaps and trim as required	Temperature	↓	Engine operation	±1°C	1/20 hour
	Surface winds and gusts	Departure runway	Direction and speed	±1 knot, ±10 degrees	1/20 hour
Confirm take-off minimums	Ceiling	Departure terminal	400 feet minimums	±50 feet	1/20 hour
	Visibility	Departure runway	1 mile minimum	±1/10 mile	1/20 hour

Table 3. (Continued)
Function -- Take-Off and Climb

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Climb procedure					
Confirm climb conditions	Temperature	Departure corridors	Location of tropopause, inversions	±1°C	1/10 hour
	Icing conditions		Accretion rate and location	±1000 feet	1/10 hour
	Turbulence		Intensity and location	±3 knots/1000 feet; ±1000 feet, ±10 miles	1/10 hour
	Hail, snow, rain, cloud movements		Intensity and location	±1000 feet, ±10 miles	1/10 hour
	Cloud tops		Occurrence	±1000 feet	1/10 hour

Table 3 (Continued)
Function -- Enroute

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Establish and continue cruise					
Monitor outside air temperature for engine temperature limits and skin heating	Temperature	Enroute flight envelopes	At 60,000 to 80,000 feet altitudes	±1°C	2 hours
Re-set altimeter as required	Altimeter setting		As received	±0.01 inches, Hg	2 hours
Adjust course and speed for winds	Winds aloft		Beam component Head/tail component	±5 knots ±10 knots	2 hours
	Turbulence		Intensity and location	±3 knots/1000 feet, ±1000 feet, ±10 miles	2 hours
Holding					
Proceed to holding fix or facility	Severe weather turbulence, icing, hail, freezing precipitation	Holding areas	Intensity, size and accretion rate	As reported	1/2 hour
Establish airspeed and altitude as required	Icing		Holding altitude approximately 30,000 feet, speed approximately M=0 95	Accretion rate	1/2 hour
	Turbulence		Holding altitude approximately 30,000 feet, speed approximately M=0 95	Intensity	1/2 hour

Table 3 (Continued)
Function -- Enroute

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
	Winds aloft	Holding areas	Beam component Head/tail component	±5 knots ±10 knots	1/2 hour
Confirm weather information at destination terminal	Temperature	Landing areas	Engine operation	±1 °C	1/2 hour
	Ceiling	↓	400 feet	±50 feet	1/2 hour
	Surface wind, gustiness	↓	40 knots, 5-knot gusts	±2 knots	1/2 hour
	Runway visibility	↓	1 mile	±1/10 mile	1/2 hour
	Icing, hail, freezing precipitation, sleet, blowing sand and dust	↓	Occurrence and boundaries	Accretion rate, size, intensity	1/2 hour
	Snow, sleet, ice, rain on runway	Landing runway	Occurrence and amount	As measured	1/2 hour
	Altimeter setting	Over control point		±0.01 inches,Hg	1/2 hour
Determine fuel remaining	Temperature	Holding areas	Engine operation	±1 °C	1/2 hour
	Turbulence	↓	Occurrence	Intensity	1/2 hour
	Winds aloft	↓	Beam component Head/tail component	±5 knots ±10 knots	1/2 hour

Table 3 (Continued)
Function -- Approach and Landing

Activity	Meteorological Information	Spatial Coverage	Critical Limits & Characteristics	Accuracy	Period of Validity
Let-down					
Determine suitability of approach	Winds aloft	Descent corridors, approach lanes	Beam component Head/tail component	±5 knots ±10 knots	1/10 hour
	Turbulence	Descent corridors, approach lanes	Occurrence and location	±1000 feet, ±5 miles	1/10 hour
	Visibility	Approach lanes	3 miles	±1/10 mile	1/10 hour
Prior to landing, verify runway and obtail latest terminal weather information	Altimeter setting	Landing surfaces		±0.01 inches, Hg	1/10 hour
	Temperature	Approach lanes, runway	Engine operation	±1°C measured at engine level	1/10 hour
	Surface winds	Approach lanes, runway	40 knots, 5-knot gusts	±2 knots	1/10 hour
	Surface snow, sleet, ice, hail, rain	Runway	As measured	As measured	1/10 hour
	Ceiling	Landing areas	400 feet	±50 feet	1/10 hour
	Visibility	Landing areas	3 miles	±1/10 mile	1/10 hour
Land and brake using techniques appropriate to the particular airplane and conditions	Surface winds, gusts	Landing runway	40 knots, 5-knot gusts	±2 knots	1/20 hour
	Ceiling	↓	400 feet	±50 feet	1/20 hour
	Runway visibility	↓	1 mile	±1/10 mile	1/20 hour
Taxi to parking area	Surface winds, gusts	Taxi way	40 knots, 5-knot gusts	±2 knots	1/20 hour

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