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REQUIREMENTS AND CONSTRAINTS OF POTENTIAL ROLES OF SUPERSONIC TRANSPORT CREWS

by Harold E. Price, Richard A. Behan, and William J. Ereneta

Prepared under Contract No. NAS 2-2209 *by*
SERENDIPITY ASSOCIATES
Chatsworth, Calif.
for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1965

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ERRATA

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and William J. Ereneta

January 1965

Page 298: The last paragraph has been quoted incorrectly. It states in part ". . . increase due to inefficient inlet compression. . . ." The correct terminology should be ". . . efficient inlet compression . . ."

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

The conduct of this study would not be possible without the cooperation and contribution of many organizations of the aviation community. It is the desire of the authors and the National Aeronautics and Space Administration that the results of this study be useful to these same organizations who have contributed to the study. While it is unfeasible to list the organizations who have cooperated or contributed to the program, they may generally be identified by the reference material used during the study. We are gratified by their interest.

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1. INTRODUCTION

1.1 PROGRAM OBJECTIVES

This program is being performed under contract NAS 2-2209 between Serendipity Associates and the Biotechnology Division of the Ames Research Center of the National Aeronautics and Space Administration. The program consists of both field research and analytical studies to provide:

1. A delineation of the operational crew task requirements under conditions of both:

   a. Normal air carrier operations

   b. Unusual and non-routine operations.

2. Development of methods for deriving crew performance tasks during the early development stage of man-machine systems.

The interim and end products from this research are expected to be useful to NASA, other government agencies, and the aviation industry in general as follows:

1. As a basis for increasing the realism and validity of piloted simulators for the supersonic transport, by defining a realistic operational task environment.

2. As data base for making objective determinations of the crew role, the number of crew members required and the division of the task requirements among them.

3. To indicate where emphasis should be placed in design, simulation, human engineering, and training.

4. To provide methods for assessing the validity of the crew performance requirements derived for the SST as well as provide a basis to systematically and consistently derive crew performance requirements in other systems.

Table I has been deleted from this report.

1.2 ORIENTATION AND APPROACH

In the Commercial Supersonic Transport Aircraft Report (ref. 1) issued jointly by Department of Defense, National Aeronautics and Space Administration, and the Federal Aviation Agency, the role and broad responsibility of the National Aeronautics and Space Administration was stated as "basic research and technical support." This program is oriented towards the broad responsibility of the NASA as stated, and more specifically towards basic research and technical support with respect to crew requirements for supersonic transports. Serendipity Associates, as contractor to the NASA for this program, is dedicated to an objective performance of this program as the organization exists for the purpose of providing analytical and empirical research and is not engaged in the development or manufacture of hardware. Thus, in short, the orientation is to provide an objective study of operational crew task requirements for supersonic transports. In addition, the program is oriented toward developing and documenting methods in support of the objectives of the program.

The approach may be characterized as one of field research, analytical studies, and synthetical studies. No empirical research is contemplated.

The field research is directed towards working with individuals and organizations who are concerned with the development and/or operation of supersonic transports. A somewhat complete list of organizations contacted during the study so far is presented in Table 6 in Section 3, SST Requirements and Constraints Review, but in general the field research was accomplished by contacting members of current commercial jet flight crews, representatives of the flight crews (Pilots' and Flight Engineers' unions), airline companies and their collective representative organizations, airframe developers and potential developers of associated equipment, the International Civil Aviation Organization,

and DOD, NASA, and FAA. Informal interviews and working sessions are being used for the field research aspect of the program.

The analytical aspect of the program is concerned with obtaining requirements, constraints, and other technical data from those representative groups and individuals described above, and analyzing this data both qualitatively and quantitatively to derive subsequent requirements and constraints necessary for investigating operational crew tasks. This aspect of the program also includes to some extent a review of potential means for meeting the derived requirements and a further analysis of these means with respect to implementation by the crew.

The synthetical aspect of the program consists of synthesizing data obtained from the field research and analytical studies as well as a great deal of additional technical data obtained primarily from technical literature. The synthesized information is presented as a data base for those interested in crew requirements for supersonic transports. Data has been synthesized and presented when it pertains to or has implications for the crew role, allocation of functions among crew members, qualifications of the crew, flight deck design, and crew efficiency. In general we were inclined to include rather than exclude data where it might have some implication for crew requirements.

1.3 PURPOSE OF THIS REPORT

This report is somewhat of a progress report in that it does represent the work done to date, but it is intended to be more of an interim report containing technical information which should be of use to other organizations involved in the development and operation of SST. There are three principal sections in the report. Section 2, SST Flight Profiles, contains (1) information on the anticipated flight profiles or flight envelopes for SST, (2) descriptions of individual phases of the flight profile, and (3) separate discussions of the sonic boom and air traffic control factors as they effect the flight profile. Section 3, SST Requirements and Constraints Review, contains (1) a collation of requirements and constraints expressed by many cognizant individuals and organizations, and (2) a limited analysis of each group of requirements and constraints as it has implications for the crew. Section 4, Potential Roles of the SST Crew, does not recommend crew roles but does, however, describe potential roles of the flight crew in terms of (1) system considerations which effect the flight crew, (2) crew role variables, (3) operational considerations and the crew, (4) crew composition, and (5) flight deck concepts.

2. SST FLIGHT PROFILES

The SST flight profile will depend entirely on a specific aircraft configuration and payload, the particular route being flown, and atmospheric conditions which exist along the route. This report presents some general or typical flight profile information which provides the basis for analysis and derivation of the crew requirements, and other objectives of the study. For general orientation purposes Table 2 presents some of the basic characteristics of supersonic transports which can be expected. The United States supersonic transport program is

TABLE 2. BASIC CHARACTERISTICS OF SST

Overall Length	200-250 ft.
Gross Weight	400,000-520,000 lbs.
Total Fuel	200,000-250,000 lbs.
Range	3500-4000 statute miles
Payload	30,000-40,000 lbs.
Passengers	150-220

currently in a design competition stage between configurations proposed by the Boeing Company and Lockheed-California Company. Since this report is in no way concerned with evaluation of these two design configurations, no description or discussion of them is presented other than to state that the Boeing configuration is known as a variable-sweep aircraft and the Lockheed configuration is known as a double-delta aircraft. Reference 2 describes the Lockheed aircraft and reference 3 describes the Boeing aircraft. Many performance and design characteristics of supersonic transports in general are contained in the body of this report, particularly in the discussions of the flight profile phases.

No particular route of flight was chosen for the flight profile data presented here. Rather a maximum range flight of 4000 statute miles was used as the basic route. As far as meteorological and atmospheric conditions are concerned, all data is generally developed on the basis of a standard day and no wind conditions using U. S. Standard Atmosphere Data (1962) as a basis for any calculation.

Generally speaking, the optimum flight path for supersonic transport performance will be dictated by considerations of aerodynamic efficiency and fuel economy within structural limitations of the aircraft. This so to speak optimum flight path cannot be flown in commercial operations because of considerations of sonic boom and air traffic control. The annoyance and damage aspects of sonic boom impose limitations on the ascent, cruise and descent of the supersonic transport, and the obvious necessity to have the aircraft operate with other traffic under air traffic control also imposes limitations in the ascent, cruise and descent portions of the flight. Because of the importance of these two factors to actual flight profile, separate discussions of sonic boom and air traffic control are provided following the flight profile discussion.

Table 3 is a summary of typical performance data for SST used in this report, and Figures 1, 2, and 3 are general profiles for SST. Table 4 is a comparison of some aspects of SST with today's large jet transports. The flight profile data presented here are more correctly flight envelopes as we have attempted to define the ranges of values which can be expected in most cases rather than a specific value or specific flight path. An average value has been shown on the profiles but it is merely the average of the range of values and does not represent any particular aircraft. In addition to flight performance data, other information is provided on the flight profiles which may be useful in understanding some of the relationships and considerations of the study. These flight profiles are not referred to in the specific descriptions of the flight profile phases, but should generally be utilized with that discussion. The flight profile phases are arbitrary and the particular

TABLE 3. TYPICAL PERFORMANCE VALUES FOR SST

PERFORMANCE CHARACTERISTICS / FLIGHT PHASES	ALTITUDE (K ft.)		EAS (Kts)		VERTICAL SPEED (Kft/min.)	TIME (MIN)		DISTANCE (STATUE MILES)		MACH	
	BEGIN	END	BEGIN	END		PHASE	ELAPSED	PHASE	ELAPSED	BEGIN	END
1. TAKE OFF	0	1.5-2	0	165-175	.5-1.5	<1	<1	3.5	3.5	—	—
2. INITIAL CLIMB	1.5-2	7-8	165-175	300-400	3-5	.5-1.5	1.5-2.5	11.5-36.5	15-40	—	—
3. SUBSONIC CLIMB	7-8	40-45	350-400	≈250	5-9	6.5-12.5	8-15	65-185	80-200	0.6	0.9
4. TRANSONIC ACCEL.	40-45	45-50	≈250	≈300	≈1	4-12	12-20	30-140	110-220	0.9	1.3
5. SUPERSONIC CLIMB	45-50	60-68	≈300	≈530	4-5	6-16	18-28	110-170	220-280	1.3	3.0
6. CRUISE	60-68	60-75	≈530	300-400	≈0.1	≈100	117-127	3500-3600	3720-3820	30	22-30
7. SUPERSONIC DESCENT	60-75	55-60	300-400	200-250	≈3	2-13	119-130	0-150	3720-3870	2.2-3.0	1.05
8. TRANSONIC DECEL	55-60	50-55	200-250	≈200	≈3	1-12	120-131	30-160	3750-3880	1.05	0.95
9. SUBSONIC DESCENT	50-55	35-40	300	300	3-5	4-15	124-135	70-170	3820-3920	0.95	0.9
10. LETDOWN	35-40	3	300	300	3-5	21-23	145-147	165-170	3985-3990	—	—
11. APPROACH	3	1.1	300	145-135	—	2-4	147-149	10	3995	—	—
12. LANDING	1.1	—	145-135	135-118	—	1-3	150	5	4000	—	—

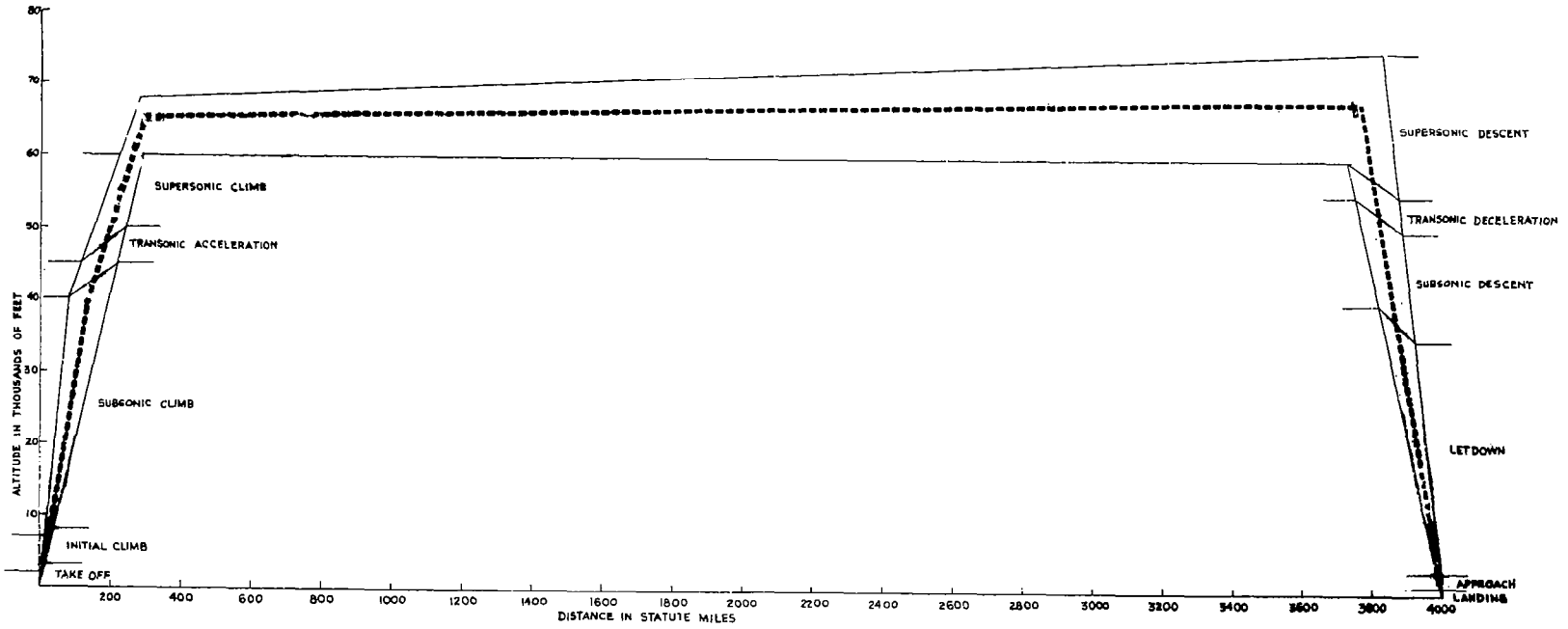


FIG. I SST ALTITUDE - DISTANCE PROFILE

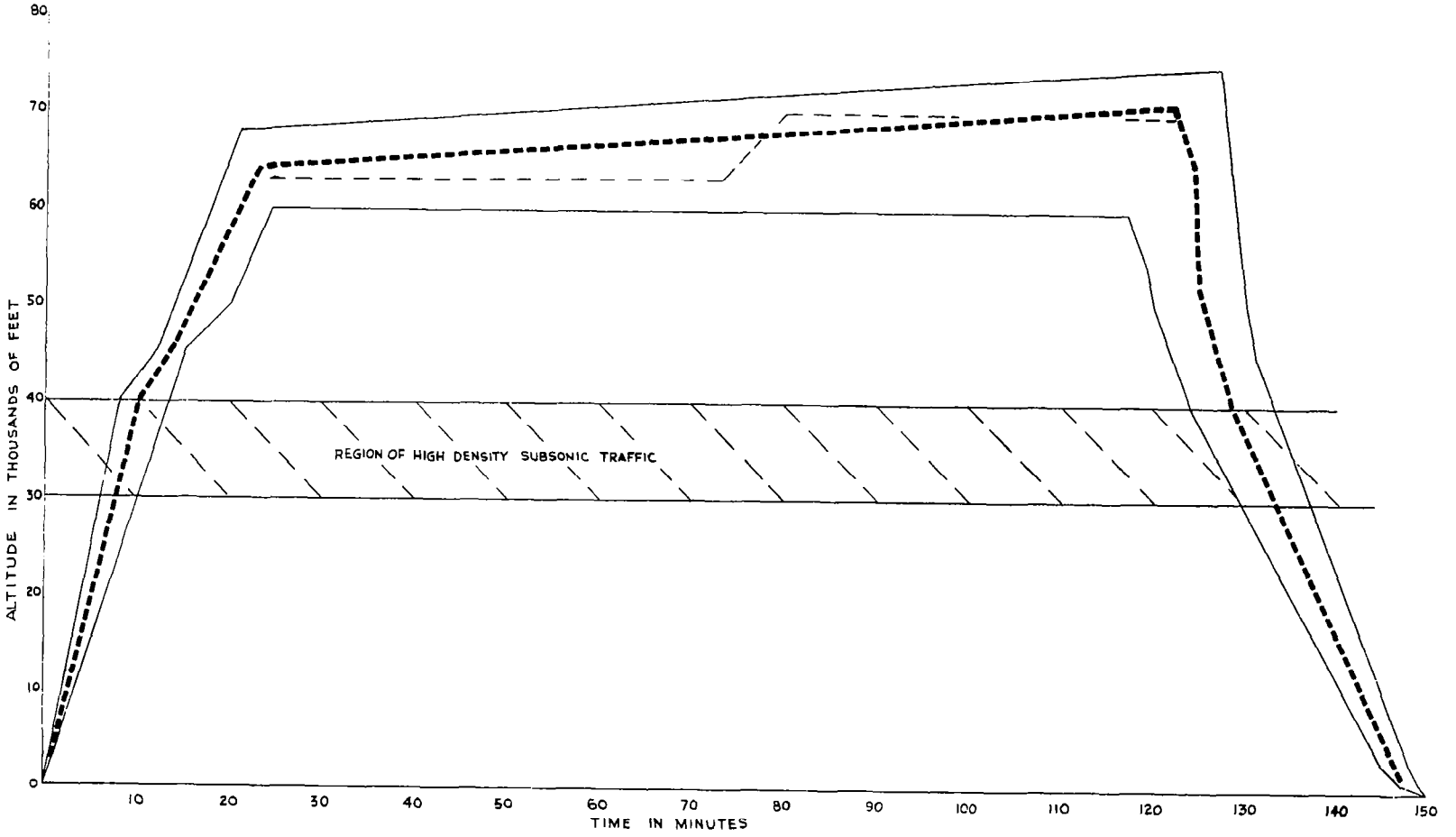


FIG. 2 SST ALTITUDE - TIME PROFILE

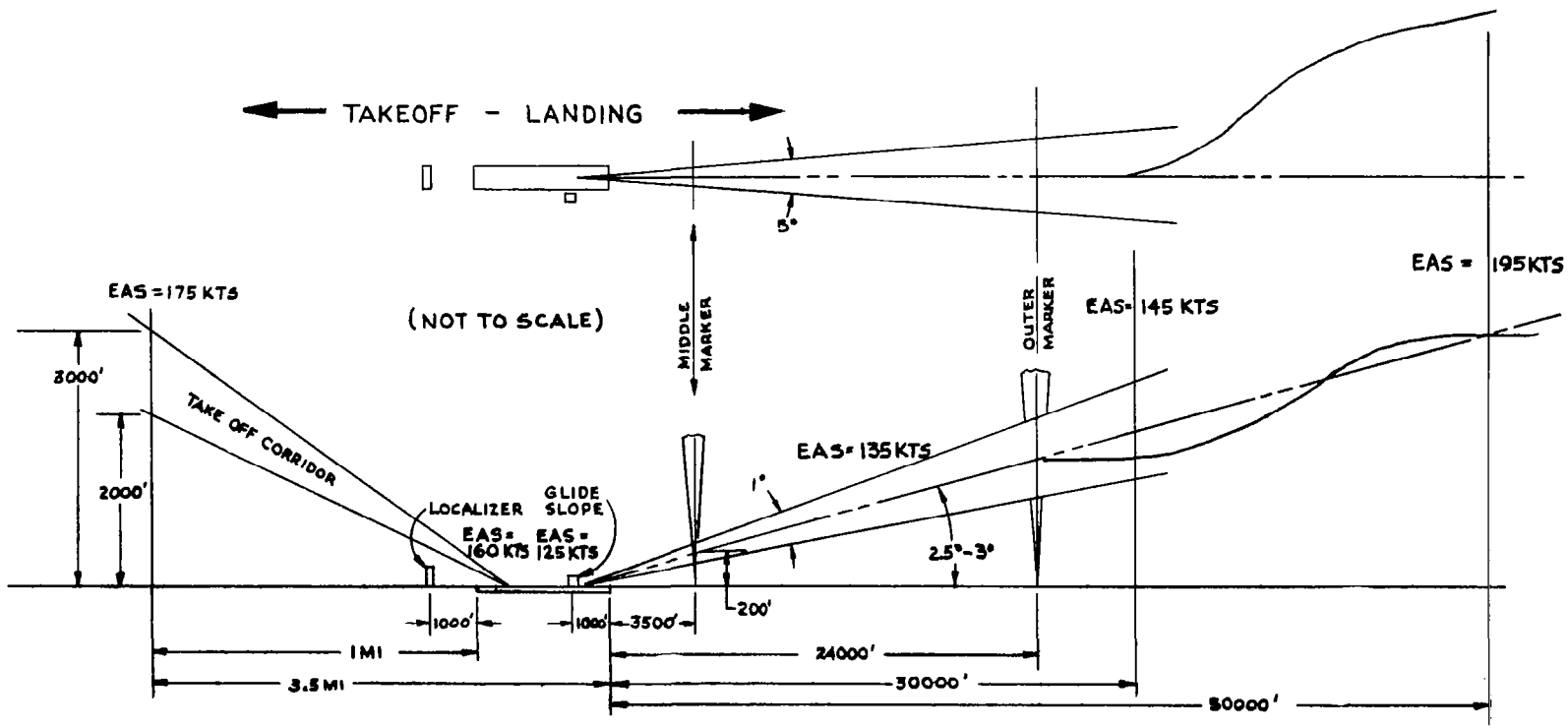


FIG. 3. SST TAKEOFF AND LANDING PROFILE

TABLE 4. A COMPARISON OF SOME ASPECTS OF SST WITH TODAY'S JET TRANSPORTS

	SST	Current Jet
Gross weight	400,000-520,000 lbs.	310,000 lbs.
Takeoff run distance	4,300-8,500 ft.	5000-8500 ft.
Acceleration during takeoff run	0.35 g	0.20 g
Time to accelerate to 100 kts. (on ground)	14 sec.	22 - 24 sec.
Lift off speed	154 - 170 kts.	140 - 165 kts.
Angle of rotation to unstick	7 - 10 deg.	5 - 8 deg.
Initial Climb speed	165 - 175 kts.	155 - 180 kts.
Climb speed	350 - 400 kts.	280 kts.
Cruise speed	M=2.2 - 3.0	M=.75-.85
Cruise altitude	60 - 75 K ft.	30 - 40 K ft.
Touchdown speed	130 - 145 kts.	110 - 120 kts.
Landing rollout	8000-9000 ft.	6,500 ft.

phases used here were developed principally because of their logical discrimination and because of their utilization to the general objectives of the program rather than because of radically different performance aspects during each phase. The twelve different flight phases used in this study are listed below and the remainder of this section of the report is devoted to a description of some of the typical performance characteristics and, occasionally, problems which may be expected for supersonic transport operations during each flight phase.

1. Takeoff
2. Initial Climb
3. Subsonic Climb
4. Transonic Acceleration
5. Supersonic Climb
6. Cruise
7. Supersonic Descent
8. Transonic Deceleration
9. Subsonic Descent
10. Letdown
11. Approach
12. Landing

2.1 FLIGHT PHASES

2.1.1 TAKEOFF

Takeoff for the supersonic transport will be similar to present jet transports and the SST will have no difficulty complying with current takeoff climb requirements. Takeoff clearance will be obtained prior to engine start so that an uninterrupted taxi to the takeoff position may be carried out and any possible air traffic control delay should be absorbed prior to engine start. Runway lengths of 10,500 feet which are available at major airports will be sufficient for the SST. The actual takeoff run distance may vary from 4300 to 8500 feet depending on configuration and gross weight. In general the high thrust-to-weight ratio necessary for supersonic flight should give a shorter takeoff field length than current subsonic jets even though the takeoff speed is likely to be higher. The high thrust-to-weight ratio will also result in higher accelerations during the takeoff run, approximately .35 g as compared to 0.20 g for the Boeing 707. The SST will accelerate to 100 knots on the ground in about 14 seconds as compared to 22 to 24 seconds for present jets. Lift-off speed will be in the order of 154 to 170 knots and the angle of rotation to unstick will be 7 to 10 degrees. This angle will increase to perhaps 20 degrees at the 35 ft. screen point corresponding to CAR requirements for takeoff over a 35 ft. obstacle. Climbout speed will be in the order of 165 to 175 knots with the rate of climb between 500 ft/min. to 1500 ft/min. governed principally by the acceptable noise levels. The FAA work statement to Boeing and Lockheed specifies the maximum community noise level as 108 PNDB at a point three miles from initiation of takeoff roll. This is approximately one mile from the departure end of the runway for a 10,500 foot runway. This requirement is similar to that specified by the Port of New York Authority, viz., that PNDB at a point three and one-half miles from the point of takeoff shall not exceed 112. Either of these requirements will probably mean a reduction in

power after lift-off. The aircraft should be some 1500 to 2000 feet above the ground at the 3 mile point, and this power reduction may present a problem of passenger comfort due to the "nose over" to a lower climb angle that results. Current jet transports experience a change in climb angle as the power is reduced at the 3.5 mile point, however, to a lesser degree than would be experienced by the SST. The boundaries for the Takeoff phase are arbitrary and for this report they will be considered as beginning with the takeoff run on the runway and continuing to the 3 mile point on a point approximately 1 mile from the departure end of the runway. As stated earlier, takeoff should be essentially similar to present jet operations but a few problems will be more pronounced; namely, the effects of errors in rotation or lift-off speeds and effects of runway roughness due to the long fuselage and distance from the flight deck to the landing gear.

2.1.2 INITIAL CLIMB

The Initial Climb phase has been included to provide for noise abatement procedures at major airports and/or on-course maneuvers whenever the intended route direction differs from the runway movement rate. From the point of view of both air traffic control and the SST, the earliest possible turn after takeoff is desirable in order to orient the SST flight path for climb toward the destination so that an uninterrupted climb can be effected. All these considerations imply a limit on speed on the order of 300 to 400 knots in order to achieve a sufficiently small radius and high rate of turn during the Initial Climb phase. The rate of climb during initial climb should be in the order of 3000 to 5000 feet per minute at climb angles of 5 to 10 degrees. While it may be possible for the SST to climb at a fixed angle, it seems more likely that it will climb at a constant indicated airspeed during the Initial Climb phase. This will result in a curved altitude vs. distance profile. Boundaries for the Initial Climb phase are arbitrarily defined as beginning at an altitude 1500 to 2000 feet at a point 1 mile from the

end of the runway and ending at an altitude of 7000 to 8000 feet at an airspeed in the order of 350-400 knots EAS.

Since air traffic control will have a complete flight profile and it is anticipated that the SST will climb out on standard types of routes, the Initial Climb phase should present no problem. However, one recent study (Ref. 4) during which the A5A made flights in and out of Los Angeles International Airport simulating the approach characteristics of supersonic transports, concluded as follows: "ATC will have to give special consideration to the SST departure to allow for increased engine noise during acceleration and takeoff, routing of the SST out of metropolitan areas to minimize sonic boom effects, and critical fuel usage during takeoff, climbout, and acceleration at altitudes. These restrictions will have to be imposed on the SST or special instrument departures will have to be devised to properly control the departing SST. The SST will have to be given a 4000 to 5000 ft. altitude advance warning for a HOLD or a LEVEL OFF during climbout, and even this much warning may produce an overshoot in altitude accompanied by an undesirable amount of negative g imposed on the passengers. It should be pointed out that even though the pilot reduced power during this hold as evidenced by the decrease in longitudinal acceleration, the altitude requested was passed and the airplane was subjected to a load approaching zero g."

2.1.3 SUBSONIC CLIMB

During Subsonic Climb phase the aircraft will accelerate rapidly to a speed of about M=0.9 (not exceeding passenger comfort levels of .25 g) and then climb at 5000 to 9000 ft/min. to an altitude of 40,000 to 45,000 feet where transonic acceleration is feasible within the noise limits of 2.0 psf specified by the FAA RFP. Climb angles during this phase will be in the order of 12 to 15 degrees. Subsonic climb for the SST is somewhat different from the present subsonic jet climbout. The

climb to acceleration altitude will be completed in about half of the time for the subsonic jet, and a little more than half the distance. This will tend to rapidly separate the outbound SST from other outbound transports. The SST may also climb at a constant airspeed until the predicted altitude to clear the sonic boom placard of 2.0 psf is reached. During the climb, in order not to exceed a cabin differential pressure limit of probably about 10.5 psi, cabin altitude would be increased at a rate of about 500 ft/min. The aircraft will remain in the Subsonic Climb phase only as long as it is necessary to clear the traffic and stay within the 2.0 psf sonic boom limitation. For our purposes, this is assumed to be at an altitude of 40-45,000 feet. It should be remembered, however, that when the SST is leaving from airports in which it does not fly over congested areas (it may for example be over water where sonic boom is no problem) it will probably be capable of attaining supersonic speeds at altitudes in the order of 20 or 25,000 feet and undoubtedly would do so for efficiency reasons if air traffic control plans permit.

2.1.4 TRANSONIC ACCELERATION

Public acceptance of sonic boom effects makes it necessary for the SST to enter the Transonic Acceleration phase at much higher altitudes than would be dictated on minimal fuel consumption considerations. The effect on climb and acceleration schedules produced by consideration of sonic booms is considerable and can cause in the order of a 20 per cent increase in climb fuel used, and a 42 per cent increase in climb time. The primary reason for the altitude sensitivity is that the vehicle must fly at a higher lift coefficient due to the reduced dynamic pressure at higher altitudes. The increased lift coefficient produces an increase drag due to lift thereby relatively lower excess thrust. Without the boom restrictions, the SST could reach sonic velocity and go supersonic at altitudes between 20,000 to 30,000 feet. The transonic acceleration phase is arbitrarily defined as beginning at an altitude of

35,000 to 40,000 feet at a speed of M=.9 and terminating at an altitude of 45,000 to 50,000 feet with a speed of M=1.3. The definition of this phase is somewhat arbitrary as is the other phases, but the terminating speed of M=1.3 is used because this generally speaking terminates the high drag area. Just below M=1.0 the aircraft experiences a considerable drag rise and this area of high drag rise lasts from roughly M=.9 to about M=1.3 after which the rate of climb could rise considerably. Transonic acceleration will probably take place at a constant rate of climb of about 1000 ft/min. Consideration has also been given to performance of transonic acceleration in level flight and one study (ref. 5) even indicates the aircraft loses about 500 feet in altitude during transonic acceleration. Generally, however, it seems the aircraft will remain in a climb during transonic acceleration which will take between three to five minutes depending on the size of the engines. If the design of the aircraft is such that it does not have a great excess of power, this transonic acceleration phase can take some time. The aircraft should travel somewhere around 50 to 100 miles during transonic acceleration. If transonic acceleration takes place in the altitude range of 35,000 to 40,000 feet, current subsonic jet traffic will be cruising at these altitudes as well as possible military traffic. However, it must be presumed that in this phase of flight the aircraft will not be amenable to controlled avoidance action although it could be told to discontinue its acceleration in an emergency. In any event, the SST will not be in the cruise altitudes of subsonic jet traffic for long periods unless it does accelerate in level flight or perhaps slightly downward.

2.1.5 SUPERSONIC CLIMB

Once the aircraft has attained a speed of M=1.3 a higher rate of climb can be established for the supersonic climb phase which will probably be in the order of 4000 to 5000 ft/min. Cabin altitude will be probably increased about 500 ft/min. to a pressure altitude of 8000 feet. There seems to be general agreement that the SST will climb at a constant

airspeed until either it reaches cruise altitude at which point it will accelerate to M=3.0, or until the aircraft reaches M=3 which may be prior to cruise altitude, in which case it will maintain at a speed approximating M=3.0 until cruise altitude is reached. The Supersonic Climb phase is bounded by a beginning altitude of 45,000 to 50,000 feet and ends at an altitude of 60,000 to 68,000 feet where cruise begins. Levelling out smoothly at selected altitude for beginning cruise for the very high rate of climb will be somewhat of a problem. The flight profiles in Figures 1 and 2 show an abrupt corner at the end of supersonic climb, but the actual flight path will be much more "rounded" for the transition to cruise. It will also be necessary to reduce power to stay below M=3.0. Proper speed control during this phase will be critical, particularly if the aircraft is to level out smoothly at the cruise altitude. The time to climb to the initial cruise altitude and accelerate to M=3.0 will be around 25 minutes.

2.1.6 CRUISE

The optimum flight path for cruise is a constant Mach number cruise-climb. A cruise using constantly improving thrust-to-weight ratio to climb as fuel is consumed provides considerable savings in fuel. Cruise at a constant altitude will require additional fuel in the order of 1.5% of the gross weight of the aircraft and a step-climb cruise flight path would require additional fuel in the order of 1/2 to 1% gross weight of the aircraft. Range penalties somewhere around 150 to 400 miles may also be incurred if the cruise-climb flight path is not permissable. As a general rule of thumb, a rate of climb approximately three feet per nautical mile for a typical SST would provide the optimum cruise climb profile. The mitigating factor against cruise climb profiles is, of course, air traffic control requirements. These may require SST to fly at specific flight levels or at best permit one or two step cruise-climb profiles. Whether a cruise-climb or a step-climb profile will be used remains to be seen. Air traffic control

will of necessity require precise speed, height and position information on all supersonic aircraft operating on the same general route and/or flight level. The Cruise phase will begin at an altitude of 60,000 to 68,000 feet and may terminate at altitudes up to 75,000 feet. (The limit of cruise altitude is undetermined and consideration is being given to cruising up as high as 85,000 feet.)

When the aircraft is some 700 to 800 miles from its destination airport, the decision to land will be made. The aircraft may be decelerated to about M=2.2 at cruise altitude. This is reasonable because the change in the altitude for maximum lift/drag ratio is relatively small in this Mach number range. Cruise will terminate somewhere between 200 to 350 miles from the destination airport.

The Cruise phase of the flight should be characterized by a high degree of schedule reliability as long as meteorological forecasting errors are not unreasonable and no maneuvers at cruise altitude are required. The effect of errors in forecast wind velocities generally will be small and ambient temperatures aloft may actually result in greater problems for ETA validation and position prediction than the wind. Any maneuvers required by air traffic control or for the purpose of weather avoidance will be costly. Slow down after cruise speed is reached will be a penalty of considerable magnitude and maneuvers such as turns will be a penalty due to excess drag and loss of speed. The Air Traffic Control system which is envisioned for the period of supersonic transport operations should almost never require any change in flight path filed prior to takeoff. Shorter block time and better weather forecasting capabilities, with the possible exception of clear air turbulence, should also preclude maneuvers at cruise altitude. Perhaps the most serious consideration for changing the flight path at cruise altitudes will be sonic boom. At present knowledge of sonic boom focusing criteria for speeds in the order of M=3 at the cruise altitudes anticipated is very limited.

2.1.7 SUPERSONIC DESCENT

Generally speaking the descent path which provides the best range is the optimum path. This is achieved by approximating a descent path which affords the best L/D, i.e., as altitude is decreased, speed decreases. The limit line for descent is basically defined by sonic boom and structural considerations and descent can be made from altitudes of 75,000 feet in as little as 8 to 12 minutes although acceleration in the order of 0.25 g would be continually imposed on the passengers. Generally recommended maximum acceleration for passenger comfort is 10 ft/sec.^{2} or .31 g. This maximum refers only to the effect of g as a force and does not consider the psychological effect of apparent change to the passengers' vertical -- the tilt in cabin floor angle. During a three minute deceleration at .35 g the aircraft would appear to be diving at an angle of 24 degrees. Passengers are accustomed to forces of only .132 g for 60 seconds during takeoff and occasionally as much as .25 g during short field landings. A second consideration for passenger comfort is the rate of change of cabin altitude. In order to eliminate any passenger discomfort, the rate of change of cabin altitude should be limited to approximately 300 ft/min. Since the cabin altitude will be approximately 8000 feet this would establish the minimum descent time as 27 minutes from cruise altitude to touchdown. Rate of descent will probably be in the order of 3000 ft/min. Supersonic descent will probably be accomplished by reducing speed at cruise altitude from M=3 to around M=2.2, then a linear reduction of Mach number with altitude will be carried out so that Mach 1.05 is reached somewhere between an altitude of 55,000 to 60,000 feet at which point the Transonic Deceleration phase will commence.

2.1.8 TRANSONIC DECELERATION

Transonic deceleration essentially should be part of supersonic descent and probably will be a continuation of the linear reduction of

Mach number with altitude so that M=0.95 will be reached between 50,000 and 55,000 feet. For purposes of this report the transonic deceleration phase is arbitrarily defined as beginning at an altitude of 55,000 to 60,000 feet at speed of M=1.05 and terminating at an altitude of 50,000 to 55,000 feet with a speed of M=0.95. Rate of descent will be still in the order of 3000 ft/min.

2.1.9 SUBSONIC DESCENT

During the Subsonic Descent phase the SST probably will descent at M=0.95 to an altitude between 35,000 to 40,000 feet and an EAS of 300 knots. Rates of descent during Subsonic Descent phase may be in the order of 3000-5000 ft/min. The end of the subsonic descent phase is arbitrarily determined as the optimum holding altitude for the SST if holding is necessary. Generally speaking it is expected that the aircraft will be cleared without delay and holding will not be necessary. However, holding would best be accomplished at altitudes of 35,000 to 40,000 feet rather than low altitudes if it is absolutely necessary. The aircraft would stay holding at this altitude until it was cleared or had a very high probability of landing at the scheduled terminal. The criticality of this hold altitude was given in an example (reference 6) in which by changing the hold altitude from 35,000 feet to 5,000 feet an increase in fuel reserve of one ton was required which effectively eliminates approximately 12 passengers if this weight was taken out of the payload. The aircraft, of course, must have some capability for low altitude holding and/or path stretching to allow for emergency situations which may prevent it from making an immediate landing.

2.1.10 LETDOWN

The Letdown phase of the flight profile could be considered a part of the subsonic descent routine. It is, however, called out as

a separate phase since it is primarily during this phase that the SST must be compatible with existing subsonic transport aircraft. Letdown begins at an altitude of 35,000 to 40,000 feet with the SST descending at 3000 to 5000 ft/min. at a constant EAS in the order of 300 knots. Letdown is arbitrarily terminated at an altitude of 3000 feet which is somewhat typical of the altitude at which the aircraft would level out to begin approach to the terminal area.

For many years after its introduction the supersonic transport will be in a small minority in its use of terminal airports. Therefore it is important to remember that for all phases of the flight profile from Letdown through Landing the SST will be flying in an airspace utilized by subsonic aircraft. If the performance characteristics of the SST were markedly different from the other aircraft types, movement rates would inevitably suffer with a consequent loss in airport utilization and delay to air transport operations generally. Thus the traffic environment during the letdown phase and other phases to touchdown will be set by the characteristics of today's subsonic jet and turbo-prop aircraft and perhaps newer versions of these types.

2.1.11 APPROACH

The Approach phase of the flight profile is quite arbitrary and, of course, in many cases will depend not only on the characteristics of the aircraft but the requirements of the terminal airport at which the aircraft is landing. For our purposes we have defined the Approach phase as beginning at a 3000 feet altitude and terminating at an altitude of 1100 feet with the aircraft "in the slot." Initial approach will be carried out at an EAS of 195 knots which would be compatible with current aircraft. The approach angle and speed of the SST will depend to a great extent on configuration and

operational characteristics of the SST. There is some consideration being given to initial glideslope angles in the order of seven degrees in order to reduce the problem of noise in the vicinity of airports. However, for present purposes we will assume glideslopes consistent with present commercial practice, i.e., 2.5 to 3 degrees. The SST would descend from its 3000 foot altitude beginning approximately 50,000 feet from the runway to approximately 1100 feet 30,000 feet from the runway in order to intercept the glideslope prior to the outer marker. EAS will be reduced to 145 knots during the ILS intercept and final approach down the glideslope will be at an EAS of 135 knots.

2.1.12 LANDING

The Landing phase of the profile consists of the flareout, touchdown and roll-out. Each of these three aspects may differ from present subsonic jet operation and the difference will depend considerably on the particular SST configuration. Flareout will probably have to occur further out (up to 200-300 feet) than present jet flare initiation distances. It may also be true that a higher angle of attack is required for landing than with present jet operations in which case the flight deck may be almost 40 feet from the runway when the main gear touches down. Another perhaps more severe problem in landing the SST, assuming the flight deck is in the front of the aircraft, is that the pilot may receive unreal motion cues because he is far from the center of gravity; his physical sensations then will be unrelated to actual aircraft performance. This has not been a problem in modern aircraft transportation, but simulation results by the National Aeronautics and Space Administration indicate this may be a problem in the supersonic transport. Visibility from the flight deck may also be a problem either because of the high angle of attack or because of the generally more restricted visibility from the windscreen designed for both subsonic and supersonic flight. Touchdown speeds, however, will be somewhat comparable to present jet operations and should be in the order of 118 to 135 knots.

Similarly, the landing roll should be no problem and will be in the order of 5800 to 7200 feet.

It is also well understood and accepted that an all-weather landing capability is a must. There is perhaps less agreement on whether this will be an automatic system or a system which the pilot is part of the primary control loop. But in any event the economics of the SST demand that it be able to land under essentially 0-0 ceiling and visibility conditions.

2.2 SONIC BOOM

The performance characteristics of civil supersonic transport aircraft will require changes in the standard operating procedures developed for subsonic aircraft, and will create new problems not previously encountered. One of these problems, sonic boom, must be dealt with by the operators of the aircraft, consistent with satisfactory relations with people on the ground. The requirement to stay within acceptable noise levels on the ground causes the SST to fly a flight profile considerably different than optimum.

In air the pressure disturbance we recognize as sound establishes the speed at which sound travels. An aircraft moving at subsonic speed creates fairly mild pressure disturbances that move faster than the aircraft itself. A supersonic aircraft, however, gets ahead of its own pressure disturbances; they stream out behind as a shock wave that creates a change in pressure as it reaches any particular point. Upon contact with the earth's surface these generated shock waves produce a noise known as "sonic boom."

The intensity of the noise produced by the shock wave, measured in decibels (db), depends on the pressure rise. ICAO reports (ref. 10) that tests show that if the pressure change does not exceed 1 pound per square foot (psf), which corresponds to 128 db, the noise is not considered objectionable and is comparable with a distant explosion or distant thunder. The FAA RFP (ref. 8) calls for less than 2 psf during climb and acceleration and a maximum of 1.5 psf during cruise. Pressure changes exceeding 2 psf can cause damage to windows. Table 5 shows some of the probable effects of sonic boom over-pressures. It is clear that this effect becomes more serious as the pressure change increases to a level which it is unfeasible to expect the public to tolerate.

TABLE 5. PREDICTION OF SONIC BOOM GROUND EFFECTS
(National Opinion Research Center)

Overpressure (psf)	General Effects
3.0	Widespread public reaction--Possible damage to windows and plaster.
2.5	Incipient damage - significant public reaction -- Close range thunder or explosion
2.0	Probable public reaction -- particularly at night
1.5	Some scattered public reaction -- no damage to ground structures
1.0	Acceptable -- no significant public reaction -- distant explosion
0.5	Acceptable -- distant thunder

NASA's Langley Research Center (as reported in Scientific American, Vol. 210, June 1964) has established the variables that govern the pressure changes in the shock wave. The investigation has established that above the speed of sound, increases of speed have comparatively little effect on sonic boom. The chief factors affecting the strength and character of sonic boom are the shape and weight of the aircraft and its altitude above the ground. The shape and weight limitations of the civil supersonic transport are not flexible because of the design and capability functions desired, but the variance of altitude can be accomplished, although at the cost of operating efficiency.

To minimize the annoyance of sonic boom, the supersonic transport will not be permitted the wide choice in altitude and speed patterns (optimum flight profile) now enjoyed by today's commercial aircraft. To prevent sonic booms at low altitudes the supersonic aircraft will be required to climb subsonically to at least 40,000 feet before it begins its transition to supersonic flight. Theoretical studies have shown that pressure rises in the area of 1 psf would be produced when the altitude is about 45,000 feet and the speed is M=1.3. At this altitude and at speeds only slightly in excess of M=1 the shock waves may not even reach the ground. This particular relationship of altitude and speed depends on the prevailing atmospheric conditions, and on whether the aircraft is climbing or descending. Necessary computations would have to be made during flight planning to obtain a flight profile which would take these factors into consideration.

The sonic boom is loudest at points directly beneath the flight path of the aircraft and decreases in intensity as the lateral distance from the flight path increases. Crosswinds will displace the lateral band in which the boom is experienced but will not appreicably affect its width. For an aircraft cruising at a speed of M=3 at an altitude of 70,000 feet the width of the area on the ground exposed to booms would be about 70 miles.

An important aspect of both theoretical and flight investigations of the sonic boom is the effect of various maneuvers and flight path angles on the intensity of the boom. Some types of maneuvers reduce the intensity of the boom, and others may create "super" booms by the focusing effect that occurs when shock waves generated at various points along a flight path arrive simultaneously at the same point on the ground. Studies of this phenomena will be necessary for the development of operational procedures aimed at minimizing boom intensity.

There is no doubt that the sonic boom is one of the greatest problems, if not the greatest problem associated with the optimum operation

of the supersonic transport. The operation of supersonic transport over heavily populated areas is practicable provided that sufficient attention is devoted to flight planning. Climb and descent below 40,000 feet must be at subsonic speeds. Between 40,000 and 60,000 feet these phases can be at low supersonic speeds. Because of the rotation of the shock wave pattern in a climb attitude, a slightly higher speed can be used in the climb than in the descent. Acceleration to high supersonic speeds will probably take place above 60,000 feet.

It cannot yet be judged what intensity of boom will be acceptable to the public on the ground. The intensity must obviously not be great enough to cause any damage to property and consideration will have to be given to its effects on animal life as well as to disturbance of or annoyance to humans. It is reasonable to conclude that the sonic boom will not prove to be an unsurmountable obstacle to the introduction of the civil supersonic transport. However, restrictions on operational procedures must be expected.

Along this same line there is need for international cooperation and collaboration in dealing with the problem of the sonic boom and its various effects. This is particularly important to avoid wasteful duplication of effort, to insure dissemination of the information obtained, and to obtain agreement on acceptable levels of noise. In particular, the opinion has been expressed that an exchange of views should be sponsored by the International Civil Aviation Organization (ICAO) between Contracting States, on the levels which can be regarded as acceptable, both by day and by night, taking into account the movement rates likely in the next 10-15 years.

Since it is obviously impractical to restrict the flight path of a supersonic aircraft to uninhabited areas, some acceptable value for the sonic boom must be achievable if there is to be a supersonic transport. One thing is certain: The sonic boom or shock wave cannot be eliminated. It is an inherent part of supersonic flight.

2.3 AIR TRAFFIC CONTROL

In any discussion of the performance of commercial supersonic aircraft one must be aware of the flight path limitations which will arise because of air traffic control, and how these limitations will affect the ultimate performance, safety, and economy of such aircraft.

The Act of 1958 gave to the Federal Aviation Agency (FAA) the responsibility for the safe and efficient use of the nation's airspace by both civil and military aircraft. As a result most FAA policies and procedures stem from this area of responsibility and have been the subject of much controversy. Safety requires adherence to regulations which often involve an economic burden to the aircraft operator. However, since the responsibility for safety stems from the Act, the final determination of proper safety levels comes from a higher authority; we, the public, as represented by the Congress.

The accomplishment of safe and efficient movement of aircraft in an airspace utilization system is achieved by providing various services to the users of the airspace. The services provided by the Federal Aviation Agency stem from the Act of 1958 and its interpretations as practically modified by various constraining factors. It is not feasible to provide services in all of the airspace for which the system is responsible. Traffic density, distribution and flow determine the various types of offered service. Uniform service in all airspace would be desirable, but costs make this goal unrealistic.

Presently the basic operational services provided by the FAA include:

1. Air traffic rules
2. navigation facilities
3. aviation weather information
4. information for flight planning

5. information for en-route aircraft
6. search and rescue alerting, and
7. air traffic control.

Most of these services affect the efficient operation of aircraft, but can without major difficulties be updated to handle the current and future operational requirements of any aircraft system.. However, in the area of air traffic control a diversity of aircraft operating characteristics may cause uncompromisable trouble areas. For this reason it is necessary to look into difficulties which will arise with the introduction of the supersonic transport (SST) into the current and projected air control systems.

2.3.1 CURRENT PROBLEMS

The air traffic control system must be considered as a service stretching from the departure ramp to the arrival ramp. Participation in the air traffic system, either as a pilot or controller, is becoming more and more difficult because of increasing operational complexity. This complexity is being reflected in rules, in airspace utilization, in navigational charts, and in ATC procedures and clearances.

It has been realized for some time that improved air traffic services are required to deal with the increases in traffic density and range of speed. The introduction of the subsonic jet with its diverse characteristics accentuated this problem.

Another critical problem is the heavy work load placed on the pilot as a result of the accumulation of many tasks. These tasks include complying with the navigational and communication requirements of the ATC system, the "deciphering" of the complicated and lengthy language of the ATC clearances, maintaining visual separation from other aircraft, frequency changes on both communication and navigation equipment, and

transponder code changes. All these are in addition to the task of flying the aircraft in accordance with an efficient flight profile. This work load creates situations which may adversely affect the expeditious movement of traffic, and makes it difficult to maintain proper safety levels.

In another area the earliest possible turn after takeoff is necessary where the intended route differs from the runway heading, if the rate of traffic movement is not to suffer. In the present ATC system outbound traffic will often be restricted until clear of inbound traffic patterns, and in some instances an early turn will result in sufficient separation to lift any climb restrictions. High speeds in this early phase of the flight result in large turning radii which could mean lengthy and unacceptable low altitude routing in order to avoid adjacent airport traffic patterns. These considerations seem to imply speed ranges in the vicinity of 300 kts. for the SST.

During cruise speeds in the range of 30 miles/minute make present compulsory position reporting impractical, and some thought must go into the feasibility of reducing them. Presently the number of reporting points could increase to the point where the work load will be excessive to both pilot and controller.

2.3.2 ACTION

Recognizing the need for a refined air control system generated by the technological advances in aviation, the President, in 1961, requested the Administrator of the FAA to conduct "a scientific, engineering review of our aviation facilities and related research and development, and to prepare a practicable long-range plan to ensure efficient and safe control of all air traffic within the United States." The result of this request was the report PROJECT BEACON which analized present methods of air traffic control and presented an advanced air traffic control system concept to meet future needs. The new system would utilize the present air defense and air traffic control system facilities.

On the basis of this report and its recommendations, the President asked the FAA to prepare a plan and design a system for the safe and efficient utilization of the airspace. Primary results listed in the DESIGN FOR THE NATIONAL AIRSPACE UTILIZATION SYSTEM (ref. 7) described the essential elements of the proposed air control system.

The primary purpose of the air traffic control (ATC) service is to increase safety by using ground-based control subsystems to keep aircraft separated from each other. The degree of service in the airspace under consideration will vary from the requirement that the ATC subsystem separate all aircraft in certain areas to no ground-based control service in other areas. Thus, the aim of ATC will be to clear aircraft on flight paths or profiles as near to optimum as possible, subject only to the need to provide safe separation between aircraft.

Once an aircraft is clear of the terminal area (the controlled airspace in the vicinity of the airport dealing with the arrival and departure of aircraft) its control by air traffic control should not present problems different from those of subsonic aircraft. Only if the operation of the aircraft is so critical that the pilot requires changes to his flight plan after takeoff will difficulties arise.

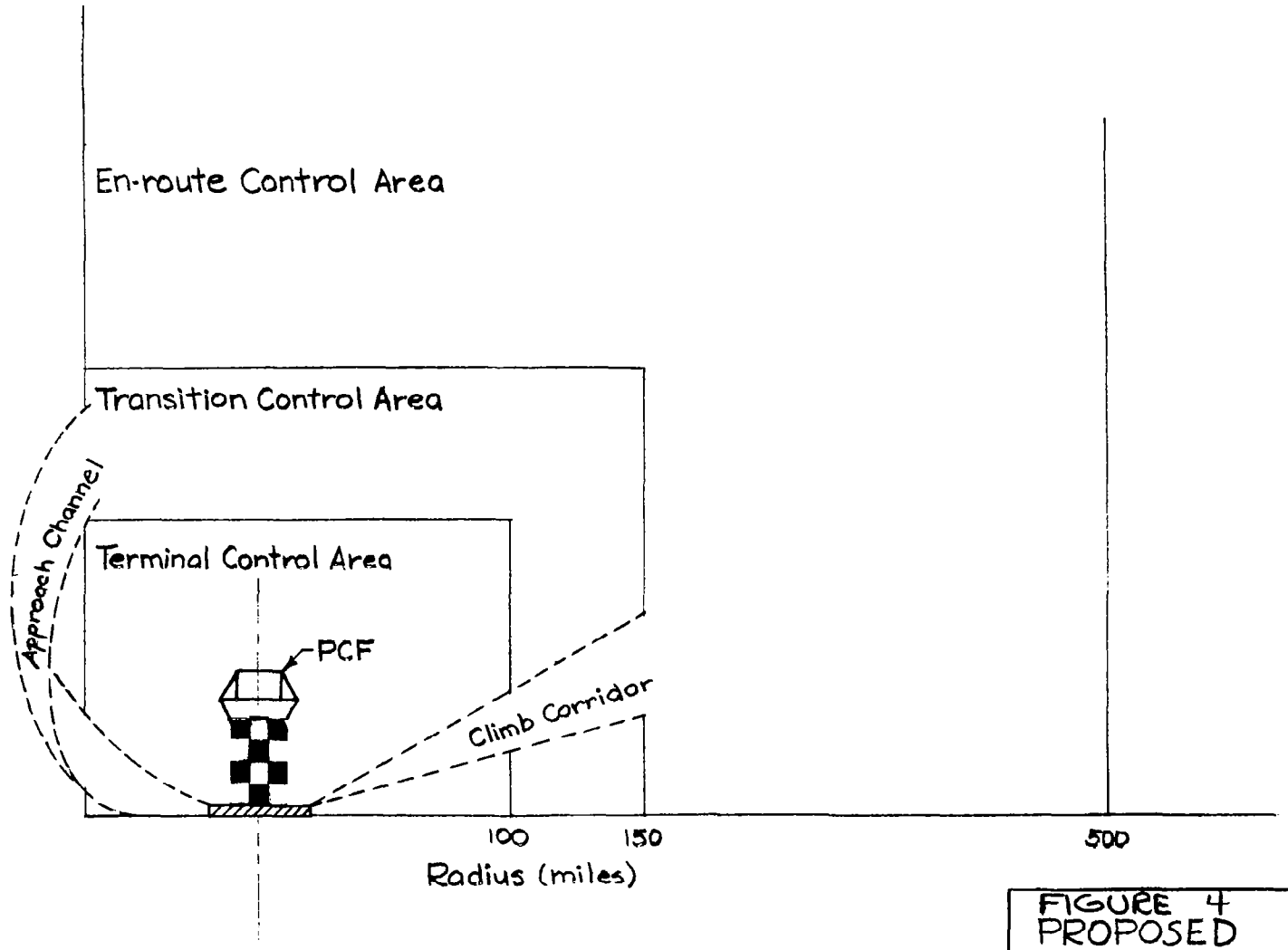
In the supersonic age of air transportation a more efficient utilization of available airspace is a prime requirement. The major changes must be in the areas of vertical, longitudinal, and lateral separation. The advances being made in navigational equipment, communications, and automation will eliminate the restriction of having air traffic conform to inflexible and narrow channels of airspace, i.e., airways. Flying of direct jet route flight plans will alleviate much of the anticipated en-route traffic congestion that would result on the present airway system. Use of flight levels, 3-D radar, and data link navigation will make changes in separation minima possible. However, while on one hand there will be a more flexible airway structure, a more definite and rigorous application of airspace will be necessary in the terminal areas to provide more efficient utilization of the airspace for all users.

According to the FAA the future airspace subsystem will consist of en-route controlled airspace linked to positive control terminal areas by controlled airway segments and terminal corridors. Whereas at present en-route air traffic control is handled by ARTCC (Air Route Traffic Control Centers), and terminal area control is handled by the airport approach control and airport tower or by a radar air traffic control center (RATCC), future operations will be handled by the same type of facilities only with larger areas of responsibility to eliminate duplication and aid coordination.

En-route facilities, probably located with selected terminal area transition centers, will cover larger areas so that long-range aircraft can be kept under the control of a single facility for a longer period of time. "This means that en-route centers will probably be fewer in number and cover diameters of up to 1000 miles from selected high-density supersonic terminals." The terminal area transition centers will have control of aircraft during the climb-out and descent phases which will probably be in the 100-150 mile range from the terminals, and the high-density terminal areas will control the takeoff and approach traffic. See Figure 4.

In the en-route traffic control system the air route traffic control centers (ARTCC) will act as a hub of the network that serves the traffic. Each center which has jurisdiction over a unique portion of the United States' airspace should by the 1970's possess high-speed data processing computers which will give them the capability of automatic handover of air traffic from center to center, or from center to terminal area. It is also expected that by this time period equipment will have been provided for the automatic identification of handoff traffic.

Besides being provided with computers, the centers will have high-speed land line communications to permit rapid and automatic interchange of information between all facilities. This is required because of the high-speed characteristics and the critical fuel nature of future high-



Not drawn to scale

FIGURE 4
PROPOSED
AIRSPACE
UTILIZATION

performance aircraft. Also, because of the more flexible airway structure, there will be requirements for a net of VHF and UHF communications utilizing data link, such as Automatic Ground-Air Communications System (AGACS), a net of direction finders to insure accurate and current aircraft positional information, and finally direct and data link communications with the pilot.

In the high-density terminal areas one of the major airports will be designated as the primary control facility (PCF) for all traffic within the area. The area controlled by the PCF will be about 100 miles in radius by 1970, and will be completely covered by surveillance radar. Multi-terminal complexes, served by Approach/Departure control facilities will be combined into a single facility for optimum utilization of airspace, to improve the coordination between the personnel controlling aircraft in different locations and to reduce coordination now required between approach control, ARTCC, departure control, etc. It must also be noted that certain areas under control of the terminal area facility will be designated high-speed climb corridors, and will be utilized in an effort to assist high-performance aircraft reach optimum flight profiles. These corridors are usually located so as to give some advantage to the aircraft. They are either over unpopulated areas where noise factors would be eliminated, or they are in an almost "on course" direction.

According to the design principles set forth in the FAA's DESIGN FOR THE NATIONAL AIRSPACE UTILIZATION SYSTEM, the future Air Traffic Control system is greatly dependent upon a data processor capability which will: (1) perform routine tasks associated with control function performance; (2) act as storehouse for relevant information; (3) handle gathering, organizing, processing and filtering of data and distribution according to individual needs; (4) perform necessary investigation in preplanning (based on pilot intent) and maintain a controlled level of traffic safety through the controlled airspace; (5) provide controllers with a plan view and/or tabular display as appropriate and the mechanism by which he can call up specific bits of information to exercise control and transfer

actions as required; (6) continuously monitor traffic flow, interpreting changes to provide advance warning of unsafe situations; (7) continuously monitor controller's actions to provide advance warning of incorrect action; and (8) maintain a legal history record with the capability of playback and data reduction.

It was previously mentioned that airspace sectors would be larger in the future. This requires that the number of aircraft which can be adequately controlled per sector be increased. This will be done by improved displays of processed and organized control information, reducing the voice communication between the pilot and controller, and by providing the controller automatically identified aircraft position information. Finally, a planning control team will assist the active control team during periods of high traffic density by providing advanced planning of traffic flow. This control team would recommend altitude changes and/or minor route changes for certain aircraft in order to reduce the incidence of a conflict situation. It is planned that the number of aircraft simultaneously under control per sector will be increased to 15 or 20. This number will be fixed by balancing control team size with the sophistication of a data processing and display system.

2.3.3 CONCLUSIONS

Short "delays" or "holds" now considered normal would be costly to the SST. It does appear, however, that the FAA's plans for the future are consistent with the difficulties which will arise. The plans to do away with the present rigid airway structure and replace it with a new one results from the advances made in navigational systems, three-dimensional radar, and partial automation. Other results are evidenced from these advances, such as reduction of existing separation minima which will in turn decrease long unwarranted delays.

Advances in all-weather landing systems coupled with the proposed changes in the basic control system should establish new requirements in the area of fuel reserves. The faster handling of en-route data, the advances in the field of weather prognostication, and newer communication systems should indicate unacceptable "holds" far enough in advance so that the SST will be able to divert to its alternate or to hold at an economical altitude. It must be remembered that although the characteristics of the SST are compatible with subsonic aircraft in the lower altitude ranges, economics mitigate against extended periods of flight in these areas.

Since the amount of SST traffic will be relatively small in comparison to other air carrier traffic in the 1970's and with the future ability for pin pointing an aircraft in three dimensions, the restraints on cruise climbs should be relaxed. This in itself will aid the economy of the SST.

Since the SST will most likely be used in international flights, extensive coordination will be needed with ICAO, IATA, and other cognizant groups so that other control systems will be able to expeditiously handle these aircraft and will not place undue hardships in the form of constraints on them. Agreement will have to be reached on tolerable noise levels, appropriate high-performance climb and descent handling, i.e., climb corridors and transition areas, and new separation minima.

3. SST REQUIREMENTS AND CONSTRAINTS REVIEW

The purpose of the SST requirements and constraints review is to present (1) a collation of requirements and constraints as expressed by cognizant groups or individuals and (2) a review, or limited analysis, of these requirements and constraints with respect to their implication on the potential crew role. A more detailed analysis of crew functions will be presented in Interim Report II. It is anticipated that this section of the report will be utilized in two ways, viz., (1) as reference material wherein the views of many different organizations concerning the same topic can be found in one place, and (2) as an initial identification of problems which may be critical to the development of the crew role.

The requirements and constraints contained in this section have been limited to those which will have more or less direct implication for the crew. Thus this section does not contain all of the requirements and constraints that apply to the SST development and operation. Specifically not included are requirements and constraints which apply to such things as (1) economics--either those concerned with financial participation of industry, or the direct operating costs of the SST, (2) materials --problems concerned with structural integrity or new technology in materials development, (3) production--any aspects concerned with the manufacture or production of SST, (4) testing--either developmental testing, or certification or airworthiness. In addition to the above limitations, this section has further been limited by consideration of a single SST operation. That is, we have not been concerned with multiple SST operations. Even in those areas of requirements and constraints which do have implications for the crew, no attempt at this time has been made to be exhaustive. An attempt was made to contact major organizations of the government or representatives of the developers and users of the SST to obtain their views, and insofar as possible these are the latest expressed views of these organizations. Since many different organizations were contacted and they are only identified briefly in the text,

Table 6 presents a list of the principal organizations which are identified, or referred to, throughout this section.

The organization of the material in this section was done on the basis of what appeared to the authors to be logical consistency. Occasionally certain requirements and constraints have been repeated as they may apply to more than one section. Insofar as possible the specific requirements and constraints expressed by an organization or individual have been quoted as we received them, or as they were contained in a technical document; and have been slightly indented in the text. Each requirement expressed by an organization or individual is identified as to the organization, the date it was stated, and a reference number. The reference number refers to the list of references appearing at the end of the report.

The final subparagraph under each second order, i.e., two-numbered heading, contains the analysis and comments concerning all requirements and constraints presented within that second order heading. Each specific requirement or group of requirements are reviewed and analyzed with respect to how they compare with today's jet operations. The comparison is made with respect to crew variables, operational variables, and flight deck design. Where crew variables, operational variables, or flight deck design appear to be different than today's jets, or unique to the SST, specific statements or discussions are presented under the "Comment" heading immediately following the table. The comment is identified in the table by its paragraph number. Other comments which are generally appropriate to the set of requirements being analyzed may also appear under the comments section whether they are referenced in the Analysis table or not. Any requirement, or group of requirements, which is analyzed to be different or unique represents an area where the impact on crew role may need more specific investigation.

TABLE 6. PRINCIPAL ORGANIZATIONS USED AS SOURCES OF REQUIREMENTS AND CONSTRAINTS

NASA	National Aeronautics and Space Administration
FAA	Federal Aviation Agency
ICAO	International Civil Aviation Organization
ALPA	Air Line Pilots Association
IFALPA	International Federation of Air Line Pilots Association
CAB	Civil Aeronautics Board
FEIA	Flight Engineers International Association
IATA	International Air Transport Association
AAAE	American Association of Airport Executives
AOC	Airport Operators Council

3.1 SYSTEM PERFORMANCE

3.1.1 GENERAL

3.1.1.1 FAA RFP, August 1963, Ref. 8

"The design objectives established in this section are for the guidance of manufacturers in the preparation of their Proposals for the development of a supersonic transport.

The objectives are not stated as requirements so that airframe and engine manufacturers may have maximum flexibility in preparing the formal Proposal. It is essential, however, that the aircraft not exceed the levels of sonic boom overpressures delineated in the RFP and that noise created by the transport on and in the vicinity of airports be kept at the levels stated as objectives. Overpressures and noise levels lower than those stipulated are desirable and manufacturers should strive to achieve lower levels to the extent that this may prove feasible.

Manufacturers should keep clearly in mind that the Government's primary objective is for them to develop a superior commercial supersonic transport desired by the airlines of the world. Acceptance of the transport will be affected by the selling price, the advantages it may possess over competitive transports in terms of safety, operational and economic characteristics, and the data of availability for passenger-carrying service.

Although it is technologically feasible to develop an aircraft having sustained cruise speed capability in the order of Mach 3, the final test of a successful commercial transport will be safety and economic performance in airline service.

The contract(s) awarded will specify the design requirements for the supersonic transport based on the manufacturers' Proposals.

The supersonic transport must comply with the airworthiness requirements of the Federal Aviation Regulations

which are applicable for the Type Certification of the particular design and applicable Public Health Service regulations."

3.1.1.2 IATA, May 1964, Ref. 13

"The IATA Imperative Design Objectives essentially represent a three-point goal to ensure that: (1) the level of safety afforded by the SST must be at least equal to that of subsonic aircraft operating at the time it is introduced into service; (2) the SST must be adaptable to air traffic control facilities existing at its introduction into service so that it is capable of integration with subsonic aircraft operating at that time; (3) the SST must be comparable with subsonic aircraft operating at the time of its introduction in such areas as economics and potential operating limitations due to noise or sonic boom."

3.1.1.3 IATA, June 1962, Ref. 12

"It is essential to the airlines, as it is to manufacturers, governments and the public, that any SST be a safe, practical and economic commercial transport."

"The level of safety afforded by the SST must be at least equal to that of subsonic aircraft operating at the time it is introduced into service. . . ."

"The SST must be adaptable to air traffic control facilities existing at the time of its introduction into service so that it is capable of integration with subsonic aircraft operating at that time. . . ."

"The SST must be competitive with subsonic aircraft operating at the time of its introduction. . . ."

3.1.1.4 IATA, May 1964, Ref. 13

"Supersonic airliners, when put into commercial use, must:

(a) have a level of safety equal to that achieved by commercial aircraft in use at that time;

(b) be compatible with subsonic aircraft, in other words, they will have to fit the existing pattern of aircraft moving in the air and on the ground at that time;

(c) be so designed that they can operate at aerodromes where large subsonic jets can take off and land.

The first of these three requirements needs no explanation: the protection of the travelling public demands it. The other two are justified by the technical difficulties and economic burden on providers of ground facilities (or on operators, if the providers should decide to increase charges for the use of those facilities) that would result if such compatibility did not exist or if runways had to be lengthened or strengthened; similarly, the provision of separate airports for supersonic aeroplanes would, in general, involve too many serious difficulties as well as unwarranted expense.

Also, when supersonic airliners are put into service they should be compatible and integrated with the economic pattern of subsonic jets existing at that time with respect to routes, operating costs and fares. (This compatibility is not meant to exclude fare differentials). The integration will require careful planning, since the premature introduction of commercial supersonic aircraft could produce economic chaos in the aviation industry which might be reflected in the social and political fields. Finally, it will be necessary to design and operate them so that the noise level experienced by the public does not exceed that acceptable for the operating of subsonic jet aeroplanes; sonic boom, which is a new problem, will also have to be solved satisfactorily. If it were not so, present indications are that there will be strong public resistance, leading inevitably to restrictions which would have a detrimental effect on the economics of supersonic airliner operations."

3.1.1.5 IFALPA, July 1963, Ref. 9

"Any attempt to introduce supersonic aircraft on a commercial basis before their problems have been resolved to the satisfaction of IFALPA should be resisted by the Federation and its pilots.

SST aircraft should commence operations in airline service only after the necessary Meteorological, Navigation,

Communications and ATC Systems and Services are proved capable of effective day by day use (up to all flight levels within the aircraft's capabilities) and the equipment has been installed and satisfactorily tested under actual operational conditions for the routes being flown.

Note

The reference to "Systems and Services" is intended to apply to the personnel operating those services as well as to the actual items of equipment.

Development work designed to make existing civil aviation safer should be given a higher priority than SST development work.

Comment

It is the opinion of IFALPA that in some countries the amount of time, skill and energy given to SST projects may, by monopolizing the attention of experts, retard the development of desirable safety items such as Boundary Layer Control, STOL, Laminar flow studies etc. On the other hand, however, SST studies may give rise to solutions to problems of general safety."

3.1.2 PAYLOAD

3.1.2.1 FAA RFP, August 1963, Ref. 8

"A weight limited payload capability in the order of 30,000-40,000 pounds for a range of 4,000 statute miles (standard day, zero wind component)."

"Provision shall be made for approximately 125-160 passengers and baggage (200 pounds per passenger and baggage) plus 5,000 pounds of cargo and mail."

"Minimum seat fore and aft spacing (center to center) pitch, for evaluation purposes, shall be established at 34 inches; minimum seat width of 17-1/2 inches between arm rests; with 2 inch side arm rests, 2-1/2 inch center arm rests; minimum aisle width of 18 inches."

"Cargo space shall be computed for a density of 10 pounds per cu. ft."

3.1.2.2 CAB (as reported in the Journal of Air Law and Commerce, 1964) Ref. 14.

"The RFP calls for a payload of 30,000-40,000 pounds with provision for 125-160 passengers and baggage plus 5,000 pounds of cargo and mail. The present family of long range jets can carry 53,000 pounds of payload including 180 passengers and baggage and 17,000 pounds of cargo and mail.

The potential loss of the excellent payload characteristics of present jets must be overcome in some manner if we are not to lose valuable ground in the economic gains achieved thus far in commercial air transport. Up to now the transport industry and the aircraft manufacturers have been able to achieve increased speed and increased payload. In any event they did not sacrifice payload for speed. We believe that the early British built Comets were too small for commercial success; as a result, for this reason and because of safety considerations, not many were acquired, and none for self-supporting commercial ventures. Not until the United States manufacturer developed a powerplant with sufficient thrust to power an economical vehicle did the airlines of the United States and the world acquire jet aircraft for their long-haul major traffic markets. We are hopeful that payload provisions can be improved to at least equal those of our existing efficient subsonic jets.

If additional frequencies are required to accommodate 1970 and subsequent traffic demands because of limited payload capabilities there would likely be a serious effect on unit costs not to mention problems of saturation of air space and navigational aids. We are not seeking the impossible, but we are hoping for payload provisions which will not cause undue economic penalty for our airlines and for the passengers and shippers who will provide the revenue to make the supersonic transport service a profitable venture."

3.1.3 RANGE

3.1.3.1 FAA RFP, August 1963, Ref. 8

"A weight limited payload capability in the order of 30,000-40,000 pounds for a range of 4,000 statute miles (standard day, zero wind component)."

"The transport shall have the capability of proceeding with two engines inoperative, or any foreseeable airplane system or component failure that would necessitate a significant change in flight plan (e.g., a reduction in cruise speed and/or altitude), from the critical point on any route to an airport where a landing can be made."

3.1.3.2 CAB (as reported in the Journal of Air Law and Commerce, 1964) Ref. 14.

"The RFP calls for a range of 4,000 statute miles with adequate payload. This seems to be a desirable design objective for the initial SST's. However, it is not clear whether this is maximum range based on fuel load or maximum range at supersonic speeds. For example, today our excellent subsonic jets will fly nonstop from New York to Rome. Similar nonstop routings are available over the Pacific and South American routes. We think it would be a step backward if these nonstop services could not be maintained with supersonic transport. It does not seem reasonable to schedule a stop at Paris enroute from Rome to the United States because of design limitations when we believe our forward planning can provide for subsonic operations over the European land area followed by supersonic over the Atlantic.

We hope this range objective is attainable so present nonstop services can be continued with a reasonable degree of certainty. We think it would be unfortunate indeed to create a system of supersonic transport which caused a condition of "hurry up and wait" because of need for frequent lengthy fuel stops.

On the other hand we have the problem of designing SST's for shorter ranges from 1,700 miles up to 3,000 miles for our domestic long-haul routes."

3.1.4 SPEED

3.1.4.1 FAA RFP, August 1963, Ref. 8

"A cruise speed capability of Mach 2.2 or faster.

The design cruising speed shall be established at that speed which will optimize safety and economic characteristics."

3.1.4.2 FEIA, August 1963, Ref. 15

"FEIA supports the principle that this aircraft should be capable of speeds in excess of Mach 2.2. We recognize that there has been considerable controversy over this subject, however, if at all possible the aircraft should be structurally capable of speeds in excess of Mach 3. We do not hold however, that this "first round" of U.S. built SST aircraft need reach this speed. If current (or near current) powerplants can be modified sufficiently to provide speed in the Mach 2.5 area and can do so economically and safely, with greatly reduced research and development costs and time (as compared with developing powerplants for Mach 3 operation) this would seem the most practical. The important fact that we must keep in sight is that an aircraft using materials thermally capable of Mach 3 operation will allow for greater speed growth consistent with the development of more powerful engines and therefore possesses an increased potential. It will preclude the necessity of our repeating the present costly venture in total. Let the competition face that dilemma."

3.1.4.3 CAB (as reported in the Journal of Air Law and Commerce, 1964) Ref. 14.

"The cruising speed for the United States SST is to be Mach 2.2 or faster.

The cruising speed of the SST will have two primary economic effects: first, as it affects the revenue producing capacity of the plane in competition with

foreign SST's and/or subsonic aircraft; second, on the cost side.

Cruising speed as such is of some value to the traveler since normally he prefers a shorter flight to a longer one between the same two points. However, particularly for the person traveling for pleasure or personal business, the monetary value for each elapsed hour in flight is not very high. For example, if a flight that takes six hours by subsonic jet can be accomplished in two and a half hours in a supersonic transport, some price differential can be charged because of the saving of three and a half hours. However, the percentage differential in total time elapsed to the traveller is considerably less than this would seem to indicate; to the actual time in the plane must be added the time to get from the point of departure to the airport, ticketing, boarding, allowances for delays in order not to miss the flight, and at the terminal airport, collecting the baggage, and getting transportation to the ultimate destination from the airport. We are hopeful there will be parallel improvements in this area.

A United States built SST designed to cruise at Mach 2.2 will probably match or better the speed objective set for the British-French Concorde. The two versions will probably have comparable lift/drag factors. The ability of the United States built transport to exceed Mach 2.2 will be related to more powerful fanjet engines yet to be developed. The cost of acquiring the additional thrust in the price of the aircraft and reduced payload because of added fuel requirements must be carefully weighed along with other potential economic trade-offs evaluated during design of powerplants."

3.1.4.4 IFALPA, July 1963, Ref. 9

" A new datum speed may be required for the calculation of operational speeds such as V_{mu}, V_{ref}, etc., as stall speeds may no longer be a significant factor if delta wing plan forms are adopted.

NOTE: The formulae used are of less significance than the achievement of safety and aircraft handling characteristics which are no less critical than those of sub-sonic aircraft."

3.1.4.5 ALPA, April 1961, Ref. 16

"6. Maintain Lowest Possible Stalling and Manoeuvring Speeds

Economic incentive has formerly been used as a reason for utilizing increased stall speed instead of establishing a stall speed limitation. In the supersonic transport airplane the thrust requirements for transition to supersonic flight should provide sufficient power which together with the latest developments in aerodynamic refinements could keep take-off and landing speeds and runway lengths comparable to existing subsonic airplanes. Every effort should be made to ensure that this is achieved. The economic aspects of runway length for stopping distance, time elements for pilot action and airplane controllability and manoeuvrability are all important factors dictating the need for no increase in stalling, take-off or touchdown speeds."

3.1.4.6 NAA, April 1963, Ref. 17

"One design requirement related to the vehicle's performance characteristics which applies during several segments of the SST mission is that of establishing the limit speed. Current criteria establish two ways of relating the limit speed to the maximum operating speed. One arbitrary criterion is that limit speed be 125 per cent of the maximum operating speed. The second, an upset criterion, specifies that the aircraft be flown for 20 seconds along a flight path 7.5 degrees below the initial flight path, holding power as required for the maximum operating speed. A pull-up and reduction of thrust are then initiated."

"It is clear that considerable attention must be given to this problem to avoid large weight penalties. Consideration might be given to various automatically controlled devices such as speed brakes to increase the drag or engine inlet controls to reduce the thrust as the speed increases above the maximum operating speed. An even better solution would be the development of an inlet whose basic characteristics would include a reduction in thrust as the Mach number increased above its design value."

3.1.4.7 ICAO, June 1962, Ref. 11

"Off-Design or Low Speed Performance

61. The major problem in the field of performance is that of combining economical cruising performance with satisfactory low speed performance associated with off-design operation, such as take-off, approach, landing, and holding in the traffic pattern. Problems associated with control and stability at low speeds have already been mentioned (see para. 52), but it is difficult to see how the low speeds required to ensure compatibility with subsonic aeroplanes, when operating in the same environment, can be achieved without the use of some form of variable wing geometry. Any increase at all in the approach and landing speeds now associated with subsonic jet aeroplanes, will be viewed with disfavor by operators, pilots, and air traffic control and airport authorities. Furthermore, it has been pointed out that while runway lengths will not exceed the figure of 3,200 metres (10,500 feet), in standard atmosphere conditions at sea level that is accepted as a satisfactory limit for subsonic jet aeroplanes in many places, there are important international airports where it may not be practicable to provide runway lengths greater than 2,440 metres (8.000 feet).

62. In spite of the design penalties associated with restrictions in take-off, approach and landing speeds, and in runway lengths, it will be imperative for manufacturers to observe such restrictions, even if they can only be achieved by the adoption of radical aerodynamic design measures such as the use of wings with variable sweep back. Such measures, of course, will also improve the slow-speed handling characteristics of the aeroplanes."

3.1.5 FLYING QUALITIES (Also see Flight Control, Paragraph 3.8.2)

3.1.5.1 FAA RFP, August 1963, Ref. 8

"Flying qualities of the supersonic transport shall be equal to or better than those of current subsonic jet transports used in international service.

In the event of stability augmentation failure, the aircraft shall be capable of being controlled by the pilot for safe completion of the flight.

The aircraft shall be capable of being operated by regular airline jet flight airmen."

3.1.5.2 ALPA, April 1961, Ref. 16

"Problems associated with sonic boom, traffic control, compatible aerodromes, etc. would appear to dictate that any supersonic transport airplane will spend a substantial portion of its total flight time in the transonic and subsonic regimes. It is, therefore, essential that flight capabilities in these regimes be equal to or better than those of our present turbine-powered transports. Performance should exceed those of our existing transports, in take-off, climb, descent, approach, landing and in all stopping regimes."

3.1.5.3 IFALPA, July 1963, Ref. 9

"If a variable geometry wing is adopted for the SST, the Federation requires that the problems of possible asymmetry be designed out of the aircraft by fail-safe or other acceptable techniques and that this requirement be satisfactorily demonstrated to IFALPA before any operations commence."

"The problems arising from such new areas as:

i Radically new wing shapes;
ii Unusual $C_l C_d$ ratios;
iii High angles of attack during approach, landing and take-off;
iv Large C of G movements in flight;
v Large C of P movements in flight;
vi Variable geometry wings.

should all be demonstrated to have been satisfactorily solved before the aircraft is introduced into service."

3.1.5.4 ICAO, June 1962, Ref. 11

"52. For maximum economy at cruising speed trim drag of the aeroplane must be as low as possible. Unfortunately this requirement conflicts with the need for satisfactory stability characteristics at subsonic speeds. The determination of the best compromise between these two requirements is one of the biggest problems involved in the aerodynamic design of the supersonic aeroplane. Research work performed to date, as well as flight experience with supersonic military aeroplanes, leads to the conclusion that supersonic transports will have to be designed so that the handling characteristics over the entire flight envelope will be just acceptable, and augmentation of the controls about each axis will be used to provide the qualities that are really desired. An erudite discussion of stability and control problems would be inappropriate in this paper. However, it is worth mentioning that supersonic aircraft are characterized by an increase in longitudinal stability and a decrease in directional stability in going from subsonic to supersonic speeds. These characteristics, combined with the high relative density and greatly differing mass distributions, produce handling qualities significantly different from those of present jet transports. As a result, automatic damping about all three axis will probably be required. There exists a critical need for development of configurations with fail-safe characteristics so that in emergency they can be flown without automatic damping."

3.1.5.5 FAA, March 1961, Ref. 18

"12. Maneuvering capability.

At subsonic speeds, the turning capability of the supersonic transport should be close to that of present jets. Above Mach 1.0, however, the aircraft maneuverability decreases rapidly with speed. Figure 5a indicates the general relationship of the speed and bank angle at both Mach 2 and Mach 3 to the turning radius. Also, included are the time and distance required to execute a change of heading of 30° using a 45° bank, a severe maneuver from the standpoint of passengers. At Mach 3 an aircraft in this maneuver would subject its occupants to 1.4g for over 45 seconds during which the aircraft would traverse some 22.5 nautical miles. A normal airline-type turn (15° ban) at Mach 3 would require a radius of

162 nautical miles and would take 1.4 minutes to complete the 30° heading change.

The limited maneuverability of the supersonic transport at cruising speed will have to be taken into account in establishing routing and air traffic practices and also to some extent in meteorological work.

13. Slow down.

Figure 5b indicates the distance and time required to reduce speed in supersonic flight. A supersonic transport at Mach 3 travels at a velocity close to 3000 feet per second. At a constant altitude, a uniform deceleration of 0.2g (6.4 fps) would reduce the speed to Mach 2 in about 2.5 minutes and the aircraft would cover a distance of about 60 nautical miles. An additional 2.5 minutes and 37 nautical miles would be required to reduce the speed to Mach 1.0. If the aircraft is descending during the maneuver, the decelerating ability must be greater than 0.2g to maintain the above values. Generally, a substantial reduction in speed will be accompanied by a reduction in altitude. Further the consequences of thermal shock on engine components may dictate gradual reductions in power, except in emergency. Emergency procedures may be circumscribed by some of these limitations."

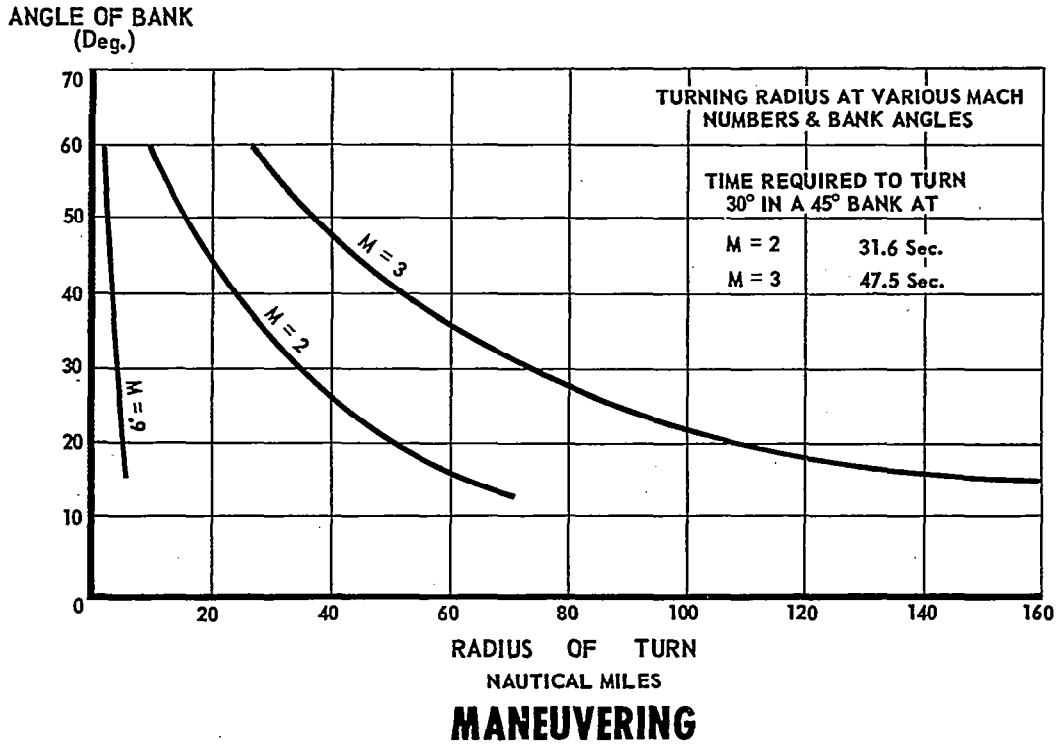


Figure 5a. Maneuvering (taken from ref. 18)

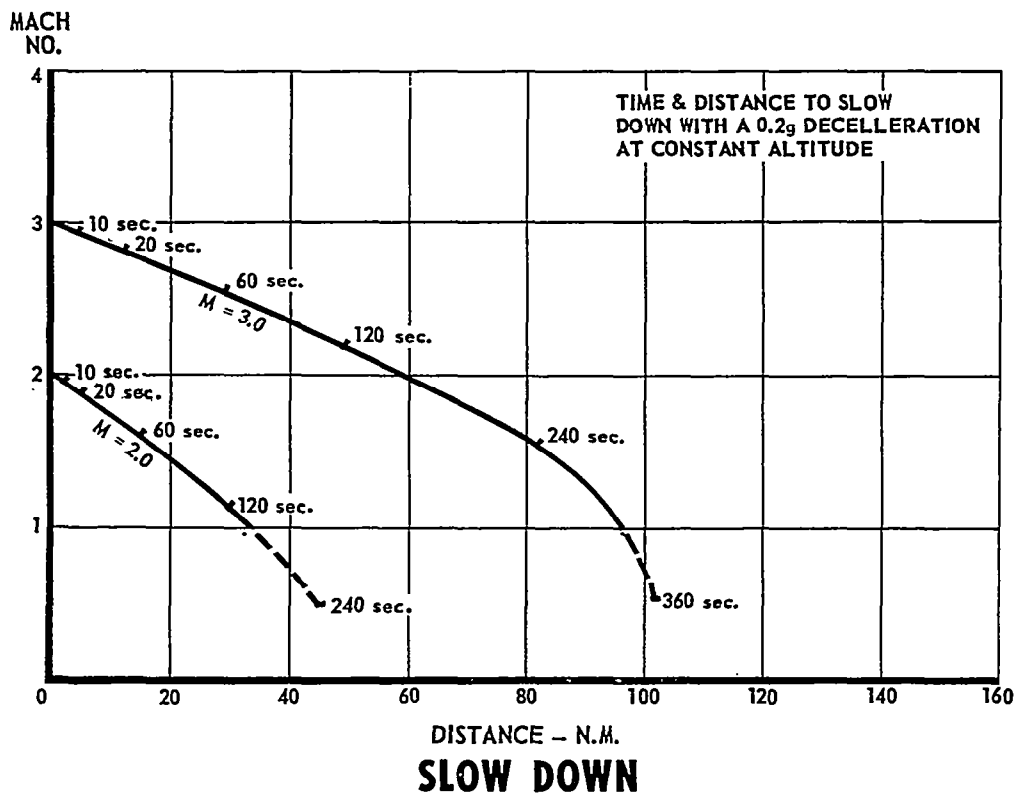


Figure 5b. Slow Down. (taken from ref. 18)

3.1.6 ANALYSIS AND COMMENTS

3.1.6.1 ANALYSIS -- (3.1.2 Payload)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training				X
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.1.6.2 COMMENTS -- (3.1.2 Payload)

3.1.6.2.1 Payload in the SST is a factor which will have little effect on the crew role. The payload of the SST will actually be smaller than that of current day aircraft, even though the gross weight of the proposed aircraft is larger. (See para. 3.1.2.2.) The new powerplants which will be utilized have much higher thrust to weight ratios than today's aircraft, which should relieve any crew anxieties about an underpowered aircraft.

The pilot will have to be more precise in his flight planning and flight management, so that loss of payload due to inefficient management will not make operation of the SST an economic unreality.

3.1.6.3 ANALYSIS -- (3.1.3 Range)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications	X			
Composition	X			
Training	X			
OPERATIONAL VARIABLES				
Responsibility	X			
Authority	X			
Acceptance	X			
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.1.6.4 COMMENTS -- (3.1.3 Range)

3.1.6.4.1 The range of the SST should not introduce any factors which will adversely affect the role of the crew. The distances proposed are similar to today's operations, and thus those things which are problem areas today, i.e. diurnal variation, and rate of fatigue, will continue into SST operations. It appears that because of the time differentials which can be anticipated with the advent of SST operations, the above

mentioned problems could be alleviated to some extent. Therefore, this area should be explored so that the optimum utilization of the crew can be attained.

3.1.6.5 ANALYSIS -- (3.1.4 Speed)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications			X	3.1.6.6.1			
Composition	X						
Training			X	3.1.6.6.1			
OPERATIONAL VARIABLES							
Responsibility					X	3.1.6.6.1	
Authority	X						
Acceptance					X	3.1.6.6.1	
FLIGHT DECK DESIGN							
Layout			X	3.1.6.6.2			
Instrumentation			X	3.1.6.6.2			
Controls			X	3.1.6.6.2			

3.1.6.6 COMMENTS -- (3.1.4 Speed)

3.1.6.6.1 At M=3.0 the normal reaction time to an event might be too slow to correct an imminent malfunction in the SST. Therefore, much work is going to have to be conducted to study which systems will have to be automated because of this slow human factor. Present systems will have to be evaluated to see if the reaction time of the human link is sufficient to cope with any foreseeable occurrence. It appears that

the human element will have to be drawn from that group of personnel possessing both youthful reaction times, and vast amounts of practical subsonic flight experience.

High speed will also introduce new aerodynamic characteristics which will have to be experienced by the crew, and proper training initiated so that the crew will not revert to "unsafe" subsonic procedures. Much of this training can be accomplished through an adequate simulation program. The responsibility of managing an aircraft capable of M=3 speeds will be unique to SST crews and their final acceptance of this role will be critical.

3.1.6.6.1 Supersonic speeds may necessitate automated systems which in turn will require new instrumentation. These new instruments will have to be designed to display the information needed by the crew to perform efficiently. It appears that the crew's role may be primarily acting as a monitor, with the capability of manual override in the case of emergencies. This will mean that extensive training will be required to transition from present day operations to the future SST flights, and that careful consideration must be given to design of the monitoring instrumentation to make it acceptable to the crew.

3.1.6.7 ANALYSIS -- (3.1.5 Flying Qualities)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications	X			
Composition	X			
Training	X 3.1.6.8.1			
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.1.6.8 COMMENTS -- (3.1.5 Flying Qualities)

3.1.6.8.1 The flying qualities which are due to the factors of speed and distance will incorporate advances in many areas to cope with the increased complexity of the entire system. As sonic flight differed from subsonic flight, so will supersonic flight introduce new pilot and crew techniques. Empirical studies in the XB70 should reveal any unique flight characteristics, and should assist in setting up supersonic flight procedures.

The automated systems will have to undergo extensive reliability tests, so that they will be readily accepted by the current pilots and crews. This in turn will require extensive training both in the simulator and in the actual aircraft for emergency and non-routine situations.

Any variable geometry configurations which are new will also require training but should not be radically new concepts to the crew.

3.2 NOISE

3.2.1 GENERAL

3.2.1.1 FAA RFP, August 1963, Ref. 8

"Compliance with these requirements (paragraphs 2.6.1 through 2.6.3 of the RFP which apply to "noise")* shall not necessitate unde· maneuvering or critical speed limiting maneuvers."

3.2.1.2 CAB (as reported in the Journal of Air Law and Commerce, 1964) Ref. 14

"Noise -- In addition to sonic boom, the RFP also calls for limitations on takeoff noise, landing noise, and ground noise. These, in a manner similar to sonic boom problems near the airport, could be limiting on the use and economic results of the SST. If noise is greater there may be more limitations placed on the SST than on our present jets."

3.2.1.3 IFALPA, July 1963, Ref. 9

"The SST must not prove itself such a nuisance to the public that the pilot in command is prevented from operating the aircraft according to the optimum procedure."

3.2.1.4 ICAO, August 1960, Ref. 10

"Since considerable aerodynamic noise can originate from such concepts as variable geometry cockpits and from detailed considerations of windshield and door design, it is recommended that airframe manufacturers should pay particular attention to this matter."

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* parenthetic insertion ours

3.2.1.5 FEIA, August 1963, Ref. 15

"Section 2.5 - Sonic Boom Overpressures
Section 2.6 - Noise
Section 2.61 - Takeoff Noise
Section 2.62 - Landing Noise
Section 2.63 - Ground Noise

The subject under discussion in these parts of the Draft Proposal represent one of the most controversial areas that must be considered when planning supersonic operation. We recognize and are in sympathy with the problems of the citizens living in communities around the airports and those who work on the airports. However, we believe that some of the current noise abatement procedures are on the ragged edge of safety and we therefore urge that this new aircraft be designed in such a manner that current noise abatement procedures can be eliminated and that it not be designed on the basis of using these procedures as the norm. The safety of those disturbed by the noise, as well as the passengers and crewmembers, has the first priority."

3.2.2 SONIC BOOM

3.2.2.1 FAA RFP, August 1963, Ref.8

". . . It is essential, however, that the aircraft not exceed the levels of sonic boom overpressures delineated in the RFP and that noise created by the transport on and in the vicinity of airports be kept at the levels stated as objectives. Overpressures and noise levels lower than those stipulated are desirable and manufacturers should strive to achieve lower levels to the extent that this may prove feasible."

"SONIC BOOM OVERPRESSURES

a. Maximum overpressure, during acceleration to supersonic cruise speeds, less than two pounds per square foot.

b. Maximum cruise and deceleration overpressures of 1.5 pounds per square foot.

c. Sonic boom overpressure predictions shall be based on the latest techniques available from the National Aeronautics and Space Administration. Sonic boom overpressure calculations shall be based on a standard atmospheric condition, zero wind gradient, a reflectivity factor of 1.9 and the assumption that the aircraft is not engaged in a maneuver."

3.2.2.2 IATA, June 1962, Ref. 12

"Economic operations at supersonic speed must be practicable over inhabited areas at any time of the day or night. Sonic boom could prevent this unless the aircraft is designed to permit practical and economic operating procedures for its alleviation."

3.2.2.3 CAB (as reported in the Journal of Air Law and Commerce, 1964), Ref. 14.

"The RFP calls for a maximum overpressure during acceleration to supersonic cruise speeds at less than two pounds per square foot, and overpressure at maximum cruise and deceleration at one and a half pounds per square foot.

Excessive sonic boom, if the design of the SST did not prevent it, could provide a practical veto over the economic use of the aircraft.

In cruising, the sonic boom spreads out in a wide path beneath the aircraft. If this shock wave were excessive, and if the public reaction is such as to prohibit flights over certain portions of this country, practical flight paths across the country would be impossible, and detours over uninhabited or water areas would be so widely circuitous as to make the flight extremely uneconomic in mileage traversed as well as the additional time taken which would reduce the time advantage of the SST.

At airports, the sonic boom over the approach paths would also have to conform to local authority problems on sonic boom and community reactions. If these were too restrictive, it might be impossible to get an SST in and out of many airports. In addition, foreign countries might likewise restrict or prohibit SST."

3.2.2.4 ICAO, June 1962, Ref. 11

"Sonic Boom

92. Work has continued in those States directly interested in possible development of supersonic transport aeroplanes, to obtain more information about the magnitude of the sonic boom; both theoretical investigations and flight tests with supersonic military aeroplanes are being made. In the United States in particular, a comprehensive test programme has been undertaken, aimed at determining the magnitude of the pressure change associated with the shock-waves, the effects on ground installations and on other aeroplanes, and the reaction of the public. While data are still being studied and a report of the tests has not yet been issued, it is known that ground measurements indicate that supersonic flight at altitudes of 15,250 metres (50,000 feet) may induce pressure pulses of the order of 7.32 kg. per square metre (1-1/2 lb per square foot). It cannot be stated yet just what figure would be acceptable to the public but it will obviously have to be greater than the figure of 4.88 kg. per square metre (1 lb per square foot), suggested in the Preliminary Study, unless the supersonic aeroplanes are to be prohibited from flying over populated areas. Operation at supersonic speeds below 12,200 metres (40,000 feet) will be out of the question.

93. In connection with the figure quoted for pressure pulses at ground level, it has been pointed out that the explanation of the sonic boom given in the Preliminary Study, which was necessarily rather brief and of a general nature, did not indicate that the pressures at ground level that affect people and structures on the ground, include a reflectivity factor of the order of 2; that is, they are about twice the pressures in the air at the same distance from the aeroplane. The reference to reflectivity in para. 91 of the Preliminary Study, which unfortunately could give the impression that the reflecting characteristics of the ground are negligible, was based on the view that it was not necessary to discuss the reflectivity factor because it was accurate enough to regard it as constant.

94. Flight tests have been made to determine the effects of shock-waves on other aircraft. These tests involved passing manoeuvres at various altitudes at various passing rates, and with separation distance varying

from 30 to 150 metres (100 to 500 feet). The conclusion reached is that the shock-waves from a supersonic aeroplane passing another aeroplane present no control or structural problems to aeroplanes in flight or on the ground, except when a supersonic aeroplane passes another supersonic aeroplane at close proximity and the passing rate is near the natural period of the aeroplane being passed. A supersonic transport should experience no difficulty nor cause any concern to any other aeroplanes, if normal separation distances are maintained.

95. An important aspect of both theoretical and flight investigations of the sonic boom is the effect of various manoeuvre and flight path angles on the intensity of the boom. Some types of manoeuvres reduce the intensity of the boom, and others may create "super" booms by the focusing effect that occurs as a result of the shock-waves generated at two or more points along the flight path arriving simultaneously at the same point on the ground. It is hoped that the tests on these aspects will help in the development of operational procedures to minimize boom intensity.

96. In the Preliminary Study (para. 91), it was stated that the magnitude of the pressure rise determined by experiments had been reasonably consistent with that calculated by theoretical methods. At that time flight testing had been performed with relatively small aeroplanes, flying at relatively low supersonic speeds, and at relatively low altitudes. The shock-waves and resultant pressure changes were due almost entirely to the geometry of the aeroplane, and it had been tacitly assumed in most quarters that the pressure rise due to lift could be ignored. Subsequently analyses of the problem have shown that lift effects cannot be neglected for supersonic aeroplanes as large as the civil transport types are expected to be, particularly as the relative importance of this effect is greater at the higher cruising altitudes that will be used by these aeroplanes. One theoretical investigation showed that lift will be the dominant factor in the shock-noise of most aeroplanes at higher altitudes and will also be the dominant factor over most of the altitude range for large aeroplanes. This is mentioned here because the way in which the boom intensity due to lift combines with that due to volume to produce the resultant boom intensity, varies with the configuration of the aeroplane as well as with the altitude. It has, therefore, been suggested that the total

intensity of the sonic boom may be reduced by so designing the aeroplane that the volume and lift effects partially cancel each other out. Theoretically, it would seem possible to produce a substantial reduction in pressure rise in this way, but whether this can be done without incurring design penalties in other directions, so serious as to make it not worthwhile, remains to be seen.

97. There is no doubt that the sonic boom is one of the greatest problems, if not the greatest problem, associated with the introduction of civil transport aeroplanes. It cannot yet be judged what intensity of boom will be acceptable to the public on the ground. The intensity must obviously not be great enough to cause any damage to property and consideration will have to be given to its effects on animal life as well as to disturbance of or annoyance to humans. If the intensity is to be kept so low as not to awaken light sleepers in normal housing in areas being overflown, as has been suggested by some authorities, then the conclusion of these authorities that civil supersonic aviation, in its presently suggested form (see para. 86), will not be feasible, must be accepted. It is not likely, however, that such a low intensity will be insisted upon. The best information now available is that the intensity of the pressure pulses will be of the order quoted in para. 92. It is reasonable to conclude that the sonic boom will not prove to be an unsurmountable obstacle to the introduction of the civil supersonic transport aeroplane; it is, however, expected to be the cause of restrictions on operational procedures. There is a need for international cooperation and collaboration in dealing with the problem of the sonic boom, for the same basic reasons as apply to engine noise (see para. 91). It has been suggested that not only the solution to the problem, but the cost involved, should be established internationally."

3.2.3 AIRPORT VICINITY

3.2.3.1 FAA RFP, August 1963, Ref. 8

"Take-Off Noise

Noise resulting from take-off operations shall be less than 112 Pndb at a point on the ground one statute mile from the departure end of the runway, on a line which

is an extension of the center line of the runway, for any gross take-off weight. (Assume a 10,500 foot runway and standard day)

Landing Noise

Noise from landing operations shall be less objectionable than that resulting from operation of current subsonic jets used in international service. Compliance with this objective does not contemplate a glide slope higher than approximately 3°.

Ground Noise

Noise resulting from ground operations shall be reduced to a level tolerable to the average traveler and airport employee."

3.2.3.2 FAA, (Statement of Work for Boeing & Lockheed Contracts), SST Design Refinement Program, June 1964

". . . the Contractor shall demonstrate to the satisfaction of the Government on or before November 1, 1964, that the Contractor can develop and produce a commercial supersonic transport clearly meeting, to the extent practicable, all of the design objective set forth below.

C. Maximum airport community noise levels as follows:

(1) On runway -- 118 PNdb 1,500 feet from center line of runway.

(2) 108 PNdb at point three miles from initiation of takeoff roll.

(3) Approach -- 118 PNdb 1 mile from runway threshold."

3.2.3.3 IATA, June 1962, Ref. 12

"No increase in the level of engine noise can be tolerated. In fact, engine noise from the SST must be lower than that of subsonic jets operating at present in order to permit round-the-clock operations."

3.2.3.4 IATA, May 1964, Ref. 13

"From the information available at the present time, it would appear that all manufacturers will not be able to meet the requirement that the level of SST engine noise must be low enough to permit round-the-clock operations. Any economic evaluation without clarification of this situation would be of doubtful value."

3.2.3.5 FAA, March 1961, Ref. 18

"Airports (CAR 40.33)

The operational aspects of the supersonic transport may prove more objectionable from the noise standpoint than subsonic aircraft due to anticipated increase of engine thrust. Present indications are that the public would vigorously oppose any increase in the airport noise level associated with the introduction of the supersonic aircraft. The FAA has issued a publication on this subject (Reference 9)."

3.2.3.6 ICAO, June 1962, Ref. 11

"Engine Noise

90. Experience with subsonic jet aeroplanes during the last two years emphasizes the importance of restricting the noise associated with the introduction of supersonic aeroplanes to levels that will be acceptable to communities in the neighborhood of airports. Operating restrictions, either on the time of day at which operation is permitted or on take-off procedures, are still being imposed at a number of important airports and are matters of concern to airlines and their pilots. It would not be wise to assume that communities will accept any increase in the present level of noise when supersonic aeroplanes are introduced into service. It is more likely that a reduction in the present level will be required, particularly when account is taken of increasing movement rates. In other words the acceptable level of noise may prove to be less than an overall sound pressure

level of 97dB (112 PNdB) recorded in the Preliminary Study (para. 38) as having been accepted at a number of airports for the operation of subsonic jet aeroplanes. The limitations quoted relate to the nearest main built-up areas under the take-off and approach flight paths, and it has been suggested that in future it will also be necessary to give consideration to noise levels behind the aircraft, to the side of the runway, and under the take-off and approach flight paths between the airport and the nearest main built-up areas.

91. Research and development work is still proceeding with a view to learning more about the nature and source of the noise, the best way to measure it from the point of view of its effect on the public, and the design measures needed to reduce noise as much as possible at its source, with the minimum economic penalty arising from the consequent reduction in power and in thrust. However successful this work may be it will still be necessary to adopt for the supersonic aeroplane, operating procedures specifically developed to reduce the noise level in communities near airports. It is important that these procedures do not impose an economic penalty on the operation of the aeroplanes and do not lead to any reduction in the level of safety. It has been suggested that international cooperation and collaboration is necessary to avoid wasteful duplication of effort, to ensure dissemination of the information obtained, and to obtain agreement on acceptable levels of noise. In particular, the opinion has been expressed that an exchange of views should be sponsored by ICAO between Contracting States, on the levels which can be regarded as acceptable, both by day and by night, within an envelope around the runway of defined dimensions, taking account of the movement rates likely to obtain in the next 10-15 years and of the noise levels likely then to be achieved by subsonic aircraft. The suppression of noise created during ground maintenance should also be considered."

3.2.3.7 AAAE, August 1964, (Private Communication)

"Whether this is germane to your studies I do not know, but I do mention that the pilots' position is that special flight procedures and techniques used in operating present sub-sonic jets at certain airports to alleviate, to a degree, the aircraft noise

problem do impose additional requirements and perhaps strain on members of jet crews. For this reason we believe that the SST should not depend on power reductions, or excessive maneuvering immediately after take-off in order to bring the aircraft noise down to level acceptable to those living in the airport vicinity.

Our position is that now in the design stage the aircraft be made sufficiently less objectionable noise-wise to make it unnecessary to resort to special patterns or techniques for noise abatement purposes."

3.2.3.8 AOC, August 1964, Private Communication:

This statement is our interpretation of a telephone conversation with the Executive Director of AOC.

"The manufacturers say that the SST is going to be capable of a high ascent angle and rate which they say will produce an acceptable level of noise near the airports. They both (Boeing and Lockheed), however, are considering power cutbacks on takeoff in order to achieve an acceptable level. AOC doesn't say whether this is good or bad. AOC just says the airplane should be capable of operating safely in such a manner that it will produce an acceptable noise level.

Landing -- Manufacturers seem to be working on a 2.5-3.0° glide slope. AOC thinks it's questionable that they will be able to build an airplane acceptable from the noise standpoint operating at present glide slope angles. AOC's recommendation is to make the aircraft capable of higher descent angles, unless they can produce a better airplane at lower descent angles.

The Airport Operators feel that a single level of PNDB should be applicable at the same point on takeoff and landing. Under the FAA RFP they had a 10 PNDB differential for takeoff and landing at the same distance from the end of the runway. AOC feels that the person who lives at that distance doesn't give a darn whether the aircraft is taking off or landing. With respect to what that level should be, AOC thinks it should be considerably less than 118 which the FAA is now using as the figure for approach noise during landing. FAA uses 108 for takeoff at the same place. AOC stresses that they are not advocating that the pilots do anything unsafe but rather that the aircraft should be designed

so that it can be operated safely and yet not produce unacceptable noise levels near the airports."

3.2.3.9 City of Los Angeles, Board of Airport Commissions Resolution No. 2059,[1] September 1963

"NOW, THEREFORE, BE IT RESOLVED that the Board of Airport Commissioners of the City of Los Angeles does hereby urge and request that those in a position of authority and policy decision on the development of the supersonic transport direct their efforts so that this new family of supersonic aircraft will:

3. Produce sound levels under the approach and departure flight paths of the airports that are less than the current jet subsonic transports

4. Produce sound levels within the airport environment from flight operations, ground and maintenance operations that are compatible with the comfort, health, and welfare requirements of all persons within this area. This includes air terminal areas, parking lots and maintenance areas.

BE IT FURTHER RESOLVED that this Commission will place operating restrictions on supersonic transport operations at Los Angeles International Airport which will control the noise levels from this aircraft unless the following operating sound levels are achieved in the aircraft design:

1. Take-off sound levels parallel to the runway at a measurement distance of 1400 feet parallel to the runway centerline shall not exceed 120 perceived noise decibels (Pndb.)

2. The take-off sound level shall not exceed 112 Pndb. at a point on the ground three miles from the start of the take-off roll on a line which is a prolongation of the centerline of the runway.

3. Approach sound levels shall not exceed 120 Pndb. at a point on the ground 4000 feet from the landing threshold of the runway; and"

[1] These levels are understood to be those accepted by AOC. AOC is currently engaged in compiling data relevant to the final standards.

3.2.4 CABIN

3.2.4.1 FAA RFP, August 1963, Ref. 8

"The inflight cabin noise shall be as acceptable to passengers and crew as in current subsonic jets."

3.2.4.2 ICAO, August 1960, Ref. 10

"One problem that has not yet been mentioned is that of boundary-layer noise. For present subsonic jet transports, the boundary-layer noise is mainly of concern from the standpoint of passenger comfort and, as a result, several thousand pounds of sound treatment material are needed in the fuselage. On supersonic transports the boundary-layer noise pressures will be higher and will be of concern not only from the standpoint of passenger comfort, but also because of possible noise induced damage to the skin structure of the aeroplane."

3.2.5 ANALYSIS AND COMMENTS

3.2.5.1 ANALYSIS -- (3.2.2 Sonic Boom)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training	X	3.2.5.2.1					
OPERATIONAL VARIABLES							
Responsibility					X	3.2.5.2.1	
Authority			X	3.2.5.2.1			
Acceptance			X	3.2.5.2.1			
FLIGHT DECK DESIGN							
Layout							X
Instrumentation					X	3.2.5.2.2	
Controls							X

3.2.5.2 COMMENTS -- (3.2.2 Sonic Boom)

3.2.5.2.1 Minimization of sonic boom is one of the constraints placed on the SST. The main approach to the control of the sonic boom depends upon a precise flight profile which has compensated for the aircraft configuration and meteorological conditions. Therefore, the crew must be able to accept the added work load placed on them by such precision. The training involved to manually fly the flight profile will be demanding even

if the primary mode of control is automatic. This will also increase the pilot's responsibility in the overall conduct of the flight. The flight path to minimize sonic boom may also cause the adoption of flight procedures which will not be liked by the crew because of their marginal characteristics.

3.2.5.2.2 New instrumentation would probably need to be introduced so that the crew would be able to operate within the precision requirements necessary to minimize sonic boom. Any new instrumentation development must take careful cognizance of the crew workload. Methods will have to be devised to combine present and proposed instruments, and then to have extensive simulation done to see if crews will be able to adapt to their new presentations.

3.2.5.3 ANALYSIS -- (3.2.3 Airport Vicinity)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X	3.2.5.4.1					
Composition							X
Training	X	3.2.5.4.1					
OPERATIONAL VARIABLES							
Responsibility	X						
Authority	X						
Acceptance	X						
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.2.5.4 COMMENTS -- (3.2.5 Airport Vicinity)

3.2.5.4.1 At this time it is not anticipated that noise abatement procedures in the vicinity of the airport will change radically from present operating procedures. However, present standards, for example those in existence at J. F. Kennedy Airport in New York, may impose a serious limitation on SST operations and ultimately upon the crew by requiring that the SST be operated in a marginal safety range. The apparent

solution is a revision of present standards taking into consideration public tolerance (after adequate public education), and public safety. Noise abatement procedures undoubtedly increase crew work load and require greater pilot skill. Thrust reduction after take off, a current noise abatement procedure, should be acceptable to crews because of the SST's greater thrust.

3.2.5.5 ANALYSIS -- (3.2.4 Cabin)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training				X
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.2.5.6 COMMENTS -- (3.2.4 Cabin)

3.2.5.6.1 Although interior noise will be an associated problem of supersonic flight, it does not appear that any design difficulties will arise which will require that the crew and passengers tolerate any increased noise levels over today's standards.

3.3 COMPATABILITY WITH OTHER SYSTEMS AND FACILITIES

3.3.1 GENERAL

3.3.1.1 FAA RFP, August 1963, Ref. 8

"The aircraft shall possess such subsonic performance characteristics, maneuverability, handling qualities and speed control capability as to be compatible with airport take-off and landing traffic patterns and approach, departures and holding procedures utilized by subsonic jet transports used in international service. Consideration shall be given to improved traffic control procedures and equipment which will be in use in the 1970 period. (Reference: Federal Aviation Agency Report "Design for the National Airspace Utilization System Summary of First Edition," dated September 1962)."

3.3.1.2 ICAO, June 1962, Ref. 11

"When flying at subsonic speeds the supersonic aeroplane will usually be in the same environment as subsonic aeroplanes. There has been complete agreement with the principle enunciated in the Report of the Council on the Preliminary Study, that when operating in the same environment the supersonic aeroplane must be compatible with subsonic aircraft. The importance of this objective cannot be overemphasized. The steps required to achieve it represent one of a number of areas requiring international cooperation and collaboration, through ICAO as regards problems within its purview, through IATA where appropriate, and between manufacturing countries. There is also a need within each State to coordinate action by all interested parties, and this is being done in a number of States including the States that are seriously considering the development of supersonic transport aeroplanes."

3.3.1.3 ICAO, August 1960, Ref. 10

"There is complete agreement among Contracting States that the supersonic aeroplane should be so

designed that it could use existing airports that are adequate for use by the large subsonic jet aeroplanes now being introduced into service. The large quantity of data obtained emphasizes the technical difficulties and the economic burden that would result in many places if runways had to be lengthened or strengthened to make them suitable for use by supersonic aeroplanes. The provision of separate airports for the supersonic aeroplanes would, in general, involve many technical difficulties as well as enormous expense. For some large cities it would not be possible to obtain the required land sufficiently near the city to enable a new effective airport to be constructed.

The performance of the aeroplane in take-off and landing determines the length of runways required. Its maximum weight and design of landing gear determine the strength of pavements needed; its approach speed determines whether it can fit into the traffic pattern associated with an existing airport. The noise from its engines determines whether its operation will be acceptable to communities in the neighbourhood of the airport. In this study it is assumed, on the basis of available information, that the characteristics of the aeroplane and the method of operating it can and will be such that it will be able to use existing airports that are adequate for the present generation of large subsonic jet aeroplanes."

3.3.1.4 IATA, June 1962, Ref. 12

"Runway length and strength requirements for the SST must be no greater than those for large subsonic jets operating at that time."

3.3.1.5 ALPA, April 1961, Ref. 16

"The pilots' experience is such that they believe the safety, operational and economic factors have reached the point where new airplanes must be required to have the capabilities of operating safely and efficiently from the same runway lengths (preferably less) as our present fleets of subsonic and transonic turbine-powered commercial transport airplanes."

3.3.1.6 IATA, June 1962, Ref. 12

"SST flight characteristics in the airport terminal area, such as speed, glide slope, and holding patterns, should permit its treatment as "just another aircraft" without undue penalty. The SST must be capable of mixing with other traffic in all weather."

3.3.1.7 IFALPA, July 1963, Ref. 9

"An SST aircraft on the ground, or in the air whilst operating in a subsonic condition, should be able at all times to manoeuvre without causing hindrance, undue delay or annoyance to other aircraft operating within the same airspace."

3.3.2 AIRPORTS

3.3.2.1 FAA, March 1961, Ref. 18

"The Federal Aviation Agency is on record as opposing continuing increases in runway length and the present FAA airport standard contains a 10,500 foot maximum sea level runway length. Further, the FAA standard airport obstacle clearance line is a slope of 1 in 50, or 2% gradient, extending approximately from the end of the runway.

The supersonic transport will apparently have several factors which will assist in improving the take-off flight path problem. First, it is anticipated that with the high thrust to weight ratio of the supersonic transport the takeoff distance need not exceed present values. Second, this same favorable ratio should provide a very good climb gradient even after the failure of one engine. Third, the increase in engine thrust values may result in greater jet noise and make it highly desirable that a rapid climb rate or climb angle be available.

With these factors in mind, it has been suggested that as a starting point for supersonic transport performance, the maximum runway length of 10,500 feet be maintained, and that the 1 in 50 obstacle clearance line mentioned above be established as the lower limit of the

net one-engine-inoperative flight path; i.e., that all points on the net takeoff flight path be above the 1 in 50 slope.

In contrast with the takeoff performance described above, the landing distance of the supersonic transport, because of higher landing speed, will probably be greater than that of present jet transports, and possibly will determine the field size. However, it is not anticipated that the supersonic transport will require approach path angles less than the present ILS glide slope angles of 2.5° to 3° (approximately 1 in 20). Hence the 1 in 50 obstacle clearance line described above should be adequate for landing."

3.3.2.2 FAA (in Aviation Week & Space Technology, July 1, 1963), P-33

"FAA studies indicate that the US supersonic transport will be capable of using about 150 airports in the nation, and will be able to operate profitably between 32 of the top 100 cities now receiving airline schedules."

3.3.2.4 ICAO, August 1960, Ref. 10

"It has been assumed that the supersonic aeroplane at maximum take-off weight will not require a runway longer than 3,050 metres (10,000 feet) under International Standard Atmosphere Conditions at sea-level. The general view is that a runway width of 45 metres (150 feet) will be required. This is the width recommended in Annex 14 for runways where the runway code letter is A, B, C, D or E. However, the opinion has been expressed that the width required will be 60 metres (200 feet).

The strength required by a runway depends both on the weight of the aeroplane and on the design of the landing gear. However, it is hardly practicable to quote a simple figure for an equivalent single wheel load or load classification number that could be used as a criterion at all airports, since this would depend not only on the landing gear (number and spacing of wheels, tire pressure) but also on the characteristics of the pavement itself (total thickness, whether the pavement is rigid or flexible, the physical characteristics of the concrete). It seems that it will be necessary, when

designing the aircraft, to study the strength of the runways at airports where large subsonic jet aeroplanes are being operated and to determine the design of the landing gear accordingly."

3.3.2.4 FAA, March 1961, Ref. 18

"The operational aspects of the supersonic transport may prove more objectionable from the noise standpoint than subsonic aircraft due to anticipated increase of engine thrust. Present indications are that the public would vigorously oppose any increase in the airport noise level associated with the introduction of the supersonic aircraft. The FAA has issued a publication on this subject.

Airport runway waviness and roughness, as well as landing gear configuration may become an important consideration, during takeoffs and landings at high speeds due to the anticipated long fuselage of the supersonic transport. This may cause objectionable vertical accelerations for the flight crew to the extent that it might interfere with proper reading of aircraft instruments. A review of runway smoothness and waviness standards may be necessary in view of the higher operational speeds.

In addition, the anticipated longer fuselage may require some rearrangement of terminal parking areas, together with possibly some modification to taxi strips especially at turnoffs. However, the present FAA standard airport runway length of 10,500 feet and width of 150 feet are considered adequate for operation of the supersonic transport.

Airports from which supersonic transports operate will be faced with increased noise problems, runway roughness and parking space requirements."

3.3.2.5 FAA RFP, August 1963, Ref. 8

"The supersonic transport shall have the capability of operating from airports currently used by the larger subsonic jet transports. FAA Circular No. AC 150/5320-8 "Airports" dated 4-5-63, contains paving design curves for dual tandem gear. Criteria for other gear configurations in terms of gross weight and pavement

thickness requirements shall be established in the Proposal.

The aircraft shall have the ability to operate on runways acceptable for the operation of subsonic transports used in international service."

3.3.2.6 ICAO, August 1960, Ref. 10

"Manufacturers' attention is drawn to the importance which airlines attach to the need for taking bearing strength capacities of runways into account if the SST is to be used world-wide. As things appear at the moment, proposed tire loadings may create problems at a number of airports around the world.

If the SST is to enjoy extensive international operations it must be capable of use at major airports all over the world. Consequently, while it is considered that the aircraft should have a minimum range capability of New York - Rome, the airlines feel manufacturers' attention should be drawn to the need for considering the characteristics of airports all over the world rather than airports in the North Atlantic region only.

The SST must not require changes which would involve expenditure on extending or strengthening runways at airports beyond what will be required for the subsonic jets."

3.3.2.7 ICAO, August 1960, Ref. 10

"It is not expected that it will be possible for the time needed for ground handling to be appreciably less than that needed for the large subsonic jet aeroplanes. Terminal buildings will probably need special sound insulation, particularly in the roof, and in the fingers (if any). If, as appears likely, passenger loads are of the same order as with subsonic jet aircraft, no special alterations in building layout seem necessary.

A considerable amount of work is being done at present to develop visual aids adequate to meet the requirements of subsonic jet aeroplanes during approach and landing. International agreement on suitable aids should be achieved well before supersonic aeroplanes are introduced. As it is assumed that the supersonic

aeroplanes will be designed with generally similar characteristics to the large subsonic jet aeroplanes so far as approach and landing is concerned, it is not anticipated that it will be necessary to develop new visual aids for the supersonic aeroplanes. The existing visual aids should be adequate when weather conditions permit manual landings to be made.

If possible, the turning circle of the supersonic aeroplane should be no larger than those of the current large subsonic jet aeroplanes. If the turning circles have to be larger, then existing curves on taxiways may have to be altered and more apron space provided. At some airports it may be impossible to do this. The aircraft may require more space on aprons than is provided at present, and the need for uninterrupted taxying from engine starting to take-off will assume even greater importance than for the subsonic jet aeroplanes. The selection of parking methods will largely determine requirements for apron stands and methods of guidance into and out of them.

It is assumed that after-burning will not be employed on or near the ground and no change in present requirements is anticipated so far as concerns the effect of blast and heat on pavements. However, the noise and blast generated by the engines will increase, and it is possible that special aprons will be required for supersonic aircraft and that the noise and blast effects on adjacent stands may be such as to require large distances between stands or to prohibit the aircraft from taxying under their own power. If they cannot taxi under their own power, delays will, of course, result.

It seems inevitable that there will be some problems related to the design of aprons and perhaps taxiways and that at some airports solution of these problems may be extremely difficult. However, in general, these problems are not likely to be so acute as to prevent suitable provision being made at existing airports."

3.3.2.8 ICAO, June 1962, Ref. 11

"It was pointed out in this Addendum that while a runway length of 3, 200 metres (10, 500 feet) in standard atmosphere conditions at sea level is accepted as a satisfactory limit for subsonic jet aeroplanes in many places, in some important international airports it may

not be practicable to provide runway lengths greater than 2,440 metres (8 000 feet). Addendum No. 1 to the Preliminary Study contains information on runways available at some airports throughout the world and on the difficulties that would be encountered in extending them. While these data are now more than two years old, they do indicate clearly the desirability not only of not exceeding the runway requirements of the subsonic jet aeroplanes, but preferably of being able to reduce such requirements, if the supersonic aeroplane is to be used most effectively throughout the world. It has since been suggested that it will be better for designers to aim at a maximum runway length requirement of 2,440 metres (8,000 feet) rather than 3,050 metres (10,000 feet), as assumed in the Preliminary Study.

Airport authorities have emphasized the importance of restricting the maximum single isolated wheel loading of the supersonic aeroplane to a value that would not require extensive reconstruction of existing runways. They have urged that aircraft designers discuss landing gear configuration, wheel spacing and tire pressures with them before deciding on the design of the landing gear. The indications have been that aircraft manufacturers were considering higher pavement loadings than airport authorities felt were acceptable.

The present subsonic jet aeroplanes are sensitive to runway roughness and require pavements to be constructed with smoothness within close tolerances. Closer tolerances would only be achieved at considerable additional cost and it is important that supersonic aeroplanes do not require this.

As stated in the Preliminary Study it is expected that supersonic transport aeroplanes will be equipped with the usual wheel brakes and thrust reversers. Tests have been made recently of ground-installed arresting devices to determine whether it would be practicable to use such devices in normal operations of transport aeroplanes. One particular scheme, in which a hook on the aeroplane engages the arresting gear and fluid-filled tapered tubes or some similar devices, installed alongside the runway are used for energy absorption, shows promise of being suitable for use with quite large transport aeroplanes. The possibility that arresting devices

will be used in normal operations of supersonic transport aeroplanes cannot be ruled out.

Studies of possible configurations of aeroplanes, indicate that the great fuselage length may be expected to increase the diameter of the ground manoeuvering envelope now required for subsonic jets by 50 to 100%. The increased turning radius will result in an increase of the radii of curves and turns on taxiways.

The concentrated blast from a number of engines, expected to be grouped closely together at a considerable height above the ground, will increase the difficulty of providing suitable blast fences where they are required.

Spacing between aeroplanes on the ground will need to be greater than with the subsonic jets, and blast, noise and fumes will have a greater influence on the design of terminal buildings and on the closeness to which the aeroplanes may approach the building.

One method that is being considered as a means of reducing the effect of turbulent wake on runway utilization is to alternate take-offs and landings whenever practicable."

3.3.2.9 FAA, March 1961, Ref. 18

"Consideration should be given to adverse operating conditions such as wet, ice coated, and snow covered runways. Because of the anticipated higher landing speeds of the supersonic transport when compared to the subsonic transport, these runway conditions will be more critical. Hence, barriers and overrun areas should be considered for abnormal braking conditions.

The 60 or 70 per cent landing distance factors are under review at this time as part of a more rational landing distance determination which will provide accountability for actual operating conditions."

3.3.2.10 City of Los Angeles, Board of Airport Commissioners, Resolution No. 2059[2], September 1963

"NOW, THEREFORE, BE IT RESOLVED that the Board of Airport Commissioners of the City of Los Angeles does hereby urge and request that those in a position of authority and policy decision on the development of the supersonic transport direct their efforts so that this new family of supersonic aircraft will:

1. Be able to operate from the existing and currently planned civil airports

2. Require no greater runway lengths and/or clear zones for landing and take-off than present subsonic jet transports"

3.3.2.11 FAA, (Statement of Work for Boeing & Lockheed Contracts), SST Design Refinement Program, June 1964

"d. The aircraft must be able to operate at maximum ramp weight from airports which can not (assumed to be "now")*accommodate the larger subsonic jets. The manufacturers will request verification from Airport Executives responsible for fifteen of the largest domestic airports that the proposed configuration would be acceptable from an airport compatibility standpoint. This will include verification that runways, taxiways, and parking aprons are adequate for the aircraft size proposed. . . ."

* parenthetic insertion ours

2 See Footnote 1 pg. 75

3.3.3 AIR TRAFFIC CONTROL

3.3.3.1 IFALPA, July 1963, Ref. 9

"The Federation believes that the ATC system for the SST should be supra-national in character, be positive, place no reliance on the "see and be seen" rule and be supported by a navigation system sufficiently accurate and a communications system sufficiently reliable to permit safe operation at the envisaged separation standards.

NOTE: (The above-stated requirement calls for revision of ICAO rules regarding IFR/VFR traffic procedures)."

3.3.3.2 ICAO, August 1960, Ref. 10

"It has been realized for some time that improved air traffic services are required to deal with the great increase in density and speed range of traffic that has taken place in recent years. The introduction of subsonic jet aeroplanes with somewhat different characteristics from those of the piston engined aeroplanes has accentuated this problem. More than one State is actively engaged in the development of substantial improvements in air traffic services, one important objective being to help the controller as much as possible by introducing semi-automatic processes for handling and printing ATC data. This will speed up the work of control by freeing the controller to concentrate largely on his essential function of making decisions.

Present plans provide for a substantial increase in use of radar for air traffic control purposes, including the use of secondary radar which will cover the altitudes that will be used by supersonic aircraft. It is expected that complete surveillance will be realized in the first instance in terminal areas, coverage being extended progressively thereafter as required to en-route areas over land. Means for displaying radar information derived from facilities remote from control centres are being produced.

These developments are being planned to cater for the increase in traffic now encountered no less than to meet the needs of subsonic jet aeroplanes, and the improved systems should be functioning smoothly before 1970 in areas where the traffic is heavy. In the altitudes now traversed by subsonic jet aeroplanes the supersonic aeroplane is expected to fly at subsonic speeds, and it has already been emphasized that its characteristics should be such as to permit integration with the subsonic traffic in terminal areas.

In particular, this requires approach and landing speeds to be of the same order as those of the subsonic jets. The general opinion is that this performance could be achieved without any substantial design penalty and it is assumed, therefore, that the improved air traffic control methods and procedures now being planned will be applicable to supersonic aeroplanes when they are flying at the lower altitudes.

If the supersonic aircraft were incompatible with other aircraft, it would be necessary either to provide separate airports and airspace for the supersonic aircraft or to attempt to modify the present concepts of air traffic control to cater for such aircraft. Serious implications of attempting to provide separate airports have already been discussed, and it would be extremely difficult, if not impossible, to make separate airspace available in congested areas for the exclusive use of supersonic aircraft. It is generally considered that it would be virtually impossible to evolve an efficient system of air traffic control to cater separately for subsonic and supersonic aeroplanes."

3.3.3.3 ICAO, June 1962, Ref. 11

"The work of developing improved air traffic services to cope with the present traffic has been intensified and more radical improvements on present methods are being aimed at than was the case with some of the schemes being investigated at the time the Preliminary Study was being written. In the international field ICAO has set up a Panel of the Air Navigation Commission to study the automation of air traffic control, and this Panel has already held one meeting. A programme of work for the Panel has been prepared covering all important aspects of this subject, including data transfer systems,

both ground to ground, and air-ground-air. A wide range of air traffic control and associated operational problems will also be discussed at a meeting of a division entitled the RAC/OPS Division, scheduled for the second quarter of 1963.

The Communications Division at its Seventh Session (see Doc 8826-COM/552) also discussed the technical problems involved in automation, including automatic data systems. The technical aspects of secondary surveillance radar were also discussed by the Communications Division. None of the discussions mentioned in this and in the preceding paragraph were specifically related to supersonic operations, but the developments that are taking place should be applicable to both subsonic and supersonic aeroplanes.

Comment has been made to the effect that no reference is made in the Preliminary Study to the problem of transition to or from supersonic speed. In this comment it was stated that in this flight stage the aircraft may be in the same airspace as other aircraft and yet clearly cannot be required to be "compatible" with them. When the Preliminary Study was written, it was not thought that the transition to or from the supersonic speed was likely to cause any problem of this nature, because considerations related to the sonic boom and to the necessity to avoid the risk of having to penetrate rain or hail, were expected to limit supersonic flight to altitudes above 13,700 metres (45,000 feet) which is higher than the cruising altitudes of subsonic aeroplanes. Investigations made subsequent to the issue of the Preliminary Study tend to confirm this view.

In the opinion of at least one national authority, whilst more precise means of navigation must necessarily contribute to the efficiency of the operation, close adherence to the flight plan on the part of the supersonic transport aeroplane alone will not materially contribute to the avoidance of delay. That authority believes that the avoidance of delay would require similar improvements in respect of other air traffic. Air traffic control cannot be considered solely in the context of supersonic aeroplanes and there will be a need to consider what is the minimum service required for supersonic aeroplanes where traffic density is low, as well as to determine the means of assimilating their operations in high traffic density areas."

3.3.3.4 ICAO, August 1960, Ref. 10

"In the discussion on fuel reserves it is pointed out that substantial delays, whether caused by traffic congestion or by weather conditions, could reduce the payload so drastically as to make the operation uneconomic. The use of an automatic landing system should largely avoid diversions and delays due to weather at the terminal airport. It will be necessary to obtain international agreement on a standard system, but present indications are that technical developments should permit of this being achieved, and of the system being installed at the major airports involved, by 1970.

The problem of avoiding delays due to other traffic is likely to be eased by the use of more precise navigational methods, which, combined with the effect of the higher speed and lower time of flight of the Mach 3 aeroplane, should enable the operator to plan the flight with greater precision and to adhere very closely to the flight plan. At the same time, in the interests of safety, it would seem to be essential for the supersonic aircraft to be under positive control during all phases of the flight and in all conditions of visibility.

Close international collaboration will be required in the development of air traffic services adequate for supersonic aeroplanes. This applies not only to the particular techniques and automatic or semi-automatic systems employed but also to agreement on the most efficient organization of the airspace (e.g. larger control areas). Provided international collaboration is achieved without appreciable delay, it is believed that it will be possible to have functioning by 1970 air traffic services capable of handling supersonic operations.

The supersonic aircraft will cruise at higher altitudes than the subsonic types; therefore, separation problems will only be concerned with other supersonic aircraft. Some of these may be military aircraft so that co-ordination of military with civil traffic will be essential. The civil supersonic aircraft will not be able to accept wide diversions in order to leave large blocks of airspace for sole use by military aircraft. Airspace restrictions imposed for military purposes will need to be minimized and of a more or less permanent nature, so that a civil aircraft could adhere to the routes on which its general operation was planned in the first instance.

Air traffic control separation will be required at all times, and the requirement for lateral separation on laterally spaced tracks, already accepted in principle for subsonic jet aeroplanes, will be emphasized. Increased use of lateral separation and appropriate use of vertical separation should materially reduce delays now caused by the use of longitudinal separation.

An automatic data link to convey relevant information between the airborne navigational equipment and the air traffic controllers will be needed. This will involve international standardization, so that the airborne equipment is compatible with the ground equipment wherever the aircraft may fly. In addition, it will have to be possible for the air traffic controller and the pilot of the aeroplane to communicate with each other by voice at any time, to exchange any important information that had not been provided through the automatic data link.

Aircraft cruising at a speed of Mach 3 over stages of 3,500 nautical miles would have a normal flight time not much more than 2 hours. For air traffic control purposes there will be a need for instantaneous and reliable communications between area control centres concerned with the flight, including those serving the airports of departure and destination. The implications of this on communications systems will be dealt with later.

So far as take-off is concerned, clearance will not be given unless there is good assurance that no conflict will arise with other aircraft as far as can be determined from flight plans filed. The semi-automatic air traffic control system will involve the preparation of all flight plans in a standardized form, so that they may be processed and compared automatically and possible conflicts revealed quickly, enabling the controller to request necessary changes in flight plans before take-off rather than ask for changes while the aircraft are in flight.

As regards the airport of destination, the normal procedure is that the first aircraft estimated to arrive over the point from which approaches are commenced will be the first aircraft cleared to approach. Other aircraft are accorded priority in the order of their estimated time of arrival over the same point. For reasons already explained, a supersonic aircraft may be expected to adhere very closely to its flight plan and to provide an accurate estimated time of arrival at a much earlier stage of the flight than is the case for subsonic aircraft. Because of this, and because of the pre-

cautions taken to minimize possible conflicts before giving take-off clearances, it is expected that it will be possible to clear the supersonic aircraft for approach and landing with little delay and without involving preferential treatment. It is generally agreed by authorities responsible for air traffic control that preferential treatment or priority is undesirable and perhaps impracticable."

3.3.3.5 ICAO, June 1962, Ref. 11

"An opinion has been expressed that airspace restrictions imposed for military purposes should not be permanent if this can be avoided, because it is considered that temporary restrictions are preferable to permanent ones. The statement of the Preliminary Study was not meant to imply that airspace restrictions imposed for military purposes are desirable, whether permanent or temporary. It is important that the supersonic transport routes planned in the first instance be as direct as possible, and that to the maximum possible extent, permanent prohibited areas or restrictions take cognizance of this need.

The difficulty of enabling full advantage to be taken of the increased accuracy on the part of the supersonic aeroplane, in following a flight plan as seen from the point of view of an air traffic control authority, is summarized in this and the following paragraphs. The extent to which precautions can be taken prior to take-off to minimize possible conflicts is questionable, particularly in terminals serving a wide diversity of air traffic. The practicability of pre-planned flow of air traffic will need to be considered, also the implications of priority treatment for the supersonic transport through the medium of the 'landing slot'. Consideration of these points would probably bring out what may be conflicting needs, as between the operating economics of the supersonic transport and that of other air traffic, and the economics of airports in so far as runway utilization was concerned. For example priority treatment for supersonic transports might require a much lower planned utilization of airports. Conversely the maintenance of high runway utilization might have an adverse effect upon the supersonic transport. Some assessment of these basic issues will be most desirable.

It was stated that if the supersonic aeroplane is truly compatible with other aircraft, then the effect of the supersonic transport on the rest of the aviation field may not be marked. Compatibility was considered to mean that the characteristics of the supersonic aeroplane would be such that when in airspace occupied by other aircraft, notably in the terminal area, it does not interfere with that traffic nor adversely affect runway utilization at the airports served. The view was expressed that priority treatment for supersonic aircraft is not only undesirable but probably impracticable, certainly when supersonic transport operations build up and each aircraft is in fact competing with one of its own kind for priority. It is most important from the outset that the basis for supersonic transport operations in relation to the rest of the aviation field be clearly set out."

3.3.3.6 ICAO, August 1960, Ref. 10

"Flight tests have shown that wing-tip vortices generated by a large aircraft can cause an uncontrollable rolling moment in a smaller following aircraft at separation times of up to three minutes. The strength of the wing-tip vortices varies directly with the weight of the aircraft and inversely with the wing span and the speed. This effect is not likely to be a problem at cruising altitudes, particularly in the vicinity of airports where the speeds of the supersonic aircraft will be of the same order as those of other aircraft in the traffic pattern. The supersonic aircraft will have substantially lower wing spans than the present large subsonic jets, and this will aggravate the problem. If it happens that the supersonic aircraft are also heavier than the subsonic jets, this will make matters worse. The solution of this problem is a matter of air traffic control."

3.3.3.7 ICAO, June 1962, Ref. 11

"The effects of turbulent wake have received increasing attention in a number of Contracting States in connection with the operation of large or heavy subsonic aeroplanes, and in several cases notices have been issued warning pilots of light aircraft of the hazards associated with the wing-tip vortices generated by the larger aircraft. Studies in one State suggest that the life of the vortices is about three minutes for an aircraft in a clean

configuration or about two minutes for an aircraft with flaps extended. On the assumption that supersonic aeroplanes will not have half-wing span flaps, vortices generated by these aeroplanes may last as long as three minutes even in the take-off or landing configurations. It has been suggested that this may influence the manner in which runways will be used. However, local meteorological conditions, or an element of cross-wind, may reduce or remove the risk, and the effect of turbulent wake is another problem that needs further study before the supersonic aeroplane is introduced into service."

3.3.4 ANALYSIS AND COMMENTS

3.3.4.1 ANALYSIS -- (3.3.2 Airports)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training	X	3.3.4.2.1					
OPERATIONAL VARIABLES							
Responsibility							X
Authority			X	3.3.4.2.1			
Acceptance			X	3.3.4.2.2			
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.3.4.2 COMMENTS

3.3.4.2.1 Operating the SST out of present day airports should not present radically new problem areas, unless for reasons of noise abatement the aircraft has to be operated in a marginal area. The thrust-to-weight ratio of the power plants will be higher, which will mean that the aircraft should require shorter take-off rolls. This in itself should help reduce any anxieties caused by weather conditions or noise abate-

ment procedures. However, the main area of concern is probably in landing roll-out. The increased weight of the aircraft coupled with the higher approach and landing speeds could be factors which will cause some apprehension. After it has been shown that the SST is compatible to current airports, then improved braking systems, thrust reversers, and mechanical arrestment can be studied if roll-out is still a problem.

3.3.4.2.2 Because of the longer fuselage, runway surface aberrations can cause oscillation of the flight deck which will make perception of flight instruments difficult.

3.3.4.3 ANALYSIS - (3.3.3 Air Traffic Control)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications		X 3.3.4.4.3		
Composition		X 3.3.4.4.3		
Training		X 3.3.4.4.1		
OPERATIONAL VARIABLES				
Responsibility		X 3.3.4.4.2		
Authority				X
Acceptance		X 3.3.4.4.2		
FLIGHT DECK DESIGN				
Layout		X 3.3.4.4.3		
Instrumentation		X 3.3.4.4.3		
Controls				X

3.3.4.4 COMMENTS

3.3.4.4.1 The introduction of the SST into the proposed air traffic control system will bring many innovations to present day concepts. Many of the functions performed by the crew at the present time will be automated and thus the training program will have to provide crews with a background in the new system, and changes in current procedures. These automated systems will need monitoring, and in cases of malfunctions the manual override procedures put into effect. However, since the change to the ATC

system will be gradual, and portions of the new systems will probably be incorporated into present day aircraft, the transition may not be formidable, assuming that SST crews come from the latest subsonic jets.

3. 3. 4. 4. 2 The current responsibility placed on crew members (because of the present ATC system) will be shifted slightly because of the proposed automated systems. The automated systems monitored by the crew, will become more responsible. The crew should be willing to accept this responsibility shift because it will alleviate their current work load.

3. 3. 4. 4. 3 Automated systems will need monitoring and this will probably take place in the cockpit so that manual over-ride can be initiated in the event of a malfunction. Monitoring requirements may result in new displays and a new allocation of responsibility and authority between crew members. For example there might be a tendency to have the lowest ranking crew member do most of the monitoring but should he also have the authority to intercede or should he merely "call out" problems? In some respects the crew member who is most active in the monitoring will be the best informed at any time, yet he may have the least authority and/or capability. The questions of responsibility, authority and acceptance are not so simple in automated systems.

3.4 ENVIRONMENT

3.4.1 GENERAL

3.4.1.1 ALPA, April 1961, Ref. 16

"Features of passenger and crew protection must include pressurization reliability and fuselage integrity equal to that of the basic wing structure. Fuselage pressurization to one full atmosphere should be a primary aim in the design of a supersonic transport airplane. The shorter duration of flights, growth potentials of the airplanes and powerplants, and increased passenger acceptance make this a desirable goal. Fail-safe pressurization features should provide a maximum cabin altitude of 5,000 feet with a 50% failure in the pressurization system.

The accumulative effects on passengers and crews of radiation, ultra-violet and infra-red light, ozone, etc. must be carefully analyzed and evaluated.

Turbulence during high altitude, high speed flight will require protective features for passenger and crew members. How these passengers and crew members will be protected from this turbulence involves many possible factors such as prior knowledge, constant use of seat belts when in the seats, elimination of meal service, weather analysis, radar surveillance, new means of sensing or identifying clear air turbulence before it is encountered, etc. It would appear necessary to answer many, if not most, of those questions involving the passenger and crew environments and protection before a basic supersonic transport airplane design could be considered."

3.4.1.2 FAA, March 1961, Ref. 18

"Due to the high speed characteristics and operating atmospheric environment of the supersonic transport, many factors and methods are being explored for emergency pressurization and of supplemental oxygen needs for passengers. However, in any case, adequate oxygen must be provided for the aircraft crew and at

least therapeutic amounts of oxygen for passengers. The need for additional oxygen beyond the objectives given above will require further study of the entire problem.

It is considered essential that the integrity of the supersonic transport must be such that direct exposure to atmospheric conditions will never be encountered. Additional oxygen requirements for the aircraft will require a complete evaluation of the aircraft's reliability concepts and flight emergency procedures."

3.4.1.3 FAA RFP, August 1963, Ref. 8.

"The transport shall be able to operate in all-weather conditions, at all geographic locations, and be able to cope with ambient temperature extremes ranging from -40° F to 122° F."

3.4.1.4 ICAO, June 1962, Ref. 11

"Another problem that may have to be faced by the structural designer is the possible adverse effect of oscillation associated with the fuselage. It has been suggested that unless suitable precautions are taken, the fuselage vertical bending frequency could be in a range dangerous to human beings because of harmonic response in some human organs."

3.4.1.5 ICAO, August 1960, Ref. 10

"It will be necessary to provide for introduction of oxygen into the air circulation system as well as to reduce the concentration of ozone."

3.4.1.6 IFALPA, July 1963, Ref. 9

"Member Associations whose countries are engaged in the development of SST should contact the appropriate authorities to ascertain that studies are carried out in the upper atmosphere to further the understanding and knowledge of the SST flight environment with

regard to the following subjects:

Meteorological Phenomena,
Radiation Hazards and
Atmospheric Composition."

3.4.1.7 CAB (as reported in the Journal of Air Law and Commerce, 1964) Ref. 14

"Because the SST is scheduled to fly at altitudes up to seventy, seventy-five, eighty thousand feet at speeds of three to four times the speed of our present jet transports, positive protection must be afforded the passengers and crew. This will require more reliable systems-worthiness, and positive fail-safe passenger pressurization and oxygen systems."

3.4.2 PRESSURE

3.4.2.1 FAA, March 1961, Ref. 18

"It is anticipated that supersonic transports will be flown at altitudes up to approximately 80,000 feet. At such altitudes, it is impossible for people to survive without pressurization. Emergency descent procedures will not be able to cope with the results of explosive decompression. Therefore, the pressurized cabin must be designed such that structural failure resulting in loss of pressurization will not occur in service. All possible causes of damage to the pressure vessel should be investigated. These include failure of rotating machinery, pressurized gas containers (oxygen and nitrogen bottles) and high pressure lines or multiple electrical faults. At this time, it is not completely evident how the pressure cabin integrity safety problem will be solved. Two methods which have been proposed are (1) the use of ram air cooled by a water spray to maintain adequate pressurization if a failure occurred or (2) the use of a double skin pressure cabin.

The pressurized cabin must be designed to preclude hazardous loss of pressurization.

The design of the pressurization system should be such that in any reasonable probable failure of the pressure vessel or system the cabin pressure altitude would not exceed a specified cabin altitude which is yet to be determined. A rapid rate of change of cabin pressure under abnormal leakage conditions or system malfunctions could create adverse physiological effects or possibly endanger the safety of flight. Demonstration tests to prove the adequacy of the system for a prolonged period of operation would seem a necessity prior to the exposure of passengers.

Laboratory tests of full scale systems which cover a wide range of environments, failures, and operational conditions is considered essential. A high degree of reliability will be needed for this system and it would therefore seem that the duplicate system concept now required may not be sufficient in all cases and, therefore, a third system may be necessary to cope with failures or malfunctions.

In the sealed cabin design concept, the air filtration and rejuvenation equipment will have to be designed to remove harmful contaminants present such as fire extinguishing agents, smoke, fumes, etc. A solution in some cases may be to isolate equipment and other sources of contamination from the cabin air. The outside-air replenishment concept adds a toxic contaminant, ozone, which is a new consideration for civil aircraft operation and must be held to acceptable levels for the safety of the occupants.

For closed cycle systems or those which take in relatively small quantities of outside air, it may be necessary to establish lower limits of oxygen concentration in the cabin air.

The acceptable levels of the above contaminants remain to be established. The equipment designed to maintain acceptable cabin atmospheric conditions must be reliable and have proven capabilities for coping with the most adverse and extreme conditions.

The high cruising altitude of supersonic transports dictates a very high order of reliability of the

cabin pressure integrity. It is anticipated that any possible failure of the pressure vessel or system would permit sufficient time to descend to a suitable altitude and speed to continue to an alternate destination. Sufficient oxygen should be provided for the crew and passengers to cover needs resulting from partial decompression, equipment malfunction, and therapeutic use.

The amount of oxygen required and the necessity for individual outlets must be determined on the basis of further study including such factors as emergency pressurization, descent capability and range at subsonic speed."

3.4.2.2 IATA, May 1964, Ref. 13

"Cabin pressurization will need to be provided with a capacity to pressurize from the highest operating altitude to sea-level or thereabouts."

3.4.2.3 ICAO, June 1962, Ref. 11

"The extent of pressurization that will be adopted is not yet certain. The higher the cabin pressure altitude, the lighter can be the structure. Manufacturers' views regarding a suitable cabin pressure altitude range from 1,680 metres (5,500 feet) for Mach 2 aircraft to 2,440 metres (8,000 feet) for a Mach 3 aircraft. Airlines would prefer a lower cabin pressure altitude, as this would reduce the time required to bring it down to sea level pressure, at the maximum acceptable rate of something like 1.5 metres per second (300 feet per minute), when the aeroplane is descending. However a lower cabin pressure altitude can only be obtained at the expense of an increase in structural weight."

3.4.2.4 Boeing Company, April 17-21, 1961, Ref. 34.

"The ozone level in this belt is fairly high and the prime consideration would be its effect versus time. However, time at cruising altitude will only be in the order of half of total flying time or possibly in the

order of 40 hours a month for flight crews. Should this be found too high, the ozone level can be brought down to currently known tolerable limits through filtration."

3.4.2.5 ICAO, June 1962, Ref. 11

"It will be necessary to provide for introduction of oxygen into the air circulation system as well as to reduce the concentration of ozone. A considerable amount of thought has already been given as to the most suitable type of air conditioning system, but a lot of experiment and testing will be required to develop and prove a satisfactory system. Two basic types being considered are the ram-air system, in which fresh air is drawn from outside the aeroplane, and the stored air system, in which make up air is available in a bottled form, either liquid or gaseous. The use of the stored air system obviates the necessity for cooling or compressing ram-air and present indications favour its adoption."

3.4.2.6 AIAA (Journal of Aircraft), Ref. 35

"It is believed that the heat generated in the high-speed compressor necessary to maintain cabin pressure at altitudes of 70,000-80,000 ft would destroy a large portion of the ambient ozone. Unfortunately, the very efficiency of these compressors depends on their speed, thus reducing the contact time of ambient air with the heat. It is probable that the ozone concentration present in the planned SST will reveal an environmental health hazard unless some means is used or an adequate dwell time is engineered in the compressor system to destroy or reduce the ozone to an acceptable level.

There are a number of ways of destroying or substantially reducing the ozone level in an aircraft, including the use of manganese dioxide-cupric oxide, cobalt, nickel wool, silver or other metal or metallic oxide types of catalytic filters, and other gas phase thermal decomposition methods. Military aircraft have successfully used catalytic filters to destroy cabin air contaminants which include aldehydes, ketones, and ozone. A lighter weight filter to destroy

ozone alone can no doubt be developed. Consequently, although ozone may represent a potential environmental health hazard, its control does not impose serious difficulties for engineers in design of the SST."

3.4.3. TEMPERATURE

3.4.3.1 ICAO, June 1962, Ref. 11

"The heat during supersonic cruise climb has a tendency to cook everything in the plane--passengers, crew, tires, electrical and hydraulic systems, fuel, etc. Many areas of the plane will have to be refrigerated. Temperatures of 650° F. are expected on the nose and leading edges and 450° F. on the fuselage."

3.4.3.2 FAA, March 1961, Ref. 18

"The supersonic transport will require an air conditioning system which must reject heat from sources such as aerodynamic heat transferred through the airplane skin and insulation, internal heat generated from electronic, electrical and food heating equipment and passenger body heat. Hence, the aircraft may have to reject or dissipate several hundred thousand BTU's per hour from the cabin during cruise. In addition, if the cabin pressurization system design utilizes the concept of outside air replenishment, the cooling system must provide for dissipation of heat caused by aerodynamic effects. In rejecting the heat, several heat sink systems have been proposed. One of these, the use of fuel, shows some merit but has limitations because of the increase in fuel temperature. A second proposal which also shows merit is to transfer the heat to water, which after vaporization is exhausted overboard. Because of the high degree of reliability required for the cabin cooling system, a duplicate system concept may not be adequate in some cases, and a third means of coping with failure or malfunction may be necessary.

Means must be provided to cool the occupied areas, and other parts of the aircraft, to acceptable

levels. Maximum allowable temperatures under all foreseeable normal and emergency conditions for cabin air, components, etc., remain to be established."

3.4.3.3 IATA, May 1964, Ref. 13

"At a speed of Mach 3 the temperature of the outer skin of the aeroplane will be about 320°C (600° F). A refrigeration or cooling system will be needed as well as good light-weight insulation. The design of an efficient light-weight and reliable cooling system will pose new problems."

3.4.3.4 FAA, Ref. 8

"The principal problem associated with speed is temperature, which increases as the square of the speed. Maximum temperatures which will be encountered at a cruising speed of Mach 2.2, on the hottest surfaces of the airframe, will be in the order of 306°F; at Mach 3.5, 882°F. See Figure 6.

The substantially higher temperatures resulting from higher cruise speeds not only dictate the type of materials used in aircraft structures, but also have a substantial effect on the design requirements for subsystems and other components. For example, seals, lubricants, fuel, rubber and plastics and other nonmetallics present problems at the higher temperatures."

3.4.3.5 Boeing Company, April 1961, Ref. 34

"Aerodynamic heat is the most significant factor affecting systems of supersonic aircraft, i.e., flight controls, electrical, pneumatic, hydraulic, fuel and air conditioning. This effect begins to be important at cruise speeds beyond M= 1.4. At cruise speeds above M=2, some cooling must be provided for most systems and at Mach =3, cooling requirements are a major consideration for all systems. The length of time at these speeds determines the type of heat sinks that can be used, the total expendable coolant to be carried and will greatly affect operational and performance reliability.

SST SURFACE TEMPERATURES

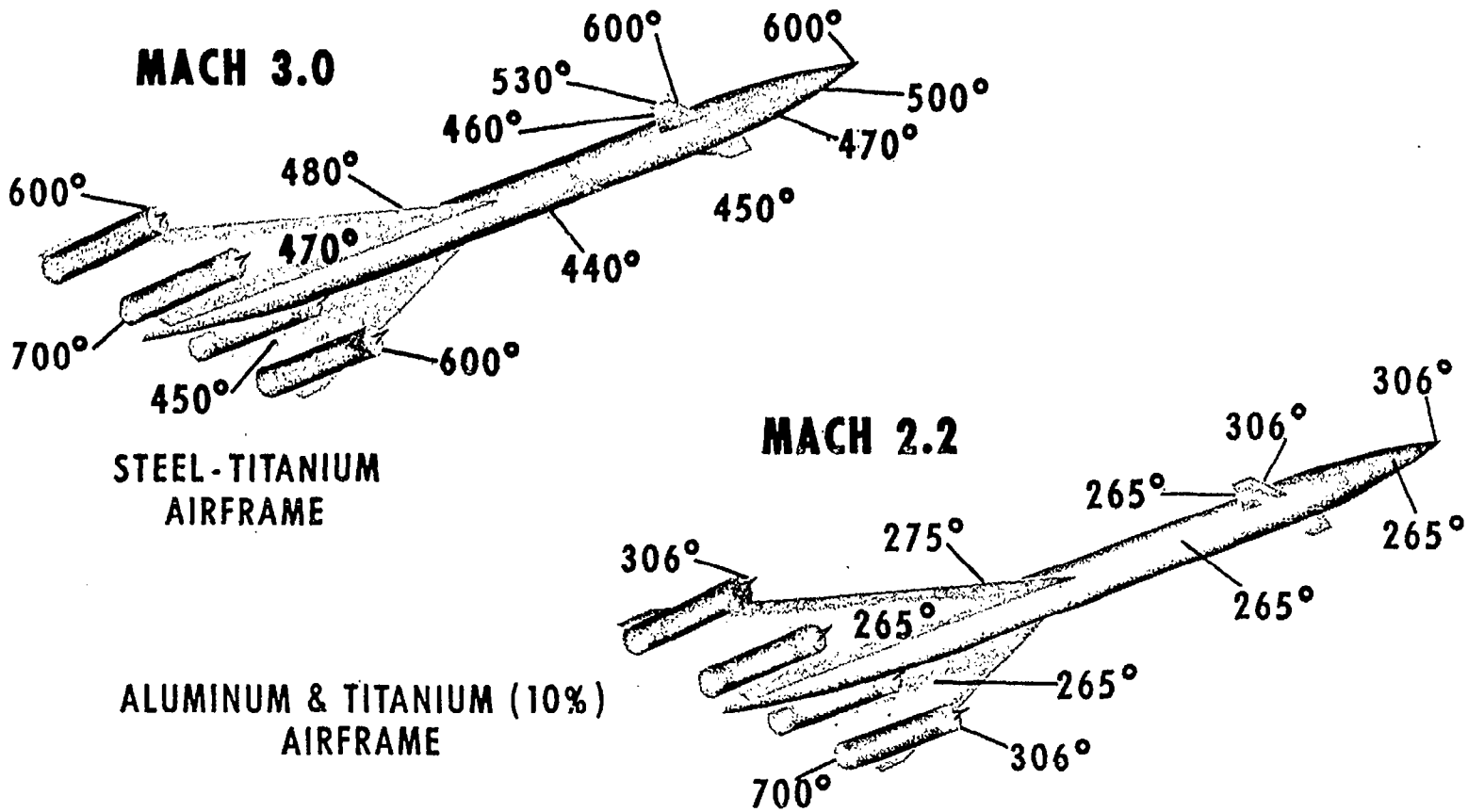

Figure 6. SST Surface Temperatures
(taken from ref. 39)

Because of the location of many system components in remote places, such as wing leading and trailing edge, it is desirable that they be able to withstand and operate under the maximum temperatures which can occur. The alternative is to cool the compartment of the component itself. This, of course, will result in a weight penalty."

3.4.3.6 ICAO, June 1962, Ref. 11

"There is also a wide variation of opinion on the most suitable system for cooling the cabin. Here again very great reliability is essential. It has been estimated in one study that complete loss of cooling capacity would result in a temperature rise in the cabin of 24° C(43° F) per minute. The same solution has been proposed as for the pressurization system, namely the provision of three separate cooling units, any two of which would be capable of providing all the cooling required. The loss of two units would still leave 50% of the normal cooling capacity available, and under these conditions the cabin temperature would rise at a rate of about 11° C (20° F) per minute. The cooling system on the French preliminary project is being designed to maintain a satisfactory cabin temperature at external ground temperatures between -31° C and +40° C (-22° F and +104° F)."

3.4.4 RADIATION

3.4.4.1 ICAO, June 1962, Ref. 11

"The possibility of the crew or passengers being adversely affected by radiation is regarded by some authorities as a basic problem of the same order of significance as the sonic boom. Whether or not this is so, there does seem to be the same need for international cooperation and collaboration in studying these two problems. A good deal is already known about the type and intensity of radiation in the atmosphere and more knowledge is continually being obtained. Perhaps the major difficulty is to specify with a real degree of certainty the intensity of radiation that can be accepted over a period of time without any harmful long-range genetic effects.

There is obviously scope for considerable differences of opinion as to whether or not it would be safe to proceed with the development and introduction into service of supersonic aeroplanes. However, the general views of scientists who have studied the intensity of the radiation encountered at the cruising altitudes that would be used by supersonic aeroplanes, is that the exposure involved is not sufficient to prevent or delay the introduction of supersonic aeroplanes. They do not anticipate that there will be any problem caused by the exposure to galactic cosmic rays during solar minimum years. However there will be a problem with the solar cosmic or energetic flare proton radiation occurring during solar activity years, which sometimes penetrates the atmosphere with significant intensity below 22, 800 metres (75, 000 feet).

Exposure to this radiation would not be acceptable, but the events causing it do not happen very frequently and can be predicted sufficiently far in advance to permit the aeroplane to descend to safe lower altitudes and either continue to its destination at those altitudes or land at an alternate aerodrome. In some cases it may prove necessary and possible to provide for these high intensity radiation events in flight planning, and either postpone the flight or follow a safer route.

It has been suggested that the study of radiation hazards is another field in which there is scope

for international cooperation in the research involved, and that ICAO should encourage such cooperation for the same reason as in the case of engine noise and some other problems already mentioned. It has also been suggested that ICAO should study the problem of radiation hazards with a view to establishing a solution or solutions to it and the cost thereof."

3.4.4.2 Boeing Company, April 1961, Ref. 14

"Another, and because of its nature, more controversial question is the effect of cosmic radiation. The limitations that have been established are based upon the genetic hazard, and because research is still being carried on these limits have been set very conservatively. Since the radiation intensities are several times as large over the geomagnetic poles as at the equator, the problems should primarily be studied for high latitudes. Furthermore, in view of intensity variations during the course of the solar cycle, the solar minimum where normal cosmic ray intensities are largest will be considered.

It then appears that a passenger's total radiation dose at the 60-80,000 feet altitudes will be small because the dose rate is small (less than 6 mrem/hour) and the exposure time at this altitude is short. For the more frequently exposed crew, the recommended maximum dose would set a limit of 16 hours per week of high altitude flying time at these particular latitudes in the solar minimum periods only. Again since high altitude flying time will be in the order of only half this time limit and the most critical latitudes and time periods will be encountered part time only, exposure seems to be well below current limitations. For comparison purposes, it can be noted that a chest X-ray represents a dose of at least 0.1 rem.

The hazard due to high atomic number primary cosmic ray particles is negligible at altitudes below 80,000 feet, but the effect of other heavily ionizing components should be considered. In particular, the fraction of cells of the retina or brain killed outright by high ionization nuclear interactions ("stars") amounts to an order of magnitude of one in a million per hour. Solar flares may increase the total dose rate by factors of two to ten. The larger flares are quite infrequent in

the order of one per three or four years, and evasive action through lower altitude operation (possibly 50,000 feet) is considered feasible. Fortunately, the common smaller flares that occur monthly produce only relatively few particles which reach into the atmosphere and they are of much less significance.

In connection with cosmic radiation, the occurrence of cascading effects and shower production have been mentioned. This increase in heavy nuclei dose rate due to metal shielding however, amounts to only 10% for the worst case, approximately 20g/cm^2 shielding, and for airplane skin structure only a few per cent increase should be expected."

3.4.4.3 FAA, June 1963, Ref. 22

"Radiation effects from major solar disturbances are more prevalent in the northern latitudes. These disturbances occur on the average of once or twice a year. Current forecasting techniques can predict these disturbances, which may last as long as 24 hours, about fifteen minutes in advance of their occurrence. With this warning, the hazard can be avoided by descending to lower altitudes.

During periods of major solar disturbances, aircraft can operate safely at altitudes less than 50,000 feet or at higher altitudes in southern latitudes. These available alternatives should preclude interruption of scheduled flights.

Radiation encountered by the supersonic transport will not, according to the best information available, be a hazard to either passengers or crew."

3.4.4.4 Space/Aeronautics, April 1964, Ref. 36

"It has been estimated that the intensity of such radiation (cosmic) at 70,000 feet is about two and one-half times what it is on the ground--over the polar regions more like five and one-half times. Thus, over the poles, at least, it might be desirable for the SST to fly at somewhat lower altitudes--say below 50,000 feet for example--than otherwise optimum. Since there is no question but what the airlines

will take proper safety precautions in operation, the problem is likely to resolve itself into one of fuel reserves and economy: to what extent will cosmic radiation force the plane to lower altitudes that eat up fuel, shorten range, and add expense?"

3.4.4.5 FAA RFP, August 1963, Ref. 8

"Consideration shall be given to the need for instrumentation for radiation or other environmental hazards monitoring."

3.4.4.6 Space/Aeronautics, April 1964, Ref. 36

"There is some danger from solar flares. During such occurrences which admittedly are relatively rare, ionization rises to levels many times above normal. There is some hope that scientists will find out how to predict such occurrences; presumably they would be considered hazards that justified grounding a flight."

3.4.4.7 IFALPA, July 1963, Ref. 9

"There should be no significant reduction in the structural reliability of the aircraft due either to intermittent or continuous exposure to radiation hazards.

Until further evidence is available, IFALPA should regard the maximum permissible whole-body doses and dose-rates recommended by the International Commission on Radiological Protection as the highest allowable for the Federation's pilots.

IFALPA should maintain contact with the International Commission on Radiological Protection, the World Health Organisation and ICAO in order to determine the effect of the introduction of SST on the significant genetic burden of mankind."

3.4.4.8 ICAO, June 1962, Ref. 11

"For the purpose of flight planning it is very desirable to be able to predict solar cosmic ray events. At the present time it is not possible to predict with sufficient accuracy intense high and medium energy events for more than 10 to 15 minutes in advance of the onset of the high energy proton influx. The increase of the high energy proton intensity to its peak in past events has taken at least thirty minutes. There is furthermore appreciable evidence that the bulk of protons which are of medium energy arrives up to one or more hours later. However, while it appears unlikely that the energy and intensity of the proton beam which encounters the earth will in the near future be predictable for more than thirty minutes in advance, it appears easier to predict at least major flares themselves for some hours in advance. This will be very useful in flight planning, and research is continuing with a view to being able to make better forecasts of these events."

3.4.5 RAIN AND HAIL

3.4.5.1 FAA, March 1961, Ref. 18

"Rain or hail may be present in cumulo-nimbus clouds which extend to altitudes of 75,000-80,000 feet in the tropics and somewhat lower altitudes in temperate latitudes. Weather radar will probably be installed on supersonic transports. However, it may not be possible to rely on this equipment to avoid rain or hail since (1) the equipment now used by civil operators has a range of approximately 100 miles and (2) the radius of a 15° banked turn for a speed of Mach 3 is approximately 160 miles, hence, avoiding action may subject passengers to uncomfortable accelerations. Furthermore, it may not be possible to construct radomes impervious to rain or hail erosion or damage at supersonic speeds.

The supersonic transport must be designed for effects of rain and hail encountered at supersonic speed unless it can be shown that contact can be avoided."

3.4.5.2 IFALPA, July 1963, Ref. 9

"In the event of inadvertent exposure of the aircraft to rain, hail and ice crystals whilst cruising at supersonic speeds, there should be protection provided against substantial and significant damage arising therefrom."

3.4.5.3 ICAO, June 1962, Ref. 11

"It has been pointed out that clouds may be found at higher altitudes than those quoted in the Preliminary Study. Even in the temperate latitudes, clouds may reach 18, 300 metres (60, 000 feet) or higher. Recent evidence suggests that cumulonimbus may be found in the tropics at altitudes above 18, 300 metres (60, 000 feet), although it is not yet understood whether or not the hail content presents a serious problem in such cases. Much research remains to be done into the nature of such areas, into their distribution and rate of buildup. 18, 300 metres (60, 000 feet) is in the range of likely cruising altitude for Mach 2 aeroplanes and is not much lower than the likely crusing altitude for Mach 3 aeroplanes. If a significant size of hailstone is found to occur above 18, 300 metres (60, 000 feet) it can hardly be expected that the aircraft will be able to fly subsonically to a great enough height to avoid all contact at supersonic speeds. If, on the other hand, lateral avoidance is not possible; e.g., because of the number or depth of the danger areas, then the possibility of carrying out the flight will depend on the relation between size of the hail, ice or water particle, and its potentiality for inflicting structural damage on the aircraft. Although the use of weather warning radar would present considerable difficulties, the absence of any satisfactory means of avoiding rain and hail requires that further thought be given to solving those difficulties or devising some alternative solution of the problem."

3.4.6 TURBULENCE

3.4.6.1 Space/Aeronautics, April 1964, Ref. 36

"On other matters, all SST customers have an equal stake. One major concern is clear air turbulence, which some feel is a more critical problem for the SST than it is for subsonic aircraft. Research is now being conducted along several lines with the aim of developing a detector that would warn the pilot of such turbulence ahead. Some kind of radar or radiometer may do the job.

There are other problems associated with weather radar. One is its range. Because of the SST's speed, the present 150-200 mile range of the radar will have to be increased, probably to 250 miles. At 1800 mph, warning time will be on the order of only 8 min, but this should be enough time for the pilot to evade "weather" without going into uncomfortable maneuvers.

Also, present weather radar does not do a good job of detecting high-altitude ice particles and the like. One idea being given sporadic consideration is to use two bands of radar: one of, say, 33 kmc for avoiding ice particles and clear air turbulence, and the other a more conventional, lower frequency for detecting the usual thunder-storms. Such a solution introduces new problems in radome and antenna design that could mitigate against its adoption."

3.4.6.2 ALPA, April 1961, Ref. 16

"Turbulence will also have a vital effect upon supersonic flights. Since it would seem impracticable, if not impossible, to slow down to accommodate in-flight turbulence, even at near-sonic speeds, the airplane must be capable of encountering this turbulence without deleterious effects upon the airframe, powerplants or any of the many "systems" and the occupants in the airplane.

Structural integrity should be insured for realistic operating conditions by Gust Criteria requirements at

V_c. The cruising speed at which supersonic airplanes will enter areas of high altitude clear air turbulence eliminates the possibility of slowing down for this condition. Therefore, the airplanes must be capable of accepting these gust loads, without any undue loss of performance or a loss in altitude. Fuel reserves may not provide for the unanticipated recovery of altitude and cruising airspeed during a flight."

3.4.6.3 IFALPA, July 1963, Ref. 9

"Will the aircraft or pilots require special protection against high "g" loadings caused by:

i) turbulence at supersonic speed?
ii) inadvertent manoeuvres at supersonic speed?
iii) transition instability (sub-sonic to supersonic and v.v.)?

In the absence of information regarding the possible incidence of high "g" loadings, caused by either turbulence, inadvertent manoeuvres or transitional instability, it is considered that the wearing of safety harness or some other protection may be required for safety purposes for all occupants of the aircraft."

3.4.7 METEOROLOGICAL SERVICES

3.4.7.1 FAA, March 1961, Ref. 18

"There is a need for more accurate forecasting of temperature, turbulence, thunderstorm activity, including hail, icing, and winds aloft up to altitudes of 80,000 feet.

The determination of altitude for transition accelerations of the supersonic transport must be based upon accurate information on temperature, pressures, wind velocity and direction, which have an important bearing on aircraft fuel consumption, and the intensity of the sonic boom.

Further research is needed on meteorological phenomena for the higher operational altitudes to determine significant weather parameters, and on the effect of ozone and cosmic radiation."

3.4.7.2 ICAO, August 1960, Ref. 10

"The introduction of the supersonic aircraft is not expected to render present or planned facilities or services obsolete, but it will impose a number of additional requirements; in some cases, a considerable amount of research and development work will be required in order to determine how these requirements can best be met.

Relevant work of this kind, already in hand, has been taken into account in the following assessment of the problems faced in attempting to meet the meteorological requirements. However, unexpectedly rapid progress in any of these projects might result in a situation significantly more favourable in some respects than that presented. Some developments --for example, the launching of a weather satellite -- are so recent that it is impossible to foresee with any certainty their eventual potentialities in this field.

A number of States consider that it will be necessary to make observations of temperature, pressure and wind up to an altitude of 30,000 metres (100,000 feet); others consider that the observations need not be made at altitudes higher than the highest operational level, i.e., about 24,000 metres (80,000 feet). In any case, the maximum altitudes involved will be much higher than the altitudes of 14,000 to 17,000 metres (45,000 to 55,000 feet) for which observations are required for operations of subsonic jet aeroplanes. It is relevant to note that there is also a non-aeronautical requirement for observations for altitudes up to 30,000 metres (100,000 feet).

Forecasting services will be required for the cruising altitudes of 18,000 to 24,000 metres (60,000 to 80,000 feet). For forecasting winds and temperatures for subsonic jet aeroplanes, information is, where possible, normally obtained for surface, 700 mb, 500 mb, 300 mb and 200 mb levels every twelve hours, supplementary information in some cases being available at the intermediate six-hour periods. Meteorological offices use

these data to prepare charts for some or all of these five levels and from these they prepare forecast charts for one or more levels. For the supersonic aeroplanes three additional sets of charts will need to be prepared, covering levels of 100 mb (16, 000 metres, 53, 000 feet), 50 mb (21, 000 metres, 68, 000 feet) and 30 mb (24, 000 metres, 78, 000 feet) or 25 mb (25, 000 metres, 82, 000 feet).

No particular difficulties are anticipated in forecasting temperatures, although the temperature can vary very rapidly with distance at altitudes from 18, 000 to 24, 000 metres (60, 000 to 80, 000 feet). Near the stratospheric jet stream over northern Canada a variation of 20° C in 800 miles has been reported. In a flight at 24, 000 metres (78, 000 feet) from Keflavik to San Francisco via New York the temperatures could well be -25° C over Keflavik, -50° C over New York and -70° C over San Francisco. However, temperature does not seem to vary quickly with time at one place. For example, the order of variation to be expected at an altitude of 24, 000 metres (78, 000 feet) in the Arctic stratosphere is from -75° C to -25°C in fourteen days.

The forecasting of wind velocity may present difficulties in certain regions. Winds have been observed at the planned supersonic operational levels which are of the same order of magnitude as the strongest winds found at current jet operational levels. For example, winds up to 200 knots occur in the winter at altitudes of 21, 000 to 27, 000 metres (70, 000 to 90, 000 feet) over the Arctic and as far south as latitude 50°, while over the western Pacific winds of 150 knots have been observed at an altitude of 20, 000 metres (65, 000 feet). These compare with winds of 300 knots which have been observed over Japan at 12, 000 metres (40, 000 feet).

The opinion has been expressed that the economic success of supersonic flight will depend on the certainty with which the flight and the payload can be planned well in advance, indicating a requirement for an accurate forecast 24 to 36 hours before take-off. As far as the safety of the flight is concerned, it has been suggested that, because of the short time of flight, it may be possible to use current observations rather than forecasts, or to use forecasts prepared by a simple method of extrapolation from current observations. However, at present upper air observations are being made at intervals of 6 or 12 hours and, if the information were required for pre-flight

planning one to two hours before take-off, then at the mid-point of a 2-hour flight the actual data might be anything from about 2 to 16 hours old. This assumes that the time required to make the data available could be limited to one hour or less.

Turbulence may be experienced up to the highest cruising altitudes, but its extent and frequency of occurrence at these altitudes are not known. It is unlikely that it will be possible to forecast such turbulence with adequate precision.

Rain or hail may be encountered in cumulonimbus clouds at altitudes up to 17,000 to 18,000 metres (55,000 to 60,000 feet) in the tropics and 11,000 to 14,000 metres (35,000 to 45,000 feet) in temperate latitudes. However, it is unlikely that it will be possible to forecast the precise location and time of occurrence of such precipitation, especially in areas where the fixed observation network is sparse (e.g. over oceans and uninhabited land areas), so that the pilot will have to take avoiding action whenever encounters are a possibility.

A type of cloud that may cause difficulties for supersonic aircraft is the so-called nacreous cloud or mother-of-pearl cloud which has been observed at altitudes of 21,000 to 30,000 metres (70,000 to 100,000 feet). It has been suggested that this cloud may consist of minute water droplets or spherical particles of vitreous ice which crystallizes only slowly. However, as little or nothing is known about the size and number of the droplets or ice particles forming nacreous clouds little can be said about the possible erosion effects on a supersonic aircraft.

There may be a requirement for the production of climatological data up to an altitude of 25,000 metres (82,000 feet). The data would probably be needed for the levels of 100 mb (16,000 metres, 53,000 feet), 50 mb (21,000 metres, 68,000 feet) and either 30 mb (24,000 metres, 78,000 feet) or 25 mb (25,000 metres, 82,000 feet). A great quantity of data is available from IGY and IGC observations, but this may take some time to process and, if climatological information is needed quickly, it will be advisable to inform WMO in the near future.

It will possibly be necessary to determine the atmospheric content of ozone and radio-active substances at high altitudes. It will also be desirable to have as much

information as possible on cosmic radiation at these altitudes, so that a summary and analysis may be made of all evidence bearing on the possible hazards from cosmic radiation.

Climb and Descent

At the altitudes now used by subsonic aircraft, the Mach 3 aeroplane will be climbing or descending at subsonic speed, and the requirements and procedures developed for the subsonic jet aeroplanes should be satisfactory. It is doubtful if it will be possible to forecast turbulence and hail with the desired precision, and it must be assumed, except in the case of clear air turbulence, that the aircraft will be able to take the necessary avoiding action. In the discussion on aircraft characteristics (see Chapter II, para. 72) it has already been stated that weather radar equipment will be installed for use during subsonic flight.

If, in planning climb and descent, advantage is to be taken of the reduction of sonic boom associated with certain atmospheric conditions, there will be a need for forecasts of the stability of the atmosphere, including the altitudes of inversions and isothermal layers.

Terminal Conditions

In general, the requirements and procedures developed for subsonic jet aeroplanes should be satisfactory for the approach and take-off phases of flight of the supersonic aeroplanes. However, it may prove necessary to provide more detailed forecasts (if technically feasible) or actual observations, of turbulence, marked wind shear, ice formation and hail. The use of automatic landing equipment may eliminate the need for information on cloud base and visibility, but, if the final flare-out and run is to be visual, it may be necessary to extend the present values of runway visual range well above the current maximum value of about 1,100 metres (1,200 yards). This would require the use of more elaborate methods of observation at many aerodromes. Terminal forecasts will be required on an hourly basis supplemented by frequent observations in the approach zone.

Additional equipment likely to be essential in connection with the forecast or observation of terminal conditions include precision ground-based weather radar and extended wind and gust observing instrumentation on the approaches and near the runways.

In order to realize, to the greatest extent practicable, the potentialities of methods expected to be available for providing meteorological service for aircraft operations, there will be a need to introduce as much automation as possible into the collection and analysis of meteorological data, into forecasting methods, and into the communication of essential information to and between air traffic control centres, terminal airports and the aircraft themselves. The implications of this so far as communications are concerned are dealt with later.

Areas in which it is evident that there is a pressing need for research and development work include longer term forecasting (i.e. of the order of 24 hours or more) of weather at the airports of departure and destination, the forecasting of turbulence at all altitudes, and the observation and forecasting of winds and weather both at cruising altitudes and at the altitudes traversed during climb and descent. The opinion has been expressed that regular observations should be made for a period of at least three years before the introduction of supersonic aircraft. This would facilitate the smooth introduction of supersonic aircraft by permitting a period of "operation on paper" as was found so helpful by some airlines when preparing to introduce subsonic jet aeroplanes.

It will be necessary to obtain international agreement as early as possible, both on the precise requirements to be met by the Meteorological Services and on the development of practical methods for providing meteorological services to meet these requirements. In this connection, it has been suggested that it will be necessary to increase the present extent of international co-operation and create forecasting centres for large regions, in view of the elaborate equipment and large staffs required to derive full benefit from the forecasting techniques being developed.

Providing no time is wasted in proceeding with the necessary research and development work and in obtaining international agreement where this is required, it is believed that the necessary meteorological services can be provided by 1970."

3.4.7.3 FAA, March 1961, Ref. 18

"Due to the speed and distance required for maneuvering of the vehicle, a radar installation, to be effective may require a range of at least 300 miles. This distance would afford the pilot sufficient time to alter his course to circumvent cumulus buildup, and turbulence conditions.

There are divergent views relative to this subject. One group strongly proposes that weather radar should not be required for this type aircraft. This proposal is based on the premise that the entire flight plan will be programmed before takeoff for each mission. This flight plan will include the immediate weather throughout the flight path and will take into account all forecasts for the relatively short time duration of the flight. Consequently, the aircraft will never be directed into a weather condition where radar would be useful.

Another group concedes that this is a valid premise, but argues that it is not possible to always accurately predict weather conditions at a particular point at a given time. Additionally, that under some conditions it may be possible to cause failure of the aircraft structure through the encounter of certain turbulence conditions during various mach regimes. Further, that since this is possible, the crew must be provided means to adequately scan weather conditions ahead so that the vehicle course may be altered when necessary, particularly during subsonic flight.

Development of a suitable radar installation is within the present state of the art. The economic considerations of such an installation, i.e., cost of equipment and installation, weight, maintenance, etc., are great. However, at this time such an installation is considered essential to the safety of the aircraft."

3.4.8 ACCELERATION

3.4.8.1 ICAO, June 1962, Ref. 11

"Special Considerations Relating to the Well-being of the Occupants

Acceleration

The actual values of the acceleration and of floor angles in the passenger cabin, will depend upon the design of the particular aeroplane. The figures given in the Preliminary Study for the accelerations and the floor angles, have been stated to be acceptable so far as concerns the medium range Mach 2 aeroplane now being designed as a preliminary project. The comment has also been made that the problem of acceleration due to aircraft manoeuvring is less serious at Mach 2 than at Mach 3. Of course, only turns of a very high radius will be made by aeroplanes at these speeds. As regards floor angles, it has been pointed out that the high attitudes that will prevail for a period of about fifteen minutes between take-off and the end of the transonic acceleration will restrict severely the activities of the cabin staff."

3.4.9 ANALYSIS AND COMMENTS

3.4.9.1 ANALYSIS -- (3.4.2 Pressure)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications			X	3.4.9.2.1			
Composition							X
Training			X	3.4.9.2.1			
OPERATIONAL VARIABLES							
Responsibility					X	3.4.9.2.2	
Authority							X
Acceptance					X	3.4.9.2.2	
FLIGHT DECK DESIGN							
Layout							X
Instrumentation			X	3.4.9.2.2			
Controls							X

3.4.9.2 COMMENTS -- (3.4.2 Pressure)

3.4.9.2.1 In general the problems involving pressurization and demanding engineering problems rather than crew operational problems will not concern the crew. Designers will have to develop pressurization systems that are essentially failure-proof. The pressure environment at the altitudes at which the aircraft will be operating is of course uninhabitable without adequate pressurization. More stringent training to acquaint the

crew with the dangers which could arise from a malfunctioning subsystem, and how they will be able to cope with them, should be introduced.

3.4.9.2.2 Since catastrophic system failure would be disastrous adequate warning instrumentation and subsequent emergency procedures will need to be developed.

3.4.9.3 ANALYSIS -- (3.4.3 Temperature)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training	X	3.4.9.4.1					
OPERATIONAL VARIABLES							
Responsibility	X	3.4.9.4.1					
Authority							X
Acceptance			X	3.4.9.4.1			
FLIGHT DECK DESIGN							
Layout							X
Instrumentation	X	3.4.9.4.1					
Controls							X

3.4.9.4 COMMENTS -- (3.4.3 Temperature)

3.4.9.4.1 This area is another difficult problem for the design engineers, and the reliability of the solution is what affects the crew. However, it should only affect them to the point where they are aware that aerodynamic heating requires an adequate cooling system, and in the event of failure of such system what procedures must be taken to alleviate the danger. The crew must also be aware of the structural limits of the aircraft so that the operations will be kept within suitable limits.

3.4.9.5 ANALYSIS -- (3.4.4 Radiation)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications					X		
Composition							X
Training					X	3.4.9.6.1	
OPERATIONAL VARIABLES							
Responsibility					X	3.4.9.6.2	X
Authority							X
Acceptance					X	3.4.9.6.1	
FLIGHT DECK DESIGN							
Layout							X
Instrumentation					X	3.4.9.6.2	
Controls							X

3.4.9.6 COMMENTS -- (3.4.4 Radiation)

3.4.9.6.1 This is a new area for commercial aviation personnel and passengers. Assurances will have to be given that adequate shielding precautions have been taken to protect both crew and passengers. Actually the radiation levels are relatively low, but it must be remembered that any exposure is additive. Since passengers will not be continually operating in these areas, there should be no real concern in the

area of total dosage. Dosimeters may have to be worn and results logged to control this possible health hazard. This could mean all crew members have to be qualified with respect to cumulative radiation exposure. In any event the crew should receive adequate orientation into radiation and its effects, and what is being done to protect them, and the uncertainty of radiation effects could unquestionably be an acceptance problem.

3.4.9.6.2 Adequate instrumentation must be available to warn the crew of intensification of radiation or impending solar flares so that measures can be taken to seek lower flight levels commensurate with other flight variables, i.e., traffic, weather conditions, available fuel, etc.

3.4.9.7 ANALYSIS -- (3.4.5 Rain and Hail)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X						
Composition							X
Training	X	3.4.9.8.1					
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation	X	3.4.9.8.1					
Controls							X

3.4.9.8 COMMENTS -- (3.4.5 Rain and Hail)

3.4.9.8.1 Flying through rain or hail while operating in either the sonic or supersonic speed ranges may have an erosive effect on the aircraft, and could possibly damage the radomes and other similar aircraft fixtures. However, no new areas of difficulty are anticipated. The crew will have to utilize all possible information to try to avoid these weather areas, i.e., PIREPS, radar, etc. Improvements in airborne radar

detection ranges will have to be made if the aircraft is expected to alter course prior to encountering rain or hail.

3.4.9.9 ANALYSIS - (3.4.6 Turbulence)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X						
Composition							X
Training	X	3.4.9.10.1					
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.4.9.10 COMMENTS - (3.4.6 Turbulence)

3.4.9.10.1 Turbulence is a meteorological phenomenon which will affect SST operations in the same manner as it affects current operations. New methods are being devised which will assist in predicting its occurrence, and crews must utilize all this information when planning a flight. However, it is not anticipated that the procedures for flying through such turbulence will drastically change from those in current use.

3.4.9.11 ANALYSIS - (3.4.7 Meteorological Services)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training							X
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation					X	3.4.9.12.1	
Controls							X

3.4.9.12 COMMENTS - (3.4.7 Meteorological Services)

3.4.9.12.1 Operating at higher altitudes, and in accord with an almost critical flight profile, the requirement exists for more extensive information on meteorological conditions. Improved meteorological services will help the crew plan a more efficient flight and should eliminate en-route course deviations due to unexpected adverse weather. Plans are being made to link the aircraft with ground and air weather facilities. Training for the crew on new weather displays will be necessary, but should not be a problem area.

3.4.9.13 ANALYSIS - (3.4.8 Acceleration)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X	3.4.9.14.1					
Composition							X
Training	X	3.4.9.14.1					
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							X
Layout							X
Instrumentation							X
Controls							

3.4.9.14 COMMENTS - (3.4.8 Acceleration)

3.4.9.14.1 At the extremely high speeds of the SST, deviations in course would subject the crew and the passengers to greater "g" accelerations than previously experienced. For this reason it may be necessary to revise in-flight procedures as pertains to passenger handling. Normal flights, however, should not introduce accelerations much different than present jet operations.

3.5 FLIGHT CREW COMPLEMENT AND STATION

3.5.1 GENERAL

3.5.1.1 FAA RFP, August 1963, Ref. 8

"The flight crew stations and facilities shall be designed and arranged to provide the maximum flight crew efficiency and comfort for safe all-weather day and night air carrier operations. The number of flight crew members for which the supersonic transport is to be designed, shall be the minimum number required to perform all functions necessary to navigate and control the airplane, without imposition of an excessive workload on any one such member, and additionally permit safe continuation of the flight in the event of sudden incapacitation of any one flight crew member.

An adequate station shall be provided on the flight deck, from which the operation of the entire flight crew may be observed by a check pilot or Federal Aviation Agency Operations Inspector."

3.5.1.2 FEIA, August 1964, (Private Communication)

"In the enclosed information, I think it is clear FEIA is of the opinion that any SST type aircraft should, of necessity, have a SAE Type III cockpit and the controls defined or allocated in accordance with APR 268C. FEIA has always believed that the duties of navigation, communication and directional control of the aircraft should be handled by the pilots, while the systems management, which takes on the mechanical or engineering functions, should be handled by the Flight Engineer. The cockpit should be initially designed to enable each crewmember to do those duties allocated to him in the most efficient manner possible. The SST is no exception."

3.5.1.3 FEIA, July 1963, (Letter from FEIA to FAA)

(FEIA suggests in the letter that the following paragraph be included in the RFP.)

"The Flight Engineer shall be provided with a separate Flight Engineer station. This station shall be provided with all necessary instruments and controls required to monitor and adjust the engines and systems sufficiently to keep them within their prescribed limits."

"The above (underlined) addition concerning flight deck arrangement is in conformance with the Type III flight decks approved by the SAE - S7 (ARP 268C revised November 15, 1963). It would assure a flight deck providing "built in" flight crew coordination and would otherwise provide for the most safe and efficient flight possible, so far as the design of flight decks are concerned."

3.5.1.4 FEIA, August 1963, (Letter from FEIA to FAA)

(FEIA suggests in the letter the following revision to the FAA RFP regarding Flight Crew Complement, stations and facilities.)

"The flight crew stations and facilities should be designed in conformity with FAA and SAE S-7 type III flight deck standards and arranged to provide the maximum flight crew efficiency and comfort for safe all weather day and night air carrier operations. The number of flight crew members for which the supersonic transport is to be designed should be the minimum number required to perform all functions necessary to navigate and control the airplane, its powerplants and systems, without imposition of an excessive workload on any one such member, and additionally permit safe continuation of the flight in the event of sudden incapacitation of any one flight crew member."

3.5.1.5 ALPA, April 1961, Ref. 16

"Flight Deck Design

The basic flight deck design, its location in the airplane and the windshield arrangement will all have a vital effect upon the efficiency of flight deck crew members.

We consider that it will be necessary to provide for

direct pilot visibility for take-off and landing and that artificial visibility systems alone would be unacceptable.

The flight deck design should provide for increased crew efficiency and reduction of reaction time while minimizing crew fatigue. The increased complexity of the aircraft systems, and the reduced reaction time available without a relative reduction in work-load would be intolerable. All emergency controls for aircraft operations must be operable from the flight deck.

Crew co-ordination makes it mandatory to maintain side-by-side pilot, co-pilot seating."

3.5.1.6 IFALPA, July 1963, Ref. 9

"It is impossible to over-emphasize the importance of providing good flight deck conditions. These should include:

i Good lighting;
ii Comfortable temperatures;
iii The absence of vibration;
iv Individual fresh air supply;
v Absence of undue noise;
vi Adequate humidity;
vii Adequate stowage for essential equipment."

"Will supersonic flight at high altitudes create special problems of:

i) crew compartment temperature and humidity?
ii) fresh air supply to individual crew members?
iii) crew's seat angles?
iv) noise in crew compartment?
v) vibration of flight instruments?"

3.5.1.7 FAA, March 1961, Ref. 18

"Windshield and Windows (CAR 4b. 352)

The windshield must be capable of withstanding pressures arising from aerodynamic loading and cabin pressurization, rapid aerodynamic heating or cooling, heat from de-fogging and de-icing systems, foreign

body impact and erosion.

The currently used soda-lime glass may be satisfactory for temperatures of 500°F. However, consideration is being given to other types of glass such as aluminum silicate, borosilicate, or fused silica. These latter glasses have a greater thermal shock resistance due to their lower values of thermal expansion, higher values of thermal conductivity and modulus of rupture. The temperature of the windshield will be affected by change in ambient temperature (change in altitude), kinetic heating or cooling, de-icing or de-fogging, and cabin heating or cooling. Since the thermal conductivity of glass is relatively low, changes in speed and/or altitude produce transient temperature gradients through the thickness of a panel.

Some consideration is being given to a heat barrier glass shield being placed some distance ahead of a pressure bearing transparency. Depending on the thickness of the heat shield and the distance between this shield and the inner transparency, the cooling of the air space may or may not be necessary.

Restraint upon the expansion of the panel will have to be avoided because of the thermal deformations. Therefore, conventional mounting techniques may not be satisfactory.

Since the mechanical properties of materials for windshields and windows are such that fracture occurs without sufficient warning, the designs must incorporate fail-safe provisions. For example, the use of double panels with one panel unloaded but capable of supporting the full pressurization loads.

Windows, if incorporated, are subject to much the same conditions as the windshield.

Conclusion: The integrity and reliability of the windshield and windows must be beyond question since they are a possible opening in the pressure cabin. Tests must be conducted to demonstrate that the windshield and windows in their respective mountings will function properly under the expected operating loads and environmental conditions. In addition, the fail-safe provisions will have to be demonstrated."

3.5.2 FLIGHT DECK LAYOUT AND INSTRUMENTATION

3.5.2.1 IFALPA, July 1963, Ref. 9

"Flight Deck Layout

The physical dimensions of the flight deck of the SST should permit the safe performance of the following functions:

a. Pilotage in accordance with Federation policy;

b. Navigation;

c. Communications;

d. Systems management."

"It is probable that existing flight instruments will not meet the very different requirements of the pilot of the SST. Any new instruments which are developed should be evaluated and accepted by the pilots before operations commence."

3.5.2.2 ICAO, June 1962, Ref. 11

"The pilot's position in the nose of the aircraft will be very high above the ground and a long way from the tail; furthermore, when landing, the aeroplane may have a very high nose up attitude. These factors make it more difficult for the pilot to exercise accurate judgment, and because serious consequences could develop from errors in flight path angle during approach and landing, the opinion has been expressed that particular care will have to be taken to provide the pilot with accurate information on the attitude of the aeroplane in pitch."

3.5.2.3 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14

"Instrument panel readability -- Sufficient dampening of crew instrument panels should be provided so that engine, flight, and navigational instruments will be readable under the most severe rough air turbulent

conditions likely to be encountered."

3.5.3 COCKPIT VISIBILITY

3.5.3.1 FAA RFP, August 1963, Ref. 8

"COCKPIT VISIBILITY

Cockpit visibility shall conform with current Federal Aviation Agency and SAE S-7 standards. A reasonable degree of forward and side visibility during supersonic flight shall be provided."

3.5.3.2 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14

"Visibility from pilot's cockpit -- The visibility afforded to the crew must be as good or better than presently accepted on jet transports, particularly for takeoff, climb, approach, and landing."

3.5.3.3 FAA, March 1961, Ref. 18

"Pilot Compartment Vision (CAR 4b. 351)

At supersonic speeds, so-called conventional windshields are reported to produce a high percentage of the total airplane drag and thus materially effect the efficiency of the design.

At subsonic speeds, during the takeoff, climb, approach and landing, visibility equivalent to the present prescribed standards appear essential. At the altitudes at which transonic acceleration, supersonic climb, and cruise will be prescribed, the amount of vision necessary for slow speed operation does not appear to be required for safety reasons, but rather by psychological considerations. For speeds above 250 knots true, it is quite obvious that the see-and-be-seen concept is not suitable for collision avoidance; therefore, traffic separation must be accomplished by some precise and reliable means rather than on the

basis of visibility.

A restriction in forward visibility in the supersonic configuration associated with variable fuselage geometry does not appear to be objectionable provided there is a satisfactory backup for the mechanism so that landings can always be made by visual references.

Conclusion: The visibility requirements as presently written appear satisfactory for the supersonic transport in subsonic operation provided attention is directed to the establishment of the reference eye level relative to the critical flight path.

For the supersonic configuration, a reduction in visibility consistent with visibility needs may be tolerated."

3.5.3.5 IFALPA, July 1963, Ref. 9

"Will the pilots of the SST be able to see any parts of the aircraft whilst:

i) in their seats?

ii) in any other part of the control cabin?"

3.5.4 CREW QUALIFICATIONS

3.5.4.1 FAA RFP, August 1963, Ref. 8

"The aircraft shall be capable of being operated by regular airline jet flight airmen."

3.5.4.2 Guggenheim foundation, June 1964, Ref. 37

" RESOLUTION

ON

SUPERSONIC TRANSPORT CREW SELECTION

WHEREAS, there is every reason to believe

that very high performance, supersonic civil transport aircraft will be developed and put into extensive operation within the next eight to ten years,

WHEREAS, the operating environment of such aircraft and the demands it will make on the physical and mental attributes and the flying proficiency of crew members are likely to differ markedly from those associated with any civil aircraft operating at the present time,

WHEREAS, the practical significance of these differences is largely unknown,

WHEREAS, the Armed Forces of the United States and NASA personnel have operated in this environment in the past and will be operating there even more extensively in the future, during the developmental period for the civil supersonic transport,

WHEREAS, present crew qualifications established by the Federal Aviation Agency are, understandably, geared to the existing aircraft environment, and the operating characteristics of present-day aircraft,

BE IT THEREFORE RESOLVED:

(1) That these problems be brought to the attention of the air carriers, the labor organizations and the responsible Departments and Agencies of the United States Government.

(2) That those so notified be urged to establish programs immediately looking ahead to solution of these problems.

(3) That, among such programs, should be included the following:

(a) A joint FAA-Air Force aviation medicine program, utilizing to the maximum medical data compiled from military personnel highly exposed to the operating environment in question over the next several years and bearing particularly in mind the probable differences between the higher exposure of crew members as distinguished from passengers.

(b) A joint FAA-Air Force technical program for evaluation of the optimum crew member

characteristics for operation of aircraft in that environment.

(c) An FAA program, within its Aviation Manpower Program, aimed at determining the best way to develop sources of the most competent crews of the future to fly the supersonic transport.

(d) An airline management-labor program for resolution in advance of techniques for crew selection not dependent on the principle of seniority but designed to insure that the most physically and mentally fit and professionally competent individuals are selected.

(4) That, based on the data and evaluations thereof compiled from these programs, the FAA should initiate well in advance of the operational date for the supersonic aircraft a proposed set of appropriate physical and mental qualifications and standards of proficiency for the airmen who will comprise the crews of the supersonic transport, and should formally adopt suitable standards sufficiently in advance of the operational date for the supersonic transport to allow a reasonable period for crew selection and training to meet the standards."

3.5.4.3 IFALPA, July 1963, Ref. 9

"Licensing

An airline pilot should be enabled to operate any type of land-plane for which he is basically qualified as a licence-holder.

Comment

It is suspected that an attempt may be made to prevent some airline pilots from flying civil supersonic transport aircraft by virtue of the pilot's age, physical characteristics, educational qualifications, etc. The above Resolution is introduced for the purpose of ensuring that a pilot's license, valid for one type of aircraft such as a DC3, should be sufficient to enable the holder to add any other type, including SST aircraft, to that license, subject only to the pilot's being able to satisfy the authorities, in the normal manner, of his ability to understand and control the new aircraft.

This Resolution is also intended to oppose the possible introduction by any authority of a special type of land-plane licence for SST aircraft."

3.5.4.4 IFALPA, July 1963, Ref. 9

"Medical

All airline pilots' health should be protected against the effects, including the cumulative effects, of atmospheric abnormalities (ozone content, ionization, radiation, etc.) up to the maximum altitude to which their aircraft are permitted to fly.

Prior to the acceptance of any operations into any new atmospheric region or level, or prior to flight at speeds greater than MACH 1, conclusive medical evidence should be obtained that airline pilots' health will not be adversely affected by the new environment."

"How will an SST pilot be compensated when due to flying an SST aircraft, he either becomes permanently medically unfit or is grounded for a temporary period due to accidental over-absorption of toxic or radiation substances?"

Pay

(a) How much, in relation to existing pilots' pay, should SST pilots be paid and what formulae should be used for Mach 2.2 and 3.0 aircraft?"

3.5.5 TRAINING AND SIMULATORS

3.5.5.1 ALPA, April 1961, Ref. 16

"Crew Training

The designers and manufacturers will have a vital effect upon pilot training requirements and crew efficiency through the cockpit design and methods of systems monitoring that are provided. Close co-operation between design and development engineers and experienced, qualified air line pilots would be most valuable in establishing a sound training program.

3.5.5.2 IFALPA, July 1963, Ref. 9

"Training Problems

(a) Will pilot flying training for SST create any special problems?

(b) Will pilot technical training for SST create any special problems?"

3.5.5.3 FEIA, 1964, Ref. 38

"Future aircraft, such as the SST, will require Flight Engineers who will utilize similar training courses, as are now utilized for present day jet aircraft. The complexity of the systems which the Flight Engineer must operate and be able to analyze should a malfunction occur will materially increase. The necessity of being a technical specialist will increase. More training and technical expertise will be required. In my opinion, it is not possible at this time to write specifics regarding Flight Engineer training for the SST's but the State of the Art is such that we know that considerable more technical ability and training will be required in at least certain specific areas such as electronics, pressurization and air conditioning."

3.5.5.4 FAA, March 1961, Ref. 18

"Pilot Selection and Training (CARs 40.280, 40.281, and 40.282)

Technological advances and training methods are constantly being improved, but the physical and psychological aspects of the pilot have not, and will not, change materially. Therefore, careful screening and comprehensive training appear to offer the only avenue available to achieve the desired results to qualify pilots to operate supersonic aircraft within the operating limitations. Possibly some of the considerations used in pilot selection will be age, pilot ability, adaptability, knowledge, stability, character, reflex time study, and psychological survey together with good physical condition to insure the maximum safety and efficiency for supersonic air travel. This may require a special

pilot rating for supersonic aircraft.

The scope of the pilot training program will be dictated by the complexity of the aircraft systems, the intended operation and navigation profile. The interrelationship of design features take on new aspects, i. e., the use of fuel as the heat sink medium for temperature control. The stress aspects of built-up steel structures when cycled through a considerable temperature range, the reliance on variable duct and nozzle scheduling for satisfactory engine operation, are a few of the types of design features which the pilot not only must understand but also must know the design background, as well as the limit of operation and the possible consequence of malfunctions which may occur.

The ground school approach will be more complex and take on new and expanded areas. It should include the fundamentals of stability and control, flight dynamics, and a study of factors limiting the parameters of flight, i. e., physics and properties of the atmosphere, effects of ozone and radiation, air mass analysis, nature and altitude of tropopause, turbulence and its effect on supersonic flight, adiabatic processes, and the study of thermodynamics.

Conclusion:

Pilot selection and training will contribute a very important part in the successful operation of the supersonic transport. It is anticipated that training of flight crews will be expanded due to the complexity of the aircraft, its systems, and its operation."

3. 5. 5. 5 ICAO, August 1960, Ref. 10

"Supersonic Flight Simulators

The airlines consider the airframe manufacturers should be responsible for development of an adequate supersonic flight simulator concurrently with the development of the SST, in order that the simulator should be available well before the time the aircraft is ready for airline service."

3.5.5.6 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"Simulated training -- Investigation of incidents and accidents has revealed that little or no simulated training is provided the crews of present jet transports by some air carriers. It is believed that an important facet in the development, certification, and operation of an SST is the simultaneous design, construction, and use of a highly sophisticated flight simulator with a visual attachment and realistic "G" force capabilities so that a continuous training program can be conducted under all anticipated flight conditions. This is especially important since there may be more frequent intervals between flights and possible loss of crew proficiency."

3.5.5.7 FAA, March 1961, Ref. 18

"Synthetic Trainers (CAR 40.286.1)

Considerable thought and study is being given to supersonic flight simulators which simulate a wide latitude of aircraft response rates and different types of controlability problems under supersonic flight conditions. It has been suggested by interested groups that the supersonic transport will normally be flown by an automatic flight control system, and operated under precise flight profiles; therefore, pilots may need additional simulator time to engage in flight maneuvers and emergency procedures to retain adequate flight proficiency.

In addition, aircraft flights for crew training will be held to a minimum due to the high costs involved, undesirable airport takeoff noise, and sonic boom problems during transition acceleration.

Conclusion:

Synthetic trainers or flight simulators for supersonic transports may contribute a greater part in maintaining crew proficiency than realized at this time by the subsonic simulator. This concept may depend on the development of a supersonic simulator which will accurately reproduce the operation of aircraft systems, engine functions, flight control characteristics, identification of emergencies and proper correction procedures."

3.5.6 ANALYSIS AND COMMENTS

3.5.6.1 ANALYSIS - (3.5.2 Flight Deck Layout and Instrumentation)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training					X	3.5.6.2.1	
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance	X	3.5.6.2.2					
FLIGHT DECK DESIGN							
Layout					X	3.5.6.2.1	
Instrumentation					X	3.5.6.2.1	
Controls					X	3.5.6.2.1	

3.5.6.2 COMMENTS - (3.5.2 Flight Deck Layout and Instrumentation)

3.5.6.2.1 The instrumentation of the SST may introduce many new visual display concepts, and do away with out-dated instruments. Before the SST is introduced into service, extensive training will be required to ready the crews for transition. The views, experiences, and attitudes of flight crews should be integrated with other consideration in the development of flight deck layout and instrumentation.

3.5.6.2.2 If a "revolutionary" new approach to cockpit design is ever to be pursued in commercial aviation, the SST era is obviously the time. There are many controversial issues involved in the revolutionary versus evolutionary approach to the SST, and many of these issues will be investigated in this study. In either case the crew acceptance of "their" cockpit will be a critical issue.

3.5.6.3 ANALYSIS - (3.5.3 Cockpit Visibility)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training		X 3.5.6.4.1		
OPERATIONAL VARIABLES				
Responsibility	X 3.5.6.4.1			X
Authority				
Acceptance		X 3.5.6.4.1		
FLIGHT DECK DESIGN				
Layout		X 3.5.6.4.1		
Instrumentation				X
Controls				X

3.5.6.4 COMMENTS - (3.5.3 Cockpit Visibility)

3.5.6.4.1 Although the RFP calls for visibility equivalent to current aircraft, structural feasibility may dictate reduced visibility as we know it today. Design features are being considered to enhance visibility. Poor visibility actually reduces the authority of the men to carry out their responsibilities.

Whatever the final layout and method devised, it must be remembered that the aircraft still needs an approved visibility capability which is independent of automatic systems to be acceptable to the crew.

3.5.6.5 ANALYSIS - (3.5.4 Crew Qualifications)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications		X 3.5.6.6.1		
Composition	X			
Training		X		
OPERATIONAL VARIABLES				
Responsibility	X			
Authority		X		
Acceptance		X		
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.5.6.6 COMMENTS - (3.5.4 Crew Qualifications)

3.5.6.6.1 The question of SST crew qualifications is a complex one and it is intended that the data developed during this study will be beneficial for making decisions about qualifications. At this time it would appear that qualifications will have to be somewhat different than today's jet crews - yet, there is no reason to believe that SST crews need to possess unique or rare qualifications. Qualifications will have to be determined in conjunction with considerations of flight deck design, specific crew responsibility and authority, and training.

3.5.6.7 ANALYSIS - (3.5.5 Training and Simulators)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications	X 3.5.6.8.1			
Composition	X 3.5.6.8.1			
Training	X 3.5.6.8.1			
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout		X 3.5.6.8.2		
Instrumentation		X 3.5.6.8.2		
Controls		X 3.5.6.8.2		

3.5.6.8 COMMENTS - (3.5.5 Training and Simulators)

3.5.6.8.1 Training and simulation will be one of the most important phases in the transition to supersonic flight. In fact in this area an adequate program must be developed so that personnel may be disqualified for sound reasons prior to actual SST flight time.

Training programs and simulators produced must be capable

of taking current subsonic crews, acquainting them with the new characteristics and instrumentation, and training them to perform efficiently in the SST. Development of the required characteristics of SST simulators for evaluation and training will be a significant effort which should be started early in the SST program.

3. 5. 6. 8. 2 The basic simulation and training program can be utilized by designers for evaluation of proposed flight deck layouts and instrumentation.

3.6 PASSENGER COMPARTMENT

3.6.1 WINDOWS

3.6.1.1 FAA RFP, August 1963, Ref. 8

"Windows shall be required in the passenger compartment."

3.6.1.2 ICAO, August 1960, Ref. 10

"The possibility of increasing the structural integrity of the cabin by doing without windows has been mentioned, but it is doubtful whether this would be acceptable to the travelling public. The opinion has been expressed by a manufacturer that effective reliable windows can be developed for a Mach 3 aeroplane."

3.6.2 INTERIOR DESIGN

3.6.2.1 IATA, May 1964, Ref. 13

"Airlines' requirements for interior layouts will necessarily vary with regard to such features as toilets, galleys and seating arrangements. Therefore, manufacturers must design the interior of the SST on a modular basis in order to permit the maximum possible flexibility in meeting individual airlines' requirements.

3.6.3 ANALYSIS AND COMMENTS

3.6.3.1 ANALYSIS - (3.6.1 Windows)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training				X
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.6.3.2 COMMENTS - (3.6.1 Windows)

3.6.1.1 Windows in the passenger compartment should have no effect on the performance capabilities of the crew. Finding materials to withstand the supersonic environment will be the problem of design sections. Provisions might be made to have variable shielding available for the supersonic phase to alleviate structural problems.

The necessity of windows stems from an acceptance need of the passengers. However, it has been suggested that entertainment and possibly close circuit television be used to eliminate the need for windows.

3.6.3.3 ANALYSIS - (3.6.2 Interior Design)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training				X
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.6.3.4 COMMENTS - (3.6.2 Interior Design)

This area of the aircraft's structure should not affect the crew. The interiors will probably be very similar to today's designs -- with an effort being made to increase utility with a corresponding reduction in weight.

3.7 FUNCTIONAL PERFORMANCE CHARACTERISTICS

3.7.1 GENERAL

3.7.1.1 ALPA, April 1961, Ref. 16

"Realistic Accelerate-Stop Distances

The development of rational regulatory requirements for establishing realistic accelerate-stop and landing runway distances should be an immediate common effort of all segments of the industry. This is needed NOW."

3.7.2 FLIGHT PLANNING

3.7.2.1 ALDA, September 1964, (Private Communication)

"Operational crew task requirements for long-haul commercial airline flying are greatly affected by the problems of (1) pre-planning the flight operation and (2) re-evaluating -- changing the plan -- once enroute. These planning functions are generally the responsibility of airline dispatchers.

The critical nature of this planning is well understood. It gains in importance as equipment becomes more elaborate as to performance capability and as the operators exploit these possibilities to increase the earning or competitive power of the equipment.

A continuity of analysis, considerable lead-time, and special work tools and procedures are required to plan properly. It cannot be done adequately by the crew. Nevertheless, a requirement continues that the crew be able to evaluate the plan, and changes thereto, in terms of flight safety. A large part of crew training and checks is devoted to this competency.

With the SST, we expect much more sophisticated planning methods machinery, and data transmission systems than are presently used. In the early

stages, of course, we can confidently expect that the demand for these improvements will outrace the supply of them, and this will throw an important capability-burden upon the crew."

3.7.2.2 IFALPA, July 1963, Ref. 9

"Prior to acceleration beyond subsonic speed, it should be obligatory that the details of the time, height and location at which the aircraft is due to return to subsonic speeds be known in advance to the pilot-in-command."

3.7.3 TAKEOFF AND CLIMB

3.7.3.1 FAA RFP, August 1963, Ref. 8

"Take-Off and Landing Speeds

The take-off and landing speeds shall be comparable with present intercontinental subsonic jet aircraft. At maximum gross take-off weight, the objective is to establish lift-off speed in the order of 160 knots (EAS). The objective is to achieve a boundary speed in the order of 135 knots or less (EAS)."

"Crosswind Capability

The aircraft shall have the ability to take off and land in 30 knots, 90-degree crosswinds."

"Take-Off Distances

The aircraft shall have the ability to take off from a 10,500 foot runway at maximum design take-off gross weight in an ISA + 15° C hot day atmosphere at sea level."

3.7.3.2 IATA, May 1964, Ref. 13

"Take-off: Maximum acceleration during take-off will be approximately 0.3 g to 0.4 g which should result in shorter take-off distances than for the present subsonic jets.

Climb: The maximum rate of climb (in subsonic flight) will be 25.5 to 51 metres per second (5,000 to 10,000 feet/minute)."

3.7.3.3 FAA (as reported in the Journal of Air Law and Commerce) 1964, Ref. 14

"The aircraft must accelerate through the transonic speed regimes at altitudes above 40,000 feet . . ." (Halaby)

3.7.3.4 FAA, March 1961, Ref. 18

"4. Takeoff Performance Determination (CAR 4T.113)

The procedures and requirements contained in the present regulations pertaining to the determination of takeoff runway lengths are considered appropriate for the supersonic transport.

The present requirements do not contain accountability for variations in runway surface conditions and the effects of crosswind.

The minimum takeoff safety speed V_2 is presently related to the stall speed, which speed, as pointed out earlier, is not a satisfactory datum to be used for establishing safety in the takeoff maneuver.

Certain objective portions of the present requirements do retain their value in establishing the necessary level of safety when applied to the supersonic transport as it is generally visualized. Other portions of the takeoff requirements, notably the specific and restrictive limitations on the takeoff procedures, need to be reexamined.

With respect to the rejected takeoff case, a number of factors which have an important bearing on the level of safety provided should be considered, for there is presently no performance margin available to account for runway surface conditions (poor braking coefficients), brakes which have been subjected to wear and the effects of crosswinds.

Because of the increased speeds envisioned in the takeoff of the supersonic jet, the seriousness of the currently unaccounted factors will be increased.

Conclusion: The subject of takeoff field length determination should be reexamined on a rational basis with consideration given to the possible variations in the operational schedule for actual runway conditions and wind."

3.7.4 CRUISE

3.7.4.1 FAA, March 1961, Ref. 18

"2. Route Requirements (CAR 40.30)

At this time, it is considered essential to operate supersonic aircraft at high altitudes over the shortest direct route for the maximum range, fuel reserve, and economy, rather than conform to designated airways, unless the airway lies approximately in a straight line between the points to be flown.

The best range is obtained by operating the supersonic aircraft near the maximum allowable Mach number established for high altitude cruise condition. Fuel burnoff rate is expected to be high. Therefore, as the weight decreases, greater utilization can be effected by operating in a climbing en route profile rather than reducing thrust output, since turbine-powered aircraft operate more efficiently at the higher altitudes.

Studies have been conducted on the range of a Mach 3 transport flown at Mach 0.9 at a lower altitude with all engines operating. Some results indicate that the range of the aircraft would not be affected appreciably when compared to operating at altitudes of 70,000 feet and possibly up to Mach 3 speeds; however, the flight time would be proportionately increased. This type of operation could be used for en route slowdown to fit into destination approach procedures which would tend to eliminate holding in traffic patterns.

At 60,000 to 80,000 feet altitudes where Mach 3 aircraft are expected to operate, the wind velocities are reported to be low and have very little directional significance.

Conclusion:

Operation of supersonic aircraft at high altitudes will normally be accomplished above the weather in the temperate and arctic latitudes which facilitates straight-line flights. This route may also be considered part of the accelerated climb profile and descent slowdown to subsonic flight prior to destination. "

3.7.5 HOLDING

3.7.5.1 FAA RFP, August 1963, Ref. 8

(Under a discussion of "Fuel Reserves" in the RFP a hold requirement is identified)

". . . a 30- minute hold at an altitude of 15,000 feet."

3.7.6 APPROACH AND LANDING

3.7.6.1 FAA RFP, August 1963, Ref. 8

"Normal Approach and Landing Characteristics

The airplane shall possess characteristics in approach and landing configurations which will enable instrument landing system (ILS) approaches to be conducted by airline flight crews to weather minimums of 200 feet and 1/2 mile without assistance from an approach coupler and/or flight director or other computing navigation devices.

Instrument Approach Capability

The airplane shall incorporate additional computing/display type equipment and/or automatic flight control equipment which will enable airline flight crews to satisfactorily complete ILS approaches to the runway threshold under ceiling and visibility conditions of "zero-zero."

Automatic Landing Capability

The airplane will be capable of utilizing automatic landing equipment."

"Take-Off and Landing Speeds

The take-off and landing speeds shall be comparable with present intercontinental subsonic jet aircraft. At maximum gross take-off weight, the objective is to establish lift-off speed in the order of 160 knots (EAS). The objective is to achieve a boundary speed in the order of 135 knots or less (EAS).

Crosswind Capability

The aircraft shall have the ability to take off and land in 30 knots, 90-degree crosswinds.

Landing Distances

The required runway length shall not exceed 8,000 feet under wet runway conditions with the aircraft at maximum authorized landing gross weight."

"Go-Around Capability

The transport shall have a go-around capability equivalent to that of the subsonic jet transports used in international service."

3.7.6.2 FAA, March 1961, Ref. 18

"5. Landing Distance Determination (CAR 4T. 122)

Some of the airplane configurations presently considered necessary for the supersonic transport may result in landing speeds considerably higher than those presently in evidence and also landing distance essentially equal to the takeoff distance.

Presently, the landing distance determination is performed in a manner not entirely consistent with daily operating practices, and the values thus established are increased by arbitrary factors which are intended to compensate for some of the variables encountered in service.

B - FLIGHT

Decelerating devices other than brakes have been incorporated on all modern transport airplanes, but there has been some hesitancy to employ full credit for these devices pending a more rational handling of all of the variables affecting safety.

One method suggested for solution of the landing distance problem is outlined as follows:

1. Landings would be scheduled for a reasonably critical runway surface and condition, and they would be measured for the all-engine-operating and the one and two-engine-inoperative conditions and scheduled for the most critical for the particular operation.

2. Approach and landing procedures consistent with operational realities would be used conservatively in establishing landing distances and followed in actual operation.

3. Combinations of available means for deceleration, shown to be dependable, may be utilized in establishing the landing distances.

4. Safety margins would be added to the actual distance only to the extent necessary to account for more critical runway surfaces and conditions and for variations in operational factors and piloting techniques. Further, the magnitude of the safety margins would vary depending upon the number of decelerating devices assumed inoperative.

Conclusion: Due to the anticipated importance of the landing field length determination and the scheduled operational values, it appears wise that this stage of flight should be the subject of a reevaluation taking into account the effects of all important factors."

3.7.6.3 IFALPA, July 1963, Ref. 9

"The take-off and landing distances required for the SST should take account of the greater distances consumed from initiation of flare-out to touchdown, and from touchdown to the lowering of nose gear onto the runway, as indicated by studies already conducted by authoritative agencies."

3.7.6.4 ICAO, August 1960, Ref. 10

"Approach: Because of the low wing loading there seems to be no necessity to design the aeroplane with an approach speed much higher than the approach speeds of subsonic jet aeroplanes. One opinion has been expressed that any substantial increase in approach speed above 140 knots would lead to additional air traffic control difficulties in the landing phase and to restrictions likely to result in a design penalty for the aircraft. In this connection, it is relevant to record that, when the present ICAO Procedures for Air Navigation Services, Holding and Approach-to-Land, were prepared, it was assumed that the true airspeed for holding and approach would not be less than 90 knots or more than 150 knots.

Landing: Landing speeds also should not exceed those of subsonic jets by more than a small amount. However, it has been noted that one out of every 100 landings of current flights of subsonic jet aeroplanes is made above a speed of 160 knots. Because its landing speed is slightly higher, the landing distance for the Mach 3 aeroplane will be slightly longer than that for the current subsonic jet aeroplanes. However, the subsonic jet aeroplanes require substantially more distance for take-off and the runway length adequate for both take-off and landing is not expected to exceed that required by present subsonic jets. A length of 3,050 metres (10,000 feet) at sea-level under International Standard Atmosphere Conditions should suffice."

3.7.6.5 FAA, March 1961, Ref. 18

"Instrument Approach Procedures (CAR 40.364)

Supersonic transports with delta wing configurations will possibly require higher approach speeds in maintaining ILS glide path descents than conventional aircraft due to the high sink rate at low speeds of this supersonic wing design. Therefore, this may require higher weather minimums due to reduced transition time for aircraft flare and landing. Emphasis should be placed on development of an all-weather approach and landing system. It is anticipated that in high density areas under instrument conditions, an aircraft which has been through a missed approach, may not be able to proceed to an alternate without a climb restriction or some other delaying terminal procedure.

Conclusion:

Traffic control and instrument flight procedures for supersonic operation should require comprehensive planning. Special consideration should be given to the automatic approach and landing systems to eliminate missed approaches and alternate airport problems."

3.7.7 ANALYSIS AND COMMENTS

3.7.7.1 ANALYSIS - (3.7.2 Flight Planning)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X	3.7.7.2.1					
Composition							X
Training	X	3.7.7.2.1					
OPERATIONAL VARIABLES							
Responsibility					X	(3.7.7.2.1)	
Authority					X	(3.7.7.2.1)	
Acceptance							X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.7.7.2 COMMENTS - (3.7.2 Flight Planning)

3.7.7.2.1 Even with the improvements scheduled to aid the flight planning stage of flight, it is not anticipated that the role of the crew will be noticeably affected. Some of the work load will be alleviated in pre-flight planning but use of automated or "canned" flight plans. Changes of the flight plan during flight will be more difficult because of the increased ground speed and rapid error accumulation.

3.7.7.3 ANALYSIS - (3.7.3 Takeoff and Climb)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X	3.7.7.4.1					
Composition	X	3.7.7.4.1					
Training	X	3.7.7.4.1	X				
OPERATIONAL VARIABLES							
Responsibility	X	3.7.7.4.1	X				
Authority	X	3.7.7.4.1	X				
Acceptance	X	3.7.7.4.1	X				
FLIGHT DECK DESIGN							
Layout							
Instrumentation							
Controls							

3.7.7.4 COMMENTS - (3.7.3 Takeoff and Climb)

3.7.7.4.1 The take-off of the SST will be similar to current jet aircraft. The aircraft will probably be leaving the runway sooner, and be established on its climb schedule sooner than current carriers. Reduction of power soon after lift-off for purposes of noise abatement should not raise serious concern because of the aircraft's high thrust-to-weight ratio.

The climb profile restriction placed on the SST will introduce new procedures, and require extensive study and training. The climb will be a series of constant speed and mach climbs which will require more crew attention. Increased speed will mean that "level-offs" will have to be anticipated well in advance to avoid "overshoots".

Another area of crew concern in the climb phase is the decreasing EAS as the aircraft climbs subsonically to above 40,000 feet. The aircraft begins to operate on the back side of the power curve and any erratic maneuver or turbulence could cause a stall. Studies will have to be conducted to determine the margins of safety required to operate in this area. This could pose severe acceptance and serious training problems to the crew.

3.7.7.5 ANALYSIS - (3.7.4 Cruise)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications	X			
Composition	X			
Training	X			
OPERATIONAL VARIABLES				
Responsibility	X			
Authority	X			
Acceptance	X			
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.7.7.6 COMMENTS - (3.7.4 Cruise)

3.7.7.6.1 The cruise phase of SST operations should not change the crew or operational variables because of the proposed operational procedures. Since the systems will be almost completely automated, the crew will act primarily as monitors during normal flight.

3.7.7.7 ANALYSIS - (3.7.5 Holding)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X	3.7.7.8.1					
Composition	X	3.7.7.8.1					
Training	X	3.7.7.8.1					
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.7.7.8 COMMENTS - (3.7.5 Holding)

3.7.7.8.1 Holding can be a very costly procedure, and every effort should be made to avoid it. At high speeds holding patterns take up large amounts of air space and use up considerable fuel. Therefore, the only problem introduced by holding is economics. If the proposed air traffic control system accomplishes all of its goals, then only short delays should be anticipated.

3.7.7.9 ANALYSIS - (3.7.6 Approach and Landing)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X	3.7.7.10.1					
Composition	X	3.7.7.10.1					
Training	X	3.7.7.10.1					
OPERATIONAL VARIABLES							
Responsibility	X	3.7.7.10.1					
Authority							
Acceptance	X	3.7.7.10.1					
FLIGHT DECK DESIGN							
Layout			X	3.7.7.10.1			
Instrumentation					X	3.7.7.10.1	
Controls			X	3.7.7.10.1			

3.7.7.10 COMMENTS - (3.7.6 Approach and Landing)

3.7.7.10.1 Approach and landing in the SST can probably be completely automatic which will expedite traffic flow and mean that approaches can be made to lower minimums. Of course the acceptance of this type of system by the crew will depend on both system reliability and the crews indoctrination. Satisfactory monitoring of automatic landing, both from a performance and acceptance standpoint, will undoubtedly require unique instrumentation.

3.8 SUBSYSTEM

3.8.1 GENERAL

3.8.1.1 IATA, May 1964, Ref. 13

"The controllability and stability of the aircraft should be such that it is controllable in the event of any two failures occurring in a system.

Because at least some SST designs appear likely to exhibit undesirable attitude and speed characteristics during approach, manufacturers' attention is drawn to the fact that such characteristics must be compensated for by providing very good handling qualities for these designs in the low speed regime; similarly, the take-off regime requires careful attention. It is considered, therefore, that manufacturers should do their utmost to improve the situation as much as possible."

3.8.1.2 ICAO, August 1960, Ref. 10

"In due course it is expected that climb and descent may also be made automatically by a pre-programmed tape operating through the automatic pilot, but this may not have been achieved when the Mach 3 aeroplanes are first put into service."

3.8.1.3 IATA, June 1962, Ref. 12

"Good aircraft control response and handling characteristics are essential to safe operation. They are important at all speeds but particularly in the low speed regime. Control response and handling characteristics of the SST must therefore be comparable to, or better than, those of subsonic aircraft."

3.8.2 FLIGHT CONTROLS

3.8.2.1 FAA, March 1961, Ref. 18

"A study of the mission profile and speed capabilities of the supersonic transport indicates an increase in the time involved in extensive speed changes. Speed changes could be accomplished within the time/force capabilities of the pilot by providing relatively low stickforce per knot stability or by greater use of longitudinal trim for airplanes with high stickforce gradients.

At speeds above those used in the airport vicinity, and in the initial subsonic climb-out and subsonic descent, there appears to be no reason for the design to provide maneuverability by means of primary controls, that would produce accelerations greater than the normal passenger tolerance threshold of .5 "g" applied.

By providing stickforce per "g" and stickforce per knot characteristics, higher than those of present transports, the possibility of inadvertently introducing unnecessary high accelerations would be reduced.

Such a design, incorporating essentially a limited authority primary longitudinal control, would, of course, place emphasis on the proper rate of response and the reliability of the secondary longitudinal control (i. e., trim) system.

Regardless of the degree to which this principle is employed, it is important that the design be such as to carefully match the rate-of-trim change provided by the system with the trim change required when the airplane is accelerating, decelerating, or in the process of configuration change.

The supersonic transport should be designed with a control effectiveness control force/speed relationship which will tend to prevent excessive accelerations from inadvertent control motions. The rate-of-trim change should be matched to that occurring with changes in configuration and speed.

In the past, it was considered satisfactory for the rudder forces involved in controlling the airplane under the condition of engine failure to be as high as 180 pounds.

It was assumed that rudder forces of this magnitude would exist only for the short period of time associated with the transition to the higher speeds at which climb would be accomplished.

Because of the difference in thrust versus velocity with the turbojet engine and that of the reciprocating engine and because of the directional control systems that are envisioned, it is considered important that the designer endeavor to provide a system which does not require rudder forces in excess of 90 pounds at the minimum control speed.

Although manual directional trimming should be capable of reducing the rudder force required to a low value at the takeoff climb safety speed and to zero force at a higher speed, it will be typical of operation that all of the rudder force will not be removed in the approach to landing condition because of the requirement for rapidly trimming during the thrust reductions necessary to effect the landing.

Because of the seriousness of excessive yaw following engine failure in high-speed flight, it is anticipated that supersonic designs will probably incorporate engine locations relatively close to the fuselage centerline, thereby minimizing the need for a directional control incorporating large hinge moments.

The reduced rudder effectiveness required for the engine-inoperative conditions may result in the selection of the required rudder effectiveness on the basis of the crosswind controllability condition.

Closely associated with the determination of the airborne minimum control speed is the determination of a satisfactory minimum critical engine-failure speed, V_1, at which the takeoff can be continued without employing exceptional skill. In view of the importance which is attached to the safety of the takeoff maneuver under the condition of engine failure at V_1, it appears that a more logical expression of the objective in this regime could be accomplished by defining permissible limitations of lateral deviation and percent of control effectiveness used in performing a continuous takeoff with a critical engine inoperative at V_1 min.

There exists considerable well documented flight test data depicting pilot reaction time and rudder force capabilities which, together with the experience gained in training regarding human force capabilities for extended periods of time, could be used to reevaluate the requirements for minimum control speed.

Because of the serious concern which is felt by many line pilots for the demands upon them during an engine failure on takeoff, the permissible force and deviation values for this maneuver should be redefined with an objective of providing an airplane behavior and rudder force easily handled in the engine-failure condition.

The present specific trim requirements are not appropriate for the various stabilized flight conditions envisioned for the supersonic transport because its normal operation will encompass a greatly expanded speed spectrum including the discontinuities of transonic aerodynamics.

The subsonic trim concept assumed that, if trim was satisfactory at low speed and at high speed, then would exist the ability to trim at all intermediate speeds. Because of aerodynamic changes in the transonic region, this assumption is no longer valid.

The ability to trim all control forces to zero during any sustained flight condition is believed to be a basic objective of a satisfactory design because it provides the pilot a benchmark or reference for the selected steady state and one from which desired changes can be initiated.

The length of time required for acceleration from climb speed to the maximum supersonic speed, as well as for deceleration back to descent speed, is anticipated to be of such duration as to require the continuous ability to trim.

As mentioned previously, the use of a stall speed as a datum does not appear suitable for the swept-wing airplane. Further, the practice of stipulating the required trim speed as a multiple of some low-speed datum . . . appears to prejudge the desirable and normal procedures and practices which will be developed for operating these new airplanes.

One additional aspect of the trim characteristics to which attention should be drawn in design is the rate-of-trim change. At high speeds, the trim rate should be slow enough to preclude trim "overshoot" of the introduction of objectional airplane accelerations. At low speeds and during configuration changes, the rate of

response of the trimming device should be matched to that required in maneuvering the airplane in all required maneuvers and transitions so that the pilot may, with little effort, continually maintain a null of elevator force.

Longitudinal trim is considered to be an essential requirement for each combination of speed and normal configuration which is maintained in steady state within the permissible limits of the flight profile. The rate-of-trim change should correspond to that required to effect necessary changes in speed and configuration.

Directional and lateral trim sufficient for rectilinear flight should be available for any steady state condition with all engines operating and with the engine-inoperative conditions and speeds at which compliance is shown with the performance requirement.

The contribution of good longitudinal stability characteristics in achieving precise speed control is well recognized. The ease with which good speed control is achieved will be of considerable importance in accomplishing the "on design" flight profile which may be essential for structural reasons as well as for mission accomplishment if only rational fuel reserves are to be stipulated.

As mentioned under the discussions of "controllability," limited authority longitudinal control may be an attractive means of precluding excessive accelerations at high speed. Limited authority, could be achieved by limited control effectiveness, by steep stickforce gradients involving high forces, high stickforce per "g" or a combination of these approaches.

With an airplane which is not required, by its use, to be highly maneuverable, the presence of a steep stickforce gradient would not be objectionable to the pilot if longitudinal trim of the proper rate was readily available together with an exceptionally small "friction band." It is believed that an airplane possessing these characteristics in the proper proportion would have the "solid feeling" which is important for precise mission accomplishment.

Stability requirements which were applied to slow subsonic airplanes were specified for the configurations associated with climb, cruise, approach and landing and with the speeds (except for cruise) corresponding to

fixed arbitrary relationship to the stall speed. In addition, the range of speeds through which the airplane was required to possess a stable stickforce, was expressed as a percentage of the trim speed or through a speed range which again was expressed in terms of multiples of the stall speed and which by their values assumed a rather wide maneuvering range without retrimming. Application of the present subsonic stability requirements to the supersonic transport would have the effect of requiring a reduction of control force so as to achieve the ability to change the speed by primary aerodynamic controls alone over a range of several hundred knots. This characteristic is not only undesirable but in some cases, could result in an unsafe condition.

The piloting technique or practice presently employed in high speed subsonic airplanes involves continuous trimming, or trim follow up, during large speed changes. It is important however for proper sensing of speed changes that the stickforce be stable during departure from any trim point through the speed range.

Static longitudinal stability should be present at those speeds and in the configurations for which sustained flight is to be conducted. A pull force should be required to obtain and maintain in speeds below the trim speed, and a push force should be required to obtain and maintain speeds above the specified trim speed. This criterion should apply over the speed range involving departures from trim which could be obtained with a force of 50 pounds.

A maneuvering stability criteria should also be developed. It has been suggested that the stickforce per "g" should be substantially linear up to the limit load factor or to a load factor at which 100 pounds is required, whichever occurs first. The stickforce value should not be less than 30 pounds for an acceleration increment of one "g"

The permissible friction band should be redefined.

There have been several approaches used in defining acceptable parameters for directional and lateral stability.

The introduction of sophisticated directional and lateral control systems has brought about characteristics

not previously encountered which have a considerable bearing upon the precision with which a desired airplane motion can be commanded and achieved. This characteristic has been reflected in the amount of time required for pilots to transition to new equipment.

In its simplest form, the problem can be identified as a nonlinearity of airplane response versus control force. The problem may however be complicated by the nonlinearity of control motion or position versus effectiveness. The combined effect may result in a tendency for the pilot to undercontrol when small displacements are desired following which he overcontrols when slightly large displacements are desired or when motions must be corrected.

The experienced development or test pilot who is conditioned by a wide variety of airplanes and response characteristics may not experience difficulty with nonlinear responses and may insist on development improvements only to the degree corresponding to the balance between cost, time and the achievement of qualities believed to be suitable in terms of his capabilities.

The "user" pilot on the other hand, having been conditioned primarily on one type of airplane will experience difficulty in achieving proficiency on an airplane which has nonlinear response characteristics, but what is more serious, may "revert back to type" when saturated with other tasks or emergencies such as engine failure or systems failure.

The standards for directional and lateral stability should be expanded to include the permissible relationship between control input and airplane response."

3.8.2.2 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"Every SST aircraft should be controllable as desired by either the pilot or the co-pilot throughout its entire speed regime, including the transition stage from subsonic to supersonic speed and vice-versa. Such control should be available at all times, including all foreseeable emergency conditions.

If reliance is placed on Boundary Layer Control systems, the integrity of such systems should first be demonstrated

to the satisfaction of the Federation."

3.8.2.3 IFALPA, July 1963, Ref. 9

"The Federation requires that any problems created by new type flight controls (such as canard type elevators) should be discussed with the appropriate pilot group, and the solutions adopted by the manufacturers of the aircraft should be demonstrated to be completely satisfactory before the aircraft is introduced into service.

The flight controls of the SST should be demonstrated to provide no undue handling problems to pilots, notwithstanding the problems arising from the configuration eventually adopted for the airframe and flight controls.

If automatic flight control sub-systems such as yaw or pitch damping are adopted, full protection should be provided against failure, if such a failure would materially worsen the aircraft's handling characteristics.

3.8.2.4 ALPA, April 1961, Ref. 16

"Manual handling characteristics of the flight controls must be provided for normal and emergency use in all regimes of flight. Past experience with control systems has convinced pilots that such a fail-safe feature is essential in any commercial transport irrespective of its ultimate speed range. Aircraft design should be based on this concept. Below the supersonic speeds the flight control system should provide a "feel" which the pilots can recognize, interpret and utilize in controlling and manoeuvring the airplane whenever necessary."

3.8.2.5 ICAO, June 1962, Ref. 11

"Because of the control forces involved a powered system must be used for the primary flight controls, and the necessary degree of reliability obtained by duplicating this system or parts of it. A simple back-up system will be provided so that the pilot may control the aeroplane in emergencies, for example if augmentation devices or trim devices fail. The design of a satisfactory control system will involve theoretical calcula-

tions, laboratory tests, and the use of piloted simulators, as well as actual flight tests on aeroplanes. As mentioned in the Preliminary Study automatic pilots will be used most of the time and the autopilot will have to be properly integrated with the augmented control system."

3.8.2.6 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"There must be a decided improvement in positive controllability as to feel and control force gradients. Control forces must be positive at all times and there must be a gradual increase in control forces from any trim condition up to the maximum movement of control deflection.

The aircraft must demonstrate positive stability about all axes."

3.8.2.7 ICAO, June 1962, Ref. 11

"The primary control system is expected to be a powered irreversible system. The pilot must be able to control the aircraft directly in all phases of flight, but the automatic pilot is likely to be relied upon to a greater extent than in the past. Automatic landing systems are now being actively developed, and by the time the Mach 3 transport enters into service these systems should be sufficiently reliable and standardized to permit all the aircraft to be fitted with the airborne equipment necessary for automatic landing in bad weather conditions. It is expected that take-off directors will be fitted and it has been suggested that provision will be made for automatic take-off and overshoot together with the associated monitoring equipment."

3.8.2.8 ICAO, June 1962, Ref. 11

"Many forms of automatic landing systems are at present being experimented with for use with subsonic jet aeroplanes. The need for an automatic landing system will be reinforced by the introduction of supersonic aircraft; it has been suggested that ICAO should examine the development of the ground-based part of the systems,

and assess the extent and cost of any special services required by supersonic aircraft exclusively, or sooner, or to a greater scale than would otherwise be required. It will take some time to develop a system that will be sufficiently accurate and reliable to permit automatic landings under all weather conditions, but a substantial decrease in airport weather minima is expected to result from the development of automatic landing systems that should be operational in the period 1970 to 1975. It is generally agreed that, however effective any automatic system may be, the aeroplane must be so designed that it can be landed and taken-off by the human pilot."

3.8.3 POWER PLANT

3.8.3.1 FAA RFP, August 1963, Ref. 8

"The engine shall be designed to obtain forward and reverse thrust, fuel consumption and installed weight for optimum performance in relationship to airframe design(s) and airline flight operations requirements.

In the design of the engine power control and ignition systems special consideration shall be given to:

a. Rapid thrust modulation over the operating range of the engine between idle and maximum thrust.

b. Effects of engine inlet conditions for both standard and nonstandard day operating conditions on the power control.

c. Reliable and safe regulation of all engine transients.

d. Aerial restarting capability in the supersonic and subsonic cruise environments.

e. Automatic engine control which provides the most economical operating conditions for a selected thrust level.

f. Effect of inlet flow distortion on engine performance.

g. Maximum ground starting time of not more than 60 seconds under all ambient conditions.

The engine lubricating system shall be completely selfcontained and self-sufficient.

Allowable distortion levels shall not result in significant engine performance degradation. Inlet unstart and instability and their related effects upon engine operations and flight safety shall be specifically demonstrated under conditions equivalent to full scale supersonic operation.

The requirement for automatic sequencing of engine and inlet controls for inflight restarting shall be determined.

The design shall consider safe means for reducing engine speed and resultant drag in the event of an inflight shutdown, with the engine fuel supply shut off, so that the aircraft can complete its flight supersonically. The aerodynamic braking feature may be incorporated in the basic engine or the powerplant installation.

Economy in the maintenance and overhaul operations shall be emphasized in the design. Consideration shall be given to designing the engine such that frequent inspection and replacement of critical maintenance items can be accomplished without disassembly of major engine components. Examples are combustion chamber liner(s), transition liner(s), etc.

The engine shall be designed to permit eventual attainment of minimum time between overhauls (TBO) of 3000 hours.

Initial in-service engines shall have a TBO of not less than 600 hours, substantiated by extended endurance testing.

The engine, including complete exhaust system as defined in aircraft configuration, shall be required to complete a test of 75 hours duration with a minimum of 25 hours at simulated supersonic transport flight altitude and speed conditions. Engine system components, if developed by the airframe contractor (e. g., nozzle and thrust reverser), shall be subjected to this FTS qualification test.

Power settings listed below assume augmentation during take-off, climb, transonic acceleration and cruise. If

augmentation is not utilized, or for only a portion of the flight trajectory, the test shall be modified accordingly."

3.8.3.2 IFALPA, July 1963, Ref. 9

"If variable geometry intake and exhaust systems are adopted for the SST, the Federation requires that the problems of possible asymmetry be designed out of the aircraft by fail-safe or other acceptable techniques and that this requirement be satisfactorily demonstrated to IFALPA before any operations commence.

The disposition and arrangements of the power-plants of the SST should be such as to preclude the ingestion of any foreign objects, ice, slush or water during ground manoeuvring (take-off, landings and taxying) or in flight when ice etc., may be shed from aircraft surfaces.

The power plants installed in the SST should undergo such test schedules as are required to establish a reliability not inferior to the power plants of current subsonic aircraft types.

It should be demonstrated that the failure or operating abnormality of any one engine does not prejudice the continued operation of the remaining engines."

3.8.4 FUEL

3.8.4.1 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14

"Preliminary information made available regarding the fuel systems of SST aircraft suggest that the problem areas include:

i Fuel temperatures within the fuel tanks;
ii Thermal degradation of fuel;
iii Fuel balance,

and the problems associated with the safe delivery of the enormous quantities required."

3. 8. 4. 2 ICAO, August 1960, Ref. 10

"The fuel itself is expected to be a petroleum derivative, somewhat similar to the kerosene type fuels used in subsonic jets but specially blended to have better high temperature stability. Aerodynamic heating when cruising at Mach 3 will result in much higher fuel operating temperatures than those associated with subsonic transports. This effect will be accentuated if, as some designers propose, fuel is also used as a heat sink for absorbing heat from the engine and various items of equipment.

The fuel tanks will need to be pressurized and provision for inerting them will be required; otherwise it is not expected that the fuel system will be significantly different from the fuel systems of the subsonic jets."

3. 8. 4. 3 ICAO, June 1962, Ref. 11

"The fuel itself and the fuel system present one of the most difficult problems in the development of the supersonic aeroplane; because of the aerodynamic heating the fuel will become quite hot. It is generally agreed that the fuel must be well insulated so as to reduce the temperature rise as much as possible. The use of the fuel as a heatsink for cooling the structure or the engine or components, as proposed by some designers, will, of course, raise its temperature. The possibility of using the fuel as a heat-sink to cool the cabin has also been mentioned; this would involve fuelling partly with pre-cooled fuel. On the other hand it may be necessary to cool the fuel during flight. Whatever is done the fuel will need to have much greater thermal stability than is needed in fuel for a subsonic aeroplane. Thermal stability is probably the most important property required of the fuel. Low volatility is also important because of the high fuel temperatures and the high operating altitudes. If the fuel is to be used as a heat-sink or for cooling it must have a high specific heat and a high thermal conductivity.

At low altitudes, where the aeroplane is operating at subsonic speed, there is no aerodynamic heating. The temperature of the fuel will be lower than when cruising and the fuel should have a low viscosity at sub-zero temperatures and a low freezing point. For long range operation a high heat content and a high density are essen-

tial. The fuel also must possess an extremely low solid contamination level in order to ensure clean and efficient operation. Low water content is also required to prevent icing of the system.

Although it must meet all these physical requirements, the price of the fuel must be kept low, otherwise the whole operation will be uneconomic. The actual temperature achieved by the fuel at various stages of the flight will depend on the flight profile, that is, the time and speed spent at various altitudes, as well as on the design and method of operation of the fuel system; and the problem of obtaining a satisfactory fuel at a reasonable price will be more difficult for aeroplanes cruising at about Mach 3 than for those cruising at about Mach 2.

It is generally agreed that chemical or exotic fuels are out of the question because of the high price. The proponents of the Mach 2 aeroplane believe that it will be possible to use current jet fuels. The proponents of the Mach 3 aeroplane also anticipate the use of hydrocarbon fuel but realize that a good deal of research remains to be done before a suitable fuel is developed. A fuel high in paraffins has been suggested as the most likely.

The pressurization and inerting of fuel tanks in the Mach 3 aircraft poses many problems, and studies are still proceeding to determine the best procedure to be followed. Inerting is needed to minimize the possibility of spontaneous ignition in the vapour space, and combustion such as this may leave a sticky residue in the fuel tank with consequent maintenance problems. Pressurization helps to reduce loss of fuel by evaporation. A considerable amount of development work will be required to determine the design of the equipment necessary for providing the inert atmosphere in the fuel tanks and for controlling its pressure and flow. The venting of the tanks, both during descent and when refueling, is a related problem that has to be considered.

A serious problem is that of guarding against fuel leakage onto hot surfaces which might ignite it. This is expected to be more crucial for a Mach 3 design than for a Mach 2. The design of the fuel system for aeroplanes cruising at either Mach 2 or Mach 3 may be further complicated by the need to maintain the correct centre of gravity, if fore and aft tanks are used in the design."

3.8.4.4 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"Fuel containment (leakage) and fuel pressures at high and low altitude under varying temperatures and pressures appear to be a real problem in the construction and preparation for flight of the XB-70. Revision of Civil Air Regulation relative to fuel reserve requirements will probably need to be considered."

3.8.4.5 FAA RFP, August 1963, Ref. 8

"a. 7% of the total calculated burnout fuel block to block.

b. Plus fuel required to fly at cruise altitudes and speed to a landing at an alternate airport 300 statute miles from the planned destination airport.

c. Plus fuel required for a 30-minute hold at an altitude of 15,000 feet.

d. The factors considered in computing fuel consumed in compliance with a, b, and c above shall be indicated. These shall include taxi and ground loiter times, time involved in maneuvering after take-off, before landing and in effecting arrival and departure routings, deviations from standard temperatures, seasonal average winds, optimum flight profiles, and from standard instrument approach procedures.

Manufacturers, in considering the applicability of the foregoing, should be cognizant of the air traffic control procedures which are programmed for application during the period of the 1970's. (Reference FAA Report "Design for the National Airspace Utilization System Summary of First Edition," September 1962).

Additional fuel tank capacity shall be provided to ensure operating flexibility in airline service through substitution of fuel for payload when desired. The weight of the fuel equivalent to this excess capacity need not be considered in computing the design gross weight of the airplane. This additional fuel tank capacity shall include the tankage required for the departure airport taxi and ground loiter fuel specified above.

The fuel system shall be designed to use commercial

aviation kerosene, or an improved fuel of equivalent cost.

The factors considered in computing fuel required for the above stated range/payload conditions shall include take-off, after take-off maneuvering and departure routings, climb, acceleration, cruise, descent, arrival routings, approach, landing, and reserve fuel. Destination and reserve fuel requirements shall be additional to unusable fuel.

Taxi and ground loiter fuel at the departure airport shall not be considered in the maximum take-off design weight but shall be considered in the maximum ramp and taxi design weight of the aircraft. Fuel for ground operation at the destination airport shall be provided from the fuel reserves listed above.

Manufacturers, in considering the aircraft fuel requirements, should be cognizant of the air traffic control procedures which are programmed for application during the period of the 1970's. (Reference FAA Report 'Design for the National Airspace Utilization System', Summary of First Edition, September 1962)."

3.8.4.6 FAA, March 1961, Ref. 18.

"A supersonic transport may have up to 55 percent or more of the takeoff weight in fuel, and the reserve fuel may be equal to or greater in weight than the payload of the aircraft. In view of the large amount of fuel necessary for normal operation, reserve fuel becomes an important factor both in planning for the safety of the flight, and because of its great influence on the aircraft payload. Therefore, a review of the current specified reserve fuel requirements is considered essential at this time in order to evaluate their applicability to the operational concepts of the supersonic transport.

Some fuel reserve studies and predicted performance criteria functioning properly, whether the aircraft exists in range with all engines functioning properly, whether the aircraft is operating supersonically at high altitudes, or operating at optimum subsonic cruise at lower altitude, although obviously the time would be greater. It is anticipated that reserve fuel for flight subsequent to planned destination will be based generally on optimum subsonic operation at the lower altitudes.

Special Regulations SR 427B effective October 23, 1960, specifies a turbine-powered aircraft (exclusive of turbo propeller-powered aircraft) may be dispatched or take off only if it carries sufficient fuel, considering the wind and other weather conditions expected, to fly to and land at the next point of landing specified in the clearance; and thereafter:

(1) to fly a period equal to ten percent of the total time required to fly from the point of dispatch to the next point of landing specified in the clearance and land at such airport; and thereafter;

(2) to fly to and land at the most distant alternate designated for that point in the clearance, and thereafter;

(3) to fly for a period of 30 minutes at holding speed at 1500 feet (presumed to be 15,000 feet)* above the alternate airport elevation under standard temperature conditions. In the case of a route approved without an available alternate for a particular stop, an aircraft dispatched to that point shall carry sufficient fuel considering wind and other weather conditions expected, to fly to that point and thereafter to fly for at least two hours at normal cruise consumption.

In considering criteria the fuel reserves for the supersonic transport, the following factors should be carefully analyzed:

(1) Route distance

(2) Alternate airports

(3) En route and terminal weather

(4) Flight plan profile

(5) Complexity of terminal procedures

(6) Air Traffic Control

(7) Airport taxi and takeoff sequence

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* parenthetic insertion ours

(8) En route communications

(9) En route navigation

(10) Possible clear weather turbulence

(11) Possible terminal holding delays

(12) Possible engine failure on routes over water or without alternate airports

Fuel reserves will be influenced by the progress made in improvements on communications, navigational, air traffic control, all weather landing systems, and airports. Further, flight planning by utilizing corridor departures and approaches, together with little traffic interference at high altitude cruise operation should practically eliminate holding patterns, and en route delays. It has been suggested by interested groups that the supersonic transport should have a landing clearance prior to takeoff.

Suggested fuel reserve proposals have included the following:

(1) That fuel reserves be predicated upon the particular route, distance to be flown, weather and other operational variables, etc., consistent with safety.

(2) That no airplane be dispatched unless it carries enough fuel to fly from the point of dispatch to next point specified in the clearance, and thereafter fly for a period of at least 45 minutes at optimum subsonic cruise.

(3) That no airplane be dispatched unless it carries enough fuel to fly from point of dispatch to next point specified in the clearance, and thereafter, fly for a period equal to five percent of the total time between dispatch points plus 30 minutes fuel at optimum subsonic cruise.

The amount of reserve fuel necessary for the operation of a supersonic transport is an important and complex question. Further study should be devoted to this problem. It is considered essential that the present level of safety be maintained for air carrier aircraft.

3.8.4.7 ICAO, August 1960, Ref. 10

"The question of requirements for fuel reserves was discussed in great detail at the IATA Symposium and is being studied by national civil aviation administrations. However, it is not yet possible to state whether the evolution of regulations governing fuel reserves to be carried by supersonic aeroplanes will result in any substantial reduction of the proportion of reserve fuel, compared with that now carried by subsonic aeroplanes. While the characteristics of the aeroplane itself, and of its navigation equipment, may reasonably be expected to make it possible for supersonic aeroplanes to adhere very closely to their flight plans, this will not be so for most other aeroplanes, and the extent to which it will be possible to guarantee to the supersonic aeroplane at, or shortly after, the time of take-off, a landing time within close limits, has yet to be determined. This would certainly be the ideal procedure for economic operation, but difficulties in achieving it, from the air traffic control point of view, have been pointed out.

The designers of the medium range supersonic aeroplane being designed as a preliminary project estimate that its rate of fuel consumption when flying at subsonic speed at moderate altitudes, will be one-half the rate of consumption when cruising at supersonic speed. At the upper end of its cruising range up to one-half the maximum take-off weight of the aeroplane is fuel, so that the economic penalties involved, if the aeroplane has to hold for any length of time, are obvious. Of course the fuel consumption when holding will vary with the design of the particular aeroplane, and the fuel reserves that will need to be allowed for holding will probably be determined as a compromise between many conflicting factors. The importance of designing the aeroplane to be efficient, and therefore to use the minimum of fuel, when holding, has already been recorded in this Addendum, and this consideration may well be a determining factor in the configuration adopted in any particular design."

3.8.4.8 IATA, May 1964, Ref. 13

"It is emphasized that airlines cannot contemplate the use of special descent and holding procedures for the SST. Manufacturers should bear this fact in mind when considering fuel requirements.

3.8.5 ELECTRICAL

3.8.5.1 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"New problems will be encountered in assuring a positive fail-safe electrical system because of the wide variance in operating pressures, temperatures, and rapid changes in altitude which will be encountered. Because of the size, speed, and rapid temperature and pressure variations encountered, an electrical system with the maximum amount of flexibility, redundancy, and reliability will be indicated."

3.8.6 HYDRAULIC

3.8.6.1 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"Because of the tremendous variations in outside air temperatures, the high operating hydraulic pressures contemplated, and the extremely high skin temperatures expected, the hydraulic system in the SST must be much more dependable and reliable than in present jet transports. The system must be so designed that no single failure will cause the interruption of any operable mechanism."

3.8.7 NAVIGATION

3.8.7.1 FAA, March 1961, Ref. 18

"Aircraft traveling at Mach 3 speeds cover a distance of approximately one mile every two seconds or 30 miles every minute.

Present day facilities were not designed for use of aircraft traveling at the altitude and speed anticipated in the supersonic field. Consequently, the accuracy, distance, and facility location of these systems do not lend themselves to a logical adaptation to supersonic aircraft operation.

Considerable research and development has been conducted on airborne doppler/astrotracking, and inertial navigational systems for aircraft. These systems include computers which will provide for display to the pilot the attitude, heading, position, ground track, wind, and accurate speed of the aircraft. In addition, this system for automatic navigation over selected geographical tracks by introduction of signals from the navigational system.

In conjunction with pilot navigational aids, considerable research and development has been done on pictorial map displays and instrument projection. One project is the application of "trichroic contrast enhancement" to the problem of providing integrated flight control data and patterns such as the contact analog, command flight path, obstacle and/or terrain clearance and any other information vital to the pilot in the forward reviewing area without degrading vision through that area.

Research and development work will continue to improve communications and navigation systems. In addition, new and improved concepts of pilot display systems will no doubt be developed. It is believed at this time there are no problems that cannot be effectively treated within the current state of the art."

3.8.7.2 IFALPA, July 1963, Ref. 9

"SST aircraft should be equipped with a reliable, proven, instantaneous, navigational self-fixing system such that both the pilot in the air and the controller on the ground will be provided with the aircraft's unambiguous and unmistakable location and height whenever the aircraft is in transonic or supersonic flight. Such a navigational system should operate reliably under all known atmospheric conditions.

This implies that States provide trained personnel on the ground, capable of correctly interpreting signals of the aircraft's exact height and position at all times when supersonic. The necessary equipment is of no use unless continuously and scientifically manned."

3.8.7.3 FAA RFP, August 1963, Ref. 8

"The communications and navigation equipments selec-

ted to perform the functions of navigation, positive reporting and identification shall be those which meet airline route requirements and operate reliably within the controlled aircraft environment. The aircraft shall possess appropriate communications and navigation equipment to facilitate world-wide all-weather operations. Optimum use of miniaturized equipment shall be considered."

3.8.7.4 ICAO, June 1962, Ref. 11

"Development work on both Inertial and Doppler Radar systems has been proceeding apace. The Doppler Radar system is now being used on subsonic jet aircraft, and investigations and studies are proceeding to determine its capabilities and limitations. Inertial navigators are now being used on military manned aeroplanes and drones as well as on missiles and spacecraft. The accelerometers and the associated computers and other electronic equipment are continuously being improved and made smaller and lighter. At the same time the price of the equipment is being reduced. While it is too soon to predict exactly what kind of airborne navigation system will be used on the supersonic transport when it is introduced into service, one report made to a government agency by an impartial study group has already expressed the opinion that an inertial guidance system capable of navigating an aircraft to within two miles of its destination, with no external aids to navigation, probably will be in production by 1970. There is little reason to doubt that by the time the supersonic aeroplane is introduced into service, some form of accurate and reliable airborne navigation system will be available."

3.8.7.5 ICAO, August 1960, Ref. 10

"When cruising the Mach 3 aeroplane travels about one mile in every two seconds. Methods of navigation used with slower aircraft will not be suitable. The development of reliable Inertial and Doppler Radar Navigation Systems is expected to result in the installation of airborne Inertial or Inertial/Doppler Navigation Systems on the aircraft. These systems will include small digital computers for continuous presentation of position and velocity information. They are also expected to provide for automatic navigation during cruising flight, in which case the com-

puters would be designed to compare actual position and velocity with desired position and velocity and apply the necessary signals to the automatic pilot to maintain the planned flight path.

The airborne navigation system will be able to provide and display to the pilot all the information he needs regarding the attitude of the aircraft. Separate instruments will not be needed for this purpose. It will be possible to design the "read-out" portion of the equipment to display other information, such as aircraft heading, distance to destination, distance to the left or right of the desired ground track, and wind information."

3.8.7.6 IATA, May 1964, Ref. 13

"The primary navigation system is expected to comprise self-contained airborne equipment. The Inertial or Inertial/Doppler system will provide, among other things, for automatic navigation during cruising flight. Present indications are that by the time supersonic aeroplanes are introduced into service airborne navigation systems of this kind will be very accurate and reliable. However they are expected to need ground based referencing systems.

There is some difference of opinion as to the short-distance aids that will be required. In the terminal areas the supersonic aeroplanes will be flown at subsonic speeds. One view is that the present standard short-distance aids, with the anticipated developments and improvements, supplementing the airborne system, should be adequate for subsonic navigation.

Another view is that the short-distance aid that will be needed is a ground-based radio navigational fix system to provide the positional information for setting the airborne equipment shortly after take-off and for resetting it at the end of cruising flight prior to descent to the airport of destination. The opinion has been expressed that the present standard short-distance aids will not afford the required accurate coverage for this purpose, but that suitable equipment can be developed by the time the supersonic aeroplane is introduced into service.

It is not clear whether a long-distance aid will be required. Most States consider that a long-distance aid

system will be required as a primary element in the overall navigation system in order to provide a ground-based reference system that will be available at any time during flight. However, one State considers that it is probable that the self-contained airborne navigational system will do away with the need for a long-distance navigational aid. Another State expressed the view that a long-distance aid may be required to fulfill a secondary role as a back-up system for the airborne navigation equipment. A decision will have to be made in the light of more knowledge of what can be expected from the airborne and ground equipment likely to be used.

A single standard long-distance aid has yet to be developed, but any specialized requirement for supersonic aircraft will likely be taken into account in the development of such a standard which is planned to take place in the next two or three years. In addition to what may be described as conventional methods, experiments now being conducted suggest that satellites may play an important role in this field. There is every reason to believe that a long-distance aid having the required accuracy and coverage for supersonic aircraft can be developed by 1970.

It will be evident from the foregoing remarks that a considerable amount of work will be needed to prepare basic specifications for the aids that will be required, to develop reliable equipment that will meet the specifications and to obtain international agreement on standardized systems to the extent that standardization is necessary. However, there is a reasonable prospect of being able to complete this task and have the navigational aids available by 1970, if action towards developing the necessary standards is taken at an early date."

3.8.7.7 ICAO, June 1962, Ref. 11

"It is not yet possible to say definitely whether or not ground based referencing systems will be needed for the airborne navigational equipment. This will be determined by the particular kind of equipment that is actually used, and by the correctness of the view, held in some quarters, that it will be possible to develop it to a state where it can function satisfactorily without ground based referencing systems.

The Seventh Session of the COM Division, which has

already been mentioned in connection with Air Traffic Control, discussed the latest developments in virtually all aspects of the use of radio or radar equipment for navigational or communications purposes (see Report of the Division, Doc 8226-COM/552). Besides discussing improvements in the present system of ground based aids, the Division also discussed the possible use of airborne Doppler equipment as a short distance navigational aid, and recommended that States be encouraged to examine the potentialities of Doppler equipment for this purpose. At the present time there is a difference of opinion as to whether airborne Doppler equipment could be relied upon completely or whether it could only be regarded as supplementary to ground based aids.

At the present time many systems are being studied and evaluated in a number of States and the Fifth Session of the COM Division recommended that ICAO schedule a meeting or meetings the first to be held commencing in 1964, in order to define agreed operational requirements, including those of ATC, relative to long distance navigation, and to decide on the need for standardization of a system or systems necessary to meet the requirements in the light of the then current systems evaluations and developments. Airborne Doppler navigation systems were also discussed, and the experience so far obtained with them on subsonic aeroplanes is encouraging. Refinements and improvements in these systems will reduce the extent to which they need to be supplemented with long distance ground based aids. However, there is no agreement yet as to whether it will be possible to dispense entirely with the ground based aids. Apart from developments in the airborne systems that will be used on supersonic aeroplanes, the needs of all aircraft will have to be considered. Furthermore, it seems essential that more than one long distance navigational system be available, and whether this objective can best be metby carrying two completely self-contained airborne systems or by having one airborne system supplemented by a ground based system, remains to be seen.

Satellite navigation systems are being studied, but the satellite navigation system is complex and not necessarily designed primarily for air navigation; consequently, airborne equipment still requires development.

It will be seen from the preceeding paragraphs that extensive research and development work is going on. ICAO is actively studying the best way of obtaining the

maximum international cooperation; this will help to achieve the objectives stated in paragraph 263 of the Preliminary Study. It is still considered that there is a reasonable prospect of being able to complete this work and have the navigational aids ready by 1970."

3.8.8 COMMUNICATIONS

3.8.8.1 FAA, March 1961, Ref. 18

"The present concept of communications and navigation based upon the utilization of currently available facilities such as the VOR/DME/TACAN and VHF communications, are questionable, except in terminal areas, for effective control of supersonic aircraft.

Communications with supersonic aircraft while in en route flight will normally be accomplished at much higher altitudes than with subsonic aircraft. This high altitude condition may present radio transmission difficulties due to the ionization phenomena. In addition, the high temperatures of supersonic flight will present problems with respect to plastic radomes and plastic materials used to cover flush mounted antennas.

The line of sight reception distance would be approximately 250 to 300 miles at 70,000 feet altitude. It is believed that this distance is not entirely satisfactory for the operation of the supersonic transport. Considerable research is being done on the automatic data link system for automatic transmissions between aircraft and ground facilities. In addition, earth satellite stations may be available in approximately five years for long range transmissions."

3.8.8.2 FAA RFP, August 1963, Ref. 8

"The communications and navigation equipments selected to perform the functions of navigation, positive reporting and identification shall be those which meet airline route requirements and operate reliably within the controlled aircraft environment. The aircraft shall possess appropriate communications and navigation equipment to facilitate world-wide all-weather operations. Optimum use of miniaturized equipment shall be considered."

3.8.8.3 ICAO, August 1960, Ref. 10

"Reliable communications services must be available at all times and as far as possible they should be automatic. The basic requirements are expected to be:

i) an automatic means for exchanging data between the aircraft and relevant control centres;

ii) a voice channel between the pilot and controllers; during supersonic flight this channel would only be used for emergency purposes;

iii) high speed communication links between airports of departure and destination and other relevant air traffic control centres;

iv) an augmented basic meteorological communications system to collect, disseminate and interchange high altitude data;

v) extension of the special meteorological communications network (Meteorological Operational Telecommunications Network - Europe) for interchange of meteorological data between main bases.

International agreement will be needed to specify precisely basic system characteristics for air/ground and ground/ground communication equipment and systems, such as information coding and rates for data links for air/ground communications, and the development and extensive installation of suitable equipment may present considerable difficulties and require a long period for provisioning. For example, a greatly extended VHF system to provide static free coverage over all routes flown by supersonic aircraft may be required, with remote operation from control centres in many cases. On transoceanic flights forward VHF and UHF relay from specially positioned ships linked to terminal areas by means of tropospheric scatter communication links may be required. Another possibility is the use of earth satellites as passive relay stations.

In addition to substantial improvement in techniques used in fixed and mobile telecommunications services it may be found necessary to provide direct cable links for communications between many terminal airports. However,

the need for improvement in the fixed and mobile services is recognized at the present time, quite apart from the possible introduction of supersonic aeroplanes. The state of the art is such that technically it would be possible to provide communication services suitable for supersonic operations by 1970. However, ability to do so on a reasonable international scale will depend on reaching agreement on basic characteristics of the systems at least 5 years before the systems are required to function."

3.8.8.4 ICAO, June 1962, Ref. 11

"Study by the Seventh Session of the COM Division of communications problems relative to air traffic control has already been mentioned. In connection with automatic or semi-automatic systems for data transfer, both ground-ground and air-ground, the Division concluded that there is an urgent need for the development of basic principles to govern the development and application of such systems on a worldwide basis and recommended that States cooperate closely in pursuing the work of developing these principles. The Division also confirmed the broad operational objectives for aero-mobile data handling systems that had been agreed upon at its Sixth Session (see Doc 7831-COM/551-1, page V-21).

An important aspect of requirements for supersonic aircraft communications has arisen recently in connection with radio-space communications. The International Telecommunication Union (ITU) is planning a revision of allocations made in the very high radio frequency bands, with a view particularly to making adequate provision for satellite communications and the use of satellites for providing meteorological and other information. However, closely associated with this revision, are requirements for supersonic aircraft operations and possible later developments in which aircraft or aero-spacecraft may function at extremely high altitudes and speeds. Consideration of these types of operation by at least one State has suggested that new concepts in communication techniques may be necessary for the guidance and control of such operations, which will require the allocation of new radio frequency bands and more communication channels than hitherto. The implications of the ITU planned revision of frequency allocations in relation to ICAO interest is being studied.

When a clear statement of basic operational objectives and requirements for automatic data systems has been established, it should be possible to state the functional characteristics of the equipment and to evolve technical specifications for it. Manufacturers could then go ahead and design suitable equipment to do the work. Several States have undertaken studies and tests in recent years aimed at evaluating the possibilities of extending the useful range of VHF communications. In general the results have been very encouraging and the work is continuing. This is an area in which collaboration and exchange of information between the States actively engaged in the work is most desirable.

A lot of attention is now being given to the use of satellites for general communications purposes. Many studies have been made to determine the number of satellites, operating in elliptical orbits or circular orbits of varying radii, that would be required for a network of stations to give complete global coverage. A satellite in a circular orbit at an altitude of 35,700 kilometres (22,300 miles) would have a speed identical to that of the earth's rotation and thus, would appear to be in a fixed position in space. Three such earth synchronous satellites would be needed to cover over 90 per cent of the earth's surface. This kind of orbit is generally regarded as the ultimate solution, but there is a difference of opinion as to whether a reliable 24-hour system would be feasible within the near future. It is, of course, much more difficult to launch a synchronous satellite than to launch one with a much smaller elliptical or circular orbit, and it remains to be seen how effective and reliable will be the signals obtainable by its use.

In the United States it is the intention to experiment with several satellites to determine what is likely to be the best system. Two of the types being discussed have synchronous orbits and the other two are relatively low-altitude satellites whose orbits will not reach a height of more than a few thousand miles. Twenty to thirty of these would be required for global coverage. All of these satellites, the testing of which is currently being discussed, are active repeater satellites capable of receiving, amplifying and re-transmitting radio signals.

As already mentioned, these experiments with satellites are aimed at developing a general communications system, and the extent, if any, to which they will be of use to aircraft has yet to be determined. However, if it is found that it is technically and economically feasible to make use of satellites for communications with, or navigation of, supersonic aeroplanes, there is little doubt

that this will be done.

In the Preliminary Study it was stated that the ability to provide by 1970 on a reasonable international scale, a communications service suitable for supersonic operations, will depend on reaching agreement on basic characteristics of the systems at least five years before they will be required to function. The time available is short but the work now going on is such that there seems to be a reasonable possibility of meeting this goal."

3.8.9 AIRCRAFT GROUND CONTROL

3.8.9.1 ALPA, April 1961, Ref. 16

"Fundamental requirements of a supersonic transport airplane include good handling and manoeuvring characteristics while in contact with the runway. This involves turning, taxiing, take-off roll, cross-wind and asymmetrical power controllability, rotation characteristics and touchdown and stopping capabilities. Experience with the present generation of turbine-powered aircraft has demonstrated that substantial improvement of ground handling and manoeuvring characteristics is required. We have experienced rotation problems on take-off, loss of control during take-off and landing due to asymmetrical power and over-runs on wet runways."

3.8.9.2 FAA RFP, August 1963, Ref. 8

"The normal ground turning radius of the aircraft shall be comparable to current subsonic jets used in international service."

3.8.9.3 ICAO, August 1960, Ref. 10

"Wheel brakes and reverse thrust are expected to be provided for braking purposes. In view of the somewhat higher landing speed of the supersonic aeroplane, special attention may have to be given to designing the landing gear, so that the braking forces do not produce unduly high shear stresses in the pavement."

3.8.9.4 IFALPA, July 1963, Ref. 9

"If braking parachutes are to be used, they should be an additional means of deceleration and not used in the calculations for certification requirements - (this is in accordance with the Federation's previous thinking and fail-safe policies)."

3.8.10 MISCELLANEOUS

3.8.10.1 IFALPA, July 1963, Ref. 9

"The potential value of flight recorders for recording flight conditions, structure loads, and systems performance should be considered by the appropriate authorities."

3.8.10.2 CAB (as reported in the Journal of Air Law and Commerce), 1964, Ref. 14.

"Accident investigations involving turbine-powered transports where flight recorders are installed have served to prove the need for the recording of several additional parameters. Altitude, airspeed, acceleration, and magnetic heading are the four parameters presently required. Consideration should be given to requiring additional parameters such as (1) engine performance, (2) component temperatures, (3) cabin pressures, (4) engine vibration, (5) degree of movement of controls, slats, spoilers, etc., (6) position of controls, (7) time, (8) angle of attack, etc."

3.8.10.3 IFALPA, July 1963, Ref. 9

"It is envisaged that the SST will require a reliable fire-warning system notwithstanding the possible difficulties in producing one."

3.8.10.4 FAA RFP, August 1963, Ref. 8

"The design shall incorporate features to minimize the possibility of inflight and ground fires or explosions and

shall provide means to detect and control these hazards should they occur. Factors to be considered are high temperature induced environment, autoignition, lightning, electrostatic potential, inerting, location and character of potential fire zones, detection and extinguishing system requirements.

The design shall provide features to minimize the possibility of fire in the event of a crash. Factors to be considered are ignition sources, (including hot surfaces, electrical sparks and friction sparks), storage provision for fuel and other combustibles and their vulnerability to damage."

3.8.11 ANALYSIS AND COMMENTS

3.8.11.1 ANALYSIS - (3.8.2 Flight Controls)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications			X	3.8.11.2.1			
Composition	X						
Training	X	3.8.11.2.1					
OPERATIONAL VARIABLES							
Responsibility			X	3.8.11.2.2			
Authority	X						
Acceptance			X	3.8.11.2.2			
FLIGHT DECK DESIGN							
Layout			X	3.8.11.2.2			
Instrumentation			X	3.8.11.2.2			
Controls			X	3.8.11.2.2			

3.8.11.2 COMMENTS - (3.8.2 Flight Controls)

3.8.11.2.1 There are many suggestions for innovations in the area of flight controls for the SST. Most of them take into consideration the new flight characteristics expected to be encountered in this unique flight range. The more experienced personnel required (see Section 3.5.6.6.1) should be able to transition to any new type of flight control. Training through simulation and actual flight (if not in an SST, a modified current aircraft) will be necessary to make the transition.

3.8.11.2.2 The SST flight control system may be an automatic

system with a manual override capability. This would alleviate some of the work load of the crew, but does not decrease the responsibility. The crew should readily accept the new concepts, when they are shown to be reliable, and if they can be adequately monitored. A modified flight deck and modified instrumentation display will accompany new flight controls.

3.8.11.3 ANALYSIS - (3.8.3 Power Plant)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X						
Composition	X						
Training	X	3.8.11.4.1					
OPERATIONAL VARIABLES							
Responsibility	X						
Authority	X						
Acceptance	X						
FLIGHT DECK DESIGN							
Layout							X
Instrumentation			X	3.8.11.4.2			
Controls							X

3.8.11.4 COMMENTS - (3.8.3 Power Plants)

3.8.11.4.1 The power plant will be similar in concept to today's jet engines with one critical exception - inlet configuration control. Positioning of the shock wave in the engine inlet will undoubtedly be under automatic control but monitoring will be critical. If the shock wave should ever have to be controlled manually this would be a difficult problem.

3.8.11.4.2 New instrumentation may be required to give the crew a

more definite means of gauging the engines output and how to constantly operate within the optimum limits.

3.8.11.4 ANALYSIS - (3.8.4 Fuel)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training							
OPERATIONAL VARIABLES							
Responsibility	X	3.8.11.6.2					
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							
Controls							X

3.8.11.6 COMMENTS - (3.8.4 Fuel)

3.8.11.6.1 One of the unique problems in transition from subsonic to supersonic flight is that the center of pressure (c.p.) moves aft. If the center of gravity (c.g.) of the aircraft is ahead of the subsonic c.p. in order to provide a positive static margin, this margin will increase considerably when the aircraft goes supersonic. This high stability of the aircraft will require large amounts of trim with the control surfaces.

Large control surface deflections increase drag and therefore fuel consumption. This drag can be reduced by the transfer of fuel to move the c. g. aft to follow the c. p. The c. g. can also be shifted by variable geometry wings. If it is necessary to shift fuel there will be an engine problem, even if done automatically and will require careful monitoring during this critical phase of flight.

3.8.11.7 ANALYSIS - (3.8.5 Electrical)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training	X			
OPERATIONAL VARIABLES				
Responsibility	X			
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation	X			
Controls				X

3.8.11.8 COMMENTS - (3.8.5 Electrical)

3.8.11.8.1 The electrical system of the SST will be supporting many automated subsystems and so, must be very reliable. No particular problem areas related to the crew are anticipated.

3.8.11.9 ANALYSIS - (3.8.6 Hydraulic)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training	X			
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout	X			
Instrumentation	X			
Controls	X			

3.8.11.10 COMMENTS - (3.8.6 Hydraulic)

3.8.11.10.1 The crew's main concern will be that the hydraulic system will be more reliable than present jet carriers. The training and possible new instrumentation relative to this system should not cause any special problems.

3.8.11.11 ANALYSIS - (3.8.7 Navigation)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X						
Composition	X						
Training					X	3.8.11.12.1	
OPERATIONAL VARIABLES							
Responsibility	X	3.8.11.12.2					
Authority	X						
Acceptance	X						
FLIGHT DECK DESIGN							
Layout					X		
Instrumentation					X		
Controls	X						

3.8.11.12 COMMENTS - (3.8.7 Navigation)

3.8.11.12.1 Most of the proposed navigational systems involve automated concepts to some degree. As such, the crews will have to be assessed of their link in the system, and also become acquainted with the new visual displays. No difficult transitional training problems should be encountered. This area of training can be easily simulated.

3. 8. 11. 12. 2 Although the work load will be decreased with the introduction of the new systems, the responsibility does not shift. The crew must be able to take over the navigational tasks in case of a system malfunction.

3.8.11.13 ANALYSIS - (3.8.8 Communications)

	Comparison with Today's Jets							
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training			X	3.8.11.14.1			
OPERATIONAL VARIABLES							
Responsibility	X						
Authority							X
Acceptance	X						
FLIGHT DECK DESIGN							
Layout					X		
Instrumentation					X		
Controls							X

3.8.11.14 COMMENTS - (3.8.8 Communications)

3.8.11.14.1 New communication systems are introduced primarily to reduce the congestion on frequency, and to reduce the work load of the crew. As with the other automated systems, the crew's main function will be to monitor the system. No difficult problems should be anticipated in changing the current operating procedures to meet the requirements of SST operations.

3.8.11.15 ANALYSIS - (3.8.9 Aircraft Ground Control)

	Comparison with Today's Jets							
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications	X						
Composition	X						
Training	X	3.8.11.16.1					
OPERATIONAL VARIABLES							
Responsibility	X	3.8.11.16.1					
Authority	X						
Acceptance	X						
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.8.11.16 COMMENTS - (3.8.9 Aircraft Ground Control)

3.8.11.16.1 Most of the proposed methods of ground control are similar to current procedures. Those which differ will require some initial training, but nothing drastic. The added responsibility of moving such a large aircraft around on a marginal size airport may be a source of some apprehension to the crew.

3.8.11.17 ANALYSIS - (3.8.10 Miscellaneous)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition							X
Training							X
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance							X
FLIGHT DECK DESIGN							
Layout	X	3.8.11.18.1					
Instrumentation	X	3.8.11.18.1					
Controls							X

3.8.11.18 COMMENTS - (3.8.10 Miscellaneous)

3.8.11.18.1 The miscellaneous subsystems to be added have little effect on the operational capability of the crew. The instrument changes required will be covered in transitional training, and no particular difficulties should be encountered.

3.9 OPERATIONAL SUPPORT

3.9.1 GENERAL

3.9.1.1 FAA RFP, August 1963, Ref. 8

"GROUND OPERATIONAL OBJECTIVES

The transport shall be capable of complete ground handling in 30 minutes for through flights and 90 minutes for turn around flights assuming maximum load conditions."

3.9.1.2 IFALPA, July 1963, Ref. 9

"Ground Handling Problems

(a) If automatic checkout equipment is used during preflight check routines, it should be demonstrated that the performance of such equipment is not inferior to that of highly trained personnel working under supervision.

(b) The special RAC, COM, MET, AGA and OPS requirements of the SST will require a substantial improvement of the existing facilities before the SST can be operated, route by route, aircraft type by aircraft type.

It should be clearly understood that existing facilities (1963) will not be adequate for even limited SST operations.

(c) The ground handling of the SST may be significantly different from that of sub-sonic aircraft. Factors to be considered include:

i Residual heat in the aircraft structure;
ii The high power/weight ratio of the aircraft;
iii Any unusual landing gear geometry such as abnormally long wheel base and narrow track and the impact these factors might have on turning circles, runway smoothness requirements and the capability of the aircraft to cope with runways that are other than clean and dry."

3.9.2 MAINTENANCE

3.9.2.1 FAA RFP, August 1963, Ref. 8

"MAINTAINABILITY

Economy and ease of inspection and servicing in airline maintenance of the aircraft, engines and related systems shall be emphasized in the design."

3.9.2.2 ICAO, June 1962, Ref. 11

"Maintenance and Servicing

57. Increasing attention is being paid by aircraft manufacturers, operators, and the manufacturers of testing equipment, to the possible use of automatic system check-outs to speed up maintenance and servicing. Light weight check-out equipment can be developed for installation on the aeroplane itself, and if this kind of equipment were used it could also perform the function of a flight recorder to permit automatic recording of as many quantities as it was considered useful to record. Possibilities offered by such equipment include the presentation to the pilot of information on the functioning of the aeroplane and its systems, and the transmission of such information to ground stations. On the other hand, some engineers prefer ground based check-out equipment to airborne equipment. However, it must be admitted that some aeroplane systems and equipment lend themselves best to check-out and troubleshooting in flight, where they are working in the normal environment. In many cases it is not possible to duplicate these working conditions on the ground.

58. There is little doubt that extensive use of some equipment of this kind will be made when the supersonic aeroplane is introduced into service. To obtain full advantage of automatic check-out equipment the aeroplane and its system (see para. 75 of the Preliminary Study) must be designed to facilitate its use, and the check-out equipment itself must be very reliable. The equipment must offer direct readings, such as "go" or "no go", or be very easy to interpret. It should be so designed as to eliminate the possibility of false conclusions in the unlikely event of a fault developing in the checking equipment it-

self. Automatic equipment of any kind loses much of its value unless the user has confidence in it. This applies to testing equipment used by the maintenance personnel as well as to automatic equipment used by the flight crew in operating the aeroplane."

"Maintenance

102. The importance of so designing the supersonic aeroplane, as to permit the maximum use of automatic check-out equipment to speed up maintenance and servicing, has been discussed in paras. 57 and 58 of this Addendum. In this connection, it has been suggested that the relatively small number of supersonic aeroplanes that will be in use, together with the small number of airports involved, as compared with subsonic operations, will probably mean that fewer maintenance centres will be required, and this would make it possible to provide the facilities, equipment and highly skilled personnel, needed for the very rapid maintenance and servicing of the aeroplanes, without incurring undue expense.

103. While the designer will have to make provision, as far as possible, for the rapid inspection of the primary structure, particularly in those areas that have been established to be the most critical under the stress and temperature cycles that will be experienced, there will undoubtedly be parts where the structure, for example brazed honeycomb core sandwich, is not easy to inspect and maintain. Increased emphasis will be placed on the use of non-destructive inspection techniques, such as use of X-ray and ultrasonic inspection. Because of the severe operating conditions, it will be important to establish the life of all components or parts of the structure that will have a limited life and to prescribe conservative replacement times for them.

104. It will be necessary to develop special maintenance procedures or practices, including sampling, new inspection techniques, periodic replacement, etc., particularly for systems and components for which no precedent of prior service experience exists. This will include provision for inspection and repair of any parts of the structure subject to sonic fatigue as a result of engine noise or aerodynamic noise.

105. Because of the complication of the aeroplane, new problems will arise in connection with servicing, which nevertheless must be performed more rapidly than ever.

Rapid refuelling will be rendered more difficult by the enormous amount of fuel to be carried and by the need to inert the fuel tanks. If it is decided (see para. 38) to fuel partly with pre-cooled fuel, this will add further complications."

3.9.2.3 FAA, March 1961, Ref. 18

"1. General

The maintenance problems unique to a civil supersonic transport aircraft can only be given in general terms, since the design of such an aircraft is not settled. Aside from some limited experience with military multi-engine aircraft, there is little or no operating experience on which to predicate a finite appraisal of the subject. Contacts, however, with the various industry and research groups have provided a preliminary indication of some maintenance areas which will require thorough study and research prior to introducing such an aircraft into scheduled operation. It is equally apparent from the discussions held, that many of the currently used maintenance practices and procedures will require careful reassessment to establish the extent to which they are applicable to supersonic transport, and that the introduction of new parameters of speed, temperature, and environmental conditions will necessitate establishing some new and different procedures to properly maintain a supersonic aircraft.

An additional generalization that should be stressed at this stage is that with the start of such a complex design incorporating many new design features, maintenance practices and procedures will have to be more closely interwoven with the basic engineering considerations than in the past. The inherent characteristics of the day-to-day operation of the supersonic transport will dictate a higher degree of operational reliability of certain components and systems than heretofore experienced. The extent of the reliability provided in such a design will therefore have to be established and evaluated early in the design stages. In addition, whatever maintenance program is laid down for the supersonic transport should be closely and conservatively correlated with all relevant experience acquired with operation of the prototypes of such aircraft.

2. Effect of Elevated Temperature on Structural Inspection

To date operators of civil aircraft have primarily been concerned with development of a Maintenance Inspec-

tion and Overhaul Schedule largely independent of elevated temperature considerations. Due to the wide range of environmental conditions under which the supersonic transport will operate, it is expected that inspection procedures and overhaul periods will have to account for the effect in this new environment and temperature range.

The temperature variation will occur in a relatively straightforward cycle of heating up during climb, stabilizing at altitude, and cooling during descent. This condition repeated many times introduces the problem of cumulative exposure to this temperature cycle. Evidence indicates for a Mach 3 design that aerodynamic heating effects in the stabilized condition will range approximately from 500° to 600° F in certain portions of the structure. This variable temperature condition raises the possibility of degradation of the materials comprising the heated primary structure.

This degradation can take the form of lower strength properties at temperature and in time it may adversely affect the physical, chemical, and metallurgical properties of these materials. For example, a phenomenon called creep may result in structural distortion or deformation. (See Section C, Item 20) It has already been stated in the case of aluminum alloys operating at Mach 2, that severe doubt exists as to whether or not a predominately aluminum alloy airplane would have acceptable service life due to prolonged annealing effects.

The view is also held that the service life of the supersonic transport should be comparable to those for the present fleets of current piston engine and turbine-powered transports. To achieve this objective, extensive exploration will be necessary of the techniques for testing supersonic aircraft and its components under operating conditions which closely simulate these temperature effects. The findings from these temperature simulation tests will have to be utilized in the development of inspection procedures and overhaul periods for supersonic aircraft.

Conclusion:

Establishment of suitable inspection and maintenance procedures will require careful consideration of at least the following items:

(1) Identification of critically stressed structural areas both under room temperature and elevated temperature conditions, (i. e., by analysis and tests).

(2) Accurate predication of, or accounting for, the "cumulative temperature damage effect" stemming from exposure to various mission profiles over the anticipated service life of the aircraft.

(3) Where necessary, specifying of acceptable minimum damage criteria in critically stressed areas.

(4) Identification of life-limited structural components and establishing of conservative replacement times thereon.

(5) Identification of inaccessible or blind structural areas and development of means other than visual for detection of damage therein.

(6) Thorough understanding by maintenance personnel of the technical basis of the "fail-safe" features incorporated in the design.

3. System and Component Reliability

Need exists to insure failure rates in service which are of a low order. This objective must receive special implementation in the maintenance area both in terms of individual systems and in instances wherein interaction occurs between systems and related components. Particular areas of such interest requiring careful study are: Cabin environmental control, cabin pressurization, flight controls, hydraulics, oxygen, automatic air data computer, navigation and communication equipment, fuel inerting, propulsion control systems, and engine air inlet duct systems.

Conclusion:

In order to achieve an acceptable level of reliability, the development of the maintenance program for components and system should follow the basic principles now applicable to subsonic transports, except that special emphasis should be placed on the following:

(1) Accessibility of components essential to safety both in flight and on the ground.

(2) Relative importance of each component from a flight safety viewpoint, i. e., consequences of failure, including interaction with other systems.

(3) Understanding of design philosophy applicable to each system and related components, i. e., fail-safe, multiple units, mechanical reversion, provisions for protection against elevated temperature effects.

(4) Results of repeated functional and reliability tests of complete systems under all reasonably forseeable operating and environmental conditions.

(5) Assessment of service history of like or similar components, both military and civil.

(6) Development of special maintenance procedures or practices, including sampling, new inspection techniques, periodic replacement, etc., particularly for systems and components for which no precedent of prior service experience exists.

4. Aircraft Materials and Processes

The metallic and non-metallic materials, successfully used for so many years in current aircraft designs, are not completely applicable due to adverse aerodynamic heating effects. Thus, in the maintenance area, the industry must be able to cope with many of the current service problems, but in a different temperature environment.

In the case of the metallics, special attention must be paid to inhibiting corrosion, and to detection of cracks. (See Section C, Item 20) Hydraulic systems may employ higher operating pressures and temperatures and necessitate special maintenance and inspection practices. Lubrication poses a special problem and may even require use of new methods such as, electroplating, graphite, teflon inserts for bearings, rather than conventionally used fluids. The organic compounds, particularly for tank sealing, brake lining, tires, cabin windows, and hydraulic systems, decompose or suffer strength loss at elevated temperature, and will, if used, necessitate very frequent replacement and servicing. In many instances, use must be made of

newly developed products or cooling techniques. The type or configuration of structure presents unusual problems. For example, brazed honeycomb core sandwich now being actively explored presents some difficulties as regards inspection and maintenance.

Conclusion:

A comprehensive program should be undertaken to familiarize maintenance personnel with the behavior of materials and processes in this new temperature environment.

5. Ground Check-Out Equipment

The high degree of reliability to be placed on properly functioning systems and instruments may necessitate use by maintenance personnel, to the maximum extent possible, of ground test devices or operational simulators to qualify the systems and sub-systems prior to flight. The problem is complex due to the interaction of many of the systems. Special attention must be paid to the use of ground facilities for systems such as the flight controls, (fully power operated and irreversible), the environmental control, as well as well as automatic control systems dependent on air data computers. The capacity and reliability characteristics of the ground equipment must be at least equivalent to the aircraft system.

Conclusion:

Vigorous and effective research and development effort is needed to provide special ground equipment to permit rapid and automatic pre-flight check out of aircraft systems and instrumentation.

6. Maintenance Personnel Training

It is recognized that the basic airplane and its various aircraft systems will be increasingly complex and therefore that special emphasis must be directed to insure aircraft reliability prior to dispatch. This suggests a correspondingly greater technical knowledge will be needed by maintenance personnel who will use simulators and other specialized ground test equipment. In addition to understanding the principles of operation of the ground facilities, these personnel must have a thorough understanding of the functioning of the aircraft systems, their interaction, the consequences of system failure, and fault isolation analysis.

Conclusion:

A comprehensive study of the maintenance personnel job requirements is needed to determine precisely the type and extent of training needed, the need for specialists in a variety of system categories, and the extent to which maintenance simulators will be used.

7. Servicing

The supersonic transport will present new servicing problems involving, for example, rapid refueling, use of liquid oxygen, and replenishment of fuel inerting means.

Conclusion:

Further study is needed to establish which servicing functions require treatment in the operating safety standards.

8. Inspection Techniques

Increased emphasis will be placed on the use of nondestructive inspection techniques such as x-ray and ultrasonic means. This will be prompted by the configuration of the structure and the new construction methods such as double wall construction and brazed honeycomb core sandwich.

New emphasis may need to be placed on more widespread use of the progressive or continuous maintenance system to reduce the length of time the aircraft has to be withdrawn from service. This will be largely influenced by the extent to which good maintainability features are incorporated in the aircraft design.

An area of concern will be the nature and scope of special structural inspections required after hard landings. Emergency descents may pose special inspection problems with the powerplant, and possibly structural areas subjected to high thermal stress gradients.

Conclusion:

Further study is needed to establish the extent to which new inspection techniques will be required procedures."

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3.9.3 ANALYSIS AND COMMENTS

3.9.3.1 ANALYSIS - (3.9.2 Maintenance)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications	X 3.9.3.2.1			
Composition				X
Training	X 3.9.3.2.1			
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.9.3.2 COMMENTS - (3.9.2 Maintenance)

3.9.3.2.1 The basic operational role of the crew will not be adversely affected by the maintenance of the SST. Naturally, ease of maintenance will aid in making the SST compatible to present day facilities. Only those systems which will necessitate in-flight maintenance should be of concern to the crew. In those cases training and equipment design must facilitate in-flight maintenance.

3.10 SYSTEM EFFECTIVENESS

3.10.1 OPERATIONAL LIFE

3.10.1.1 FAA RFP, August 1963, Ref. 8

"OPERATIONAL LIFE

The primary structure of the airplane shall be designed for a service life of not less than 36,000 flight hours of operational use."

3.10.1.2 IATA, May 1964, Ref. 13

"Service Life

Because the capital investment in the SST will be very large, the airlines expect that the aircraft will be in use for at least 15 years. Therefore, they believe that the aircraft should be designed for a service life in the neighbourhood of 50,000 hours before the annual maintenance costs begin to increase significantly due to factors such as airframe fatigue."

3.10.2 RELIABILITY

3.10.2.1 FAA RFP, August 1963, Ref. 8

"RELIABILITY

A comprehensive reliability program designed to ensure maximum attention being placed on reliability of all components and systems is required during the development program, including "fail-safe" provisions."

3.10.2.2 FAA, March 1961, Ref. 18

"Reliability

In the supersonic airplane, the functioning of

certain systems and equipment will be as vital to safety as the structural integrity of the airframe. Reliability and human factors studies, fault analyses, fail safe provisions, and testing under simulated environmental and malfunction conditions, therefore, attain a new order of importance. Depending upon the degree of reliability achieved and the hazards involved, the single failure or duplicate system concept may not be adequate in some cases, and a third means of coping with failure or malfunction may be necessary.

It may be well here to restate two of the presently effective sections of the civil air regulations pertaining to reliability. They are CAR 4b. 606(a):

> "All equipment, systems, and installations the functioning of which is necessary. shall be designed and installed to ensure that they will perform their intended functions reliably under all reasonably forseeable operating conditions."

and CAR 4b. 606(b):

> "All equipment, systems, and installations shall be designed to safeguard against hazards to the airplane in the event of malfunctioning or failure."

3.10.2.3 IATA, June 1962, Ref. 12

"There must be a vast improvement over existing materials, structures, systems and instruments prior to introduction of the SST into airline service. Only thus can the necessary standards of reliability and maintainability be achieved. Only thus can the desired airframe life of at least 30,000 hours be attained and satisfactory overall reliability be expected."

"Cabin structural integrity must be assured, since the possibility of rapid decompression in flight cannot be tolerated."

3.10.2.4 IFALPA, July 1963, Ref. 9

"The importance of maintaining at all times an acceptable cabin atmosphere requires an exceptional degree of demonstrable reliability of the pressurisation/air conditioning systems.

The structural reliability of pressurized areas must be assured since the possibility of rapid decompression in flight cannot be tolerated.

Comment

If any decompression is to be countenanced, the rate of decompression must be such as to allow descent to the altitude required to ensure the continued survival of all occupants, using reasonable procedures."

3.10.2.5 FAA, March 1961, Ref. 18

"24. Flight Control Systems (CAR 4b.320)

Present control systems generally have dual actuation paths to the control surface achieved through the use of duplicated system or independent trim systems. In some cases, the systems are supplemented by power boost or are completely power operated. In the future, the magnitude of control forces on supersonic transports will probably dictate the use of fully powered systems.

Supersonic transport flight control systems will need to meet a much more complex array of conditions than any of the past or present civil transports. In addition to the present low-to-high subsonic speed controllability with suitable feel characteristics there must be adequate control and pilot feel through the transonic and supersonic ranges. Changes in airframe configuration such as variable sweep, hinged wing tips and other devices may be employed. Automatic flight control, automatic landing systems and other advances may be incorporated in the systems of the aircraft. (See Section C-39)

The primary control system will be one of the most vital elements of the supersonic transport. Its reliability will be of paramount importance. Because

of the variety of conditions to be met and the magnitude of the forces involved, power assist or actuation with secondary and other standby means of operation will be essential. The matter of primary control operation in the event of failure of all engines must be considered. Some preliminary studies indicate that the power demands for even limited controllability are beyond the capability of present energy sources such as batteries.

Conclusion: A high degree of reliability equivalent to that of mechanical primary control systems with independent trim systems should be maintained on supersonic transports."

3.10.2.6 ALPA, April 1961, Ref. 16

"Improve Landing Gear Reliability

The landing gear assembly including wheels, brakes and tires should be developed for a reliability much greater than has been achieved to date. We believe that landing gear assemblies should be designed to provide the same degree of reliability and integrity as the basic airplane wing structure itself. If safety were not such a major reason for this need, economics certainly should furnish sufficient incentive, for the cost in airplanes out of operation -- even when not destroyed -- is too great a penalty. No airports should be closed to all operations, because of landing gear failures such as has occurred with existing aircraft."

3.10.2.7 IFALPA, July 1963, Ref. 9

"The anticipated erosion of the weather radar nose cone due to supersonic flight in conditions of precipitation should not reduce the continued effectiveness of the radar equipment."

"All aircraft systems which have given trouble on subsonic aircraft such as wheel brakes, etc., should receive special attention by the designers of the SST, and the latter should (by contacting the Federation) take heed of the enormous store of experience of such previous shortcomings available to them.

3.10.3 EMERGENCIES

3.10.3.1 FAA RFP, August 1963, Ref. 8

"OVER-WATER PROVISIONS

The transport shall incorporate space for emergency equipment necessary for operating over water and consideration shall be given to ditching capability."

3.10.3.2 ICAO, August 1960, Ref. 10

"Ditching

73. The aircraft will probably be designed to have acceptable ditching characteristics. The usual provision will probably be made for emergency evacuation and the usual life-saving equipment will be carried."

3.10.3.3 IFALPA, July 1963, Ref. 9

"Emergencies

SST civil aircraft should be regarded as unacceptable to the pilot unless they are so designed that, under all foreseeable emergencies, the chances of survival of the passengers and cabin attendants must be either the same as, or the equivalent to, those intended for operating crew members.

Comment

This opposes any attempt which may be made either to separate passengers from crews by pressure bulkheads or to provide crew members with special equipment which might result in all passengers and cabin attendants being killed or seriously injured, without operating crew members being so jeopardized."

3.10.3.4 FAA, March 1961, Ref. 18

"Power-Off Landing Capability

Some of the supersonic transport configurations proposed to date do not appear to have a L/D ratio that would provide the capability of a power-off landing.

All of the presently certificated transport category airplanes do have this capability, as well as a glide ratio, in the "clean" configuration such as to provide a wide selectivity of emergency landing areas if all thrust is lost at moderate to high altitudes.

Conclusion: The supersonic transport airplane should have power-off landing capabilities.

The development of variable geometry wing configurations is one possible means which would provide a sufficiently high L/D for subsonic flight and the low drag necessary for supersonic flight."

3.10.3.5 ALPA, April 1961, Ref. 16

"Collision Avoidance

Another item of extreme concern to pilots is that of collision avoidance and high speed flight manoeuvres. The effect on aircraft occupants of any manoeuvre at supersonic speeds would undoubtedly be drastic, and such manoeuvres would probably be ineffective in providing collision avoidance. However, at the subsonic speeds there must be a capability of manoeuvring which can accommodate both collision avoidance and approach pattern manoeuvres.

We consider the primary requirement for collision avoidance to be a co-operative means for positive indication of relative position and altitude separation to both aircraft involved in possibly converging flight paths. Since all supersonic aircraft, military and civil, will be utilizing the same airspace it is realistic to insist that all should be subject to mandatory requirements for such compatible, co-operative collision avoidance devices. Such devices should incorporate fail-safe features, direct coupling to the flight control systems with simultaneous pilot alerting features, and control sensitivity limitations to ensure that unwarned passengers will not receive injuries resulting from such in-flight manoeuvres."

3.10.4 ANALYSIS AND COMMENTS

3.10.4.1 ANALYSIS - (3.10.1 Operational Life)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications				X
Composition				X
Training				X
OPERATIONAL VARIABLES				
Responsibility				X
Authority				X
Acceptance				X
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.10.4.2 COMMENTS - (3.10.1 Operational Life)

3.10.4.2.1 Operational life will be a function of design, materials and environmental conditions of service, and so should not affect the crew's role.

3.10.4.3 ANALYSIS - (3.10.2 Reliability)

	Comparison with Today's Jets						
	Similar		Different		Unique		N/A
CREW VARIABLES							
Qualifications							X
Composition			X	3.10.4.4.1			X
Training							X
OPERATIONAL VARIABLES							
Responsibility							X
Authority							X
Acceptance					X	3.10.4.4.1	X
FLIGHT DECK DESIGN							
Layout							X
Instrumentation							X
Controls							X

3.10.4.4 COMMENTS - (3.10.2 Reliability)

3.10.4.4.1 Certainly reliability of the SST and any of its subsystems or materials will be a concern to the crew. It is well known and discussed that the SST does not have a military counterpart from which we can expect to gain experience and improvement in reliability.

System reliability can also have an effect on crew composition.

Philosophically at least if we had an extremely reliable automatic system the number of crew members could be minimized. Yet - the systems could be so complex that specialized personnel would be required to monitor and operate them.

3.10.4.5 ANALYSIS - (3.10.3 Emergencies)

	Comparison with Today's Jets			
	Similar	Different	Unique	N/A
CREW VARIABLES				
Qualifications	X			
Composition	X			
Training	X 3.10.4.6			
OPERATIONAL VARIABLES				
Responsibility	X			
Authority	X			
Acceptance	X			
FLIGHT DECK DESIGN				
Layout				X
Instrumentation				X
Controls				X

3.10.4.6 COMMENTS - (3.10.3 Emergencies)

3.10.4.6.1 The complexity of the SST will be such that the malfunctioning of certain subsystems must be considered as an emergency because of the increased workload it will place on the crew. The crew's capability to operate the aircraft manually under these conditions will be an important research area and data from such studies should be incorporated into the emergency procedures.

4. POTENTIAL ROLE OF SST CREW

Many reports and studies refer to the role of man (references 19, 20, 21). The word "man" is used here in its generic sense and would apply to a crew, a single pilot, a single operator, etc. Most of these studies do not, however, show any consistency or define what is meant by the role of man. This question like others which deal with functional concepts rather than physical concepts can best be answered by considering the use to which the information is to be put. In the case of this study, as in most others, the utility of information concerning the role of man is to acquaint the reader with some general impression of what man will do in the system under consideration or the situation under discussion. Thus, the general purpose of this study is to acquaint an audience concerned with the development and operation of a supersonic transport with the potential or feasible performance of flight crews of supersonic transports. Most of the material in this section has been taken from technical references prepared by many authorities.

It is important to note that we are not at this time specifying what the role of the crew will be in SST, but rather we are attempting to present a discussion of the different potential or feasible roles of the crew based on various requirements and constraints of Section 3 and on a review of impending developments (particularly with respect to automation of functions now performed manually) which may ultimately affect the final role of the crew.

4.1 SYSTEM CONSIDERATIONS

Man is frequently conceptualized as consisting of three subsystems (ref. 15 and 22) which may be generally referred to as his sensory, cognitive, and motor subsystems although different authors use different terms for these things. An expanded technical discussion of man as a

system component will be contained in the Final report on the section on Methodology. Westbrook (ref. 19) discussed man as an actuator or motor, a computer, and a sensor system. This reference also gives a good review of the historic utilization of man in aircraft systems. Because of its relevance to this study a few paragraphs from reference 19 are quoted below:

> "In the past by careful aerodynamic design it was possible to use the actuator capabilities of man directly. With the advance in performance of aircraft it became very difficult to design a system that under all conditions of flight would stay within the envelope of desirable forces. This led to the general adoption of powered controls on newer aircraft. The important point is that the variation in characteristics is responsible for the need for supplementing man as an actuator. It corresponds roughly to the situation on an automobile with power steering. In this case we must control the vehicle at various speeds and still swivel the low pressure tires for parking. However, an automobile design requirement for power steering is still marginal, whereas on the B-58, for example, we need over 200 horsepower at full rate and loading to assist the pilot to control the elevons.
>
> In the early days of flight the abilities of man as a sensor were largely used, unaided by resorting to instruments. His eyes together with computational elements of the brain were used to determine a multitude of information including positions, rates, and accelerations. His ears were used for auditory signals that were useful in vehicle control. The mechanism in the inner ear assisted then, as now, with signals regarding the balancing and turning of the body. Senses of pressure on the skin and tension in the muscles aided in the vehicle control. With the development of improved aircraft there came a vast expansion of instrumentation designed to aid the pilot in accomplishment of his mission, primarily through the visual sense. The ability of man to perform many sensory functions is an example of his adaptability.
>
> It is said that the individual brain contains 10 billion cells, all in certain groupings with some function or other. This capacity of man to compute, make judgments, and determine actions is now and will be in the foreseeable future the same as it was in the days of the Wright Brothers. We all knew that we can exceed certain characteristics of

the human brain with machines. One example that comes readily to mind is the use of digital computers such as UNIVAC to process mountains of data or their use to solve a formidable equation, orders of magnitude faster than a man could. However, to duplicate all the capabilities of the human brain for computation and judgment is at this time certainly an impossible task . . ."

A second reference (22) contains a much more theoretical discussion of the man-machine system including a diagram of this concept shown in Figure 7a. A modified version of Figure 7a is shown in Figure 7b. This modified version is somewhat more useful to this study as it shows inputs which may be directly perceived by the man, e. g., acceleration and outputs which may be made directly to the situation by man, e. g., verbal conversation, in addition to the inputs that the human perceives from the machine and responses he makes to the machine.

The above discussions of man as a system component considering his sensory, cognitive, and motor capabilities are useful when considering simple man-machine systems or singular man-machine relationships, but the role of man in more complex systems requires that we resort to more system-oriented descriptors which may each contain aspects of man's sensory, cognitive, and motor capabilities. The descriptors that we shall use were developed in a previous study (ref. 23). This study states:

"There are numerous controversial issues concerning man's capabilities and limitations for system performance. The philosophy adopted here is (1) that man has certain unique capabilities and limitations which cannot be compared against machines, (2) there are many types of performance in which man can participate or which can be automated, and (3) for those performances where man does participate there is an optimum design to complement his capabilities and limitations. In general it may be stated that the concept proposed here is to develop a design solution for trade-off which exploits man's capabilities and compensates for his limitations. Four questions must be considered:

1. What are the limitations that constrain man's

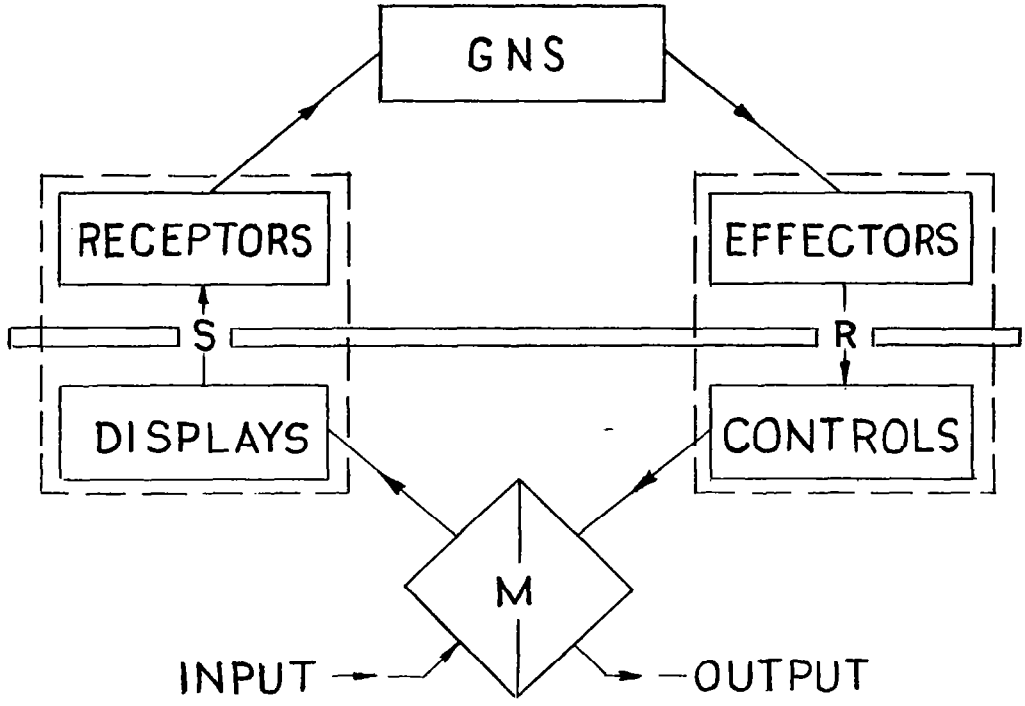

Fig. 7a The man-machine system as represented in (R-22)

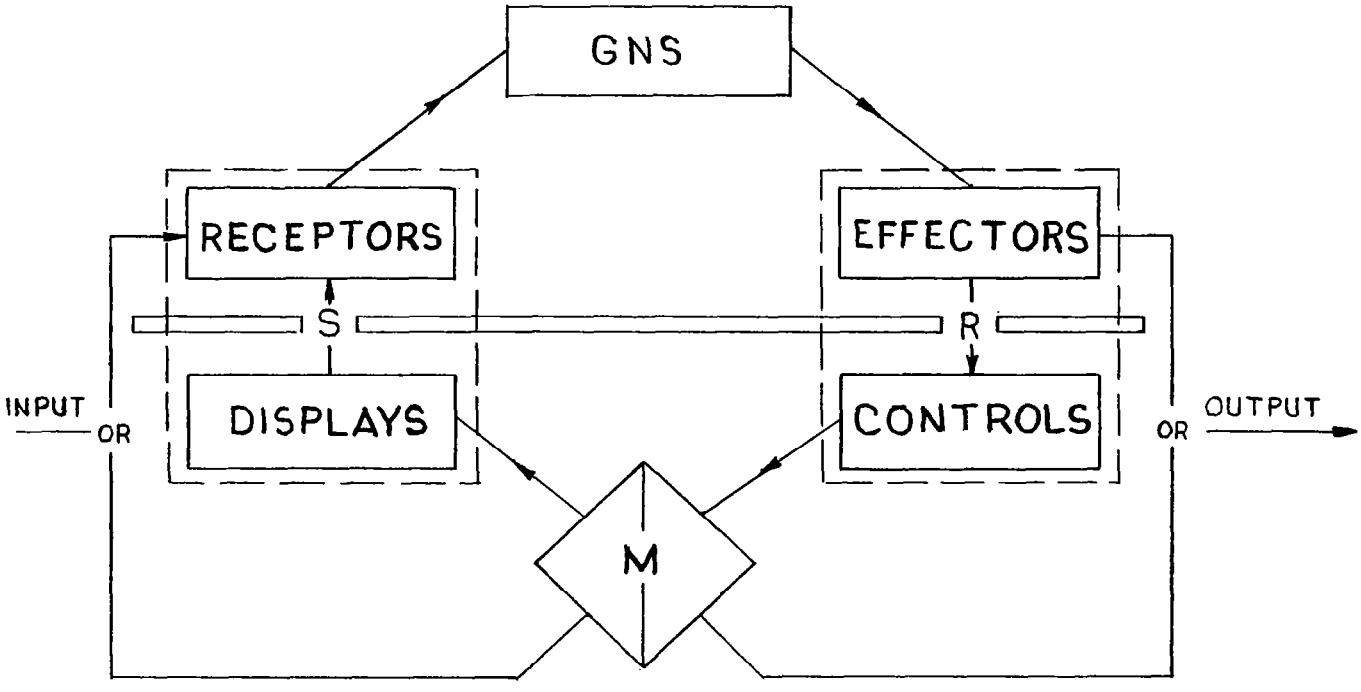

Fig. 7b A modified version of the man-machine system.

use in the system? . . .

2. What systems performance requires man? . . .
3. What system performance could be implemented by man? . . .
4. Given man's required (question 2) or feasible (question 3) inclusion in the system, what can be done to use his unique capabilities to maximize his performance reliability in the system? . . .

These questions shall be considered in a system context as (1) crew limitations, (2) required crew performance, (3) crew reliability, and in addition a discussion of the effective use of automation is included.

4.1.1 LIMITATIONS WHICH CONSTRAIN THE CREW'S EFFECTIVENESS

All human beings have limitations in their range of capabilities just as machines do. Generally speaking man's limitations occur at the extremes of any performance situation. For example, he cannot perform certain tasks at extremely fast rates where his channel capacity and response rates are exceeded. Similarly, he cannot perform certain tasks at extremely slow rates where he is apt to be bored or inattentive. These limitations are either due to individual characteristics of human beings such as motivation, intelligence, their understanding of the task or set towards the task, span of attention, and, psychological or physiological well being, or due to factors pertaining to the situation itself such as the duration of the task, rest period and psychological and physiological stress requirements of the task. It is of no importance whether the limitations are a function of individual or system factors as long as they are recognized. The remainder of this section will be identification and brief discussion of some factors in supersonic transport operation which will limit the crew's effectiveness.

Human performance limitations will be discussed under two different headings: (1) Those limitations of performance which result from an interaction of the performance environment and the human; (2) Those

performance limitations arising from characteristics of the vehicle.

4.1.1.1 Interaction of the Human and the Performance Environment

4.1.1.1.1 The Human Diurnal Cycle

It is characteristic of the human being that he shows a highly patterned behavior sequence. At the most gross level of analysis, man shows a regular pattern of wake and sleep cycles, which approximates closely a regular series of 16 hours awake followed by 8 hour rest sequences. Within the wakeful part of any 24 hour period certain other behavior patterns typically occur in a regular sequence. These include:

food ingestion;
waste elimination;
work; and
recreational activities.

In addition, the diurnal cycle includes regular and predictable changes in:

thermic cycle,
cardio-vascular behavior,
respiratory equilibrium,
digestive regulation.

The exact nature of the diurnal cycle in any given human is partly a function of the society in which that individual is found. However, for any society, the healthy individual in that society experiences very little deviation from day to day in the pattern of the diurnal cycle. Continual disruption of the diurnal cycle can result in the development of chronic fatigue (ref. 24) and stress effects (ref. 25) which are disruptive of human performance. Leamer (ref. 24) who has studied flight engineers whose complaint was chronic fatigue, reports that after a transition from piston engined aircraft to jet aircraft, fatigue became chronic over a period of 2-3 months. The subjects were more tired after a flight, did not regain their vitality prior to the next flight, showed a lessened in-

terest in their homes, social activities and a reduction of libido. They were increasingly interested in sleeping, consumed more fluids, were the victims of an increase in dandruff, dry scaly skins and chapped lips. The onset of symptoms was correlated with a schedule change of 3-4 days between flights in piston-driven airplanes as opposed to 1-2 days between flights in jet-driven aircraft. The subjects complained about difficulties associated with loss or gain of time, the necessity of having to adjust to time changes and disruption of eating and elimination routines. Routine medical examinations showed no physical symptoms which could account for the complaint.

Stutman (ref. 25) has also studied flight engineers who complained of chronic fatigue and schedule change. However Stutman reports changes in the chemical constitution of the body fluids which are regularly accepted as indicators of stress:

1. high average serum cholesterol levels;

2. total esterified fatty acid elevated well above the normal fasting level.

Juin (ref. 26) discusses the diurnal cycle with respect to today's jet transport operations:

> " . . . a human body (like every animal body) possesses—it is important to recall—a physiological rhythm, cellular, organic and functional, conditioned by the harmonious succession of days and nights.
>
> Studying the nycthemeral rhythm, it is clear how much this rhythm regulates numerous human activities. The first manifestation of this rhythm is the change between awakening and the night's sleep.
>
> Now with aircrews doing these long-distance flights with considerable "timetable readjustments", sleep trouble is a very important problem and a source of serious fatigue.

Juin (ref. 26) also discusses another important manifestation of nycthemeral rhythm often being disturbed after flights, viz., digestive

regulation with divisions of digestion, sensations of hunger, etc.

> ". . . there is no doubt that perpetual modifications of meal timings, different types of food (especially in certain Far Eastern ports) upset the digestive harmony. The conditioned reflexes of hunger with their train of biological and physiological reactions (digestive secretions, gastric and intestinal contractions) are strongly opposed, and rapidly the ensemble of these physiological mechanisms starts to function out of time."
>
> "On the other hand, we (Juin) observe from the examination of aircrews a great number of gastro-intestinal disorders such as severe colic, gastric troubles, and even a number of gastro-intestinal ulcers more acute than in most humans of the same age. . ."
>
> "Thus, after several years of attentive observation among numerous crews of French Commercial Aviation, we would include 'time-table readjustments' in the list of important fatigue factors in this profession. . ."

A very recent paper by Dr. Ludwig Lederer (ref. 27) states:

> "With respect to SST operation and disruption of the physiological time clock of the flight crews, in some respects, due to the speeds contemplated, there would be less disruption because it may be possible to bring crews back the same day they started. When this is not possible, keeping the crew on the same meal and rest schedule as when at home by appropriate destination accommodations can be the answer."

Thus it seems the SST operations could be such that their tremendous speed and consequent disadvantage with respect to the human diurnal cycle may also turn out to be an advantage while very real diurnal problems could result from a "one way" flight, a "round trip" flight, with properly planned facilities and meals could possibly keep the crew on their normal schedule.

4.1.1.1.2 Climate Changes

If the diurnal problem could be resolved by round trip scheduling there would still remain a problem of the crew possibly being in two vastly different climates in the same day. Juin (ref. 26) expresses the effects of climate change as follows:

> "Sudden and frequent changes of climates are experienced by aircrews frequently employed on North-South crossings and vice versa. After some hours of flight, without any transition, and without any possibility of adaptation or of acclimatization, these bodies already pass and will pass more and more quickly from a torrid, tropical, humid temperature (as in Black (sic) Africa) to an icy temperature (for example, Paris in winter).
>
> Those who embark wearing necessary warm clothes and breathing cold air, will have to take most of them off some hours later, having become a prey to insupportable heat. Since this factor already exists with conventional piston machines, it is clear that this change of climate, without any transition, will be still more sudden, and more aggressive after a jet crossing at double the speed. (Obviously, this problem will be even more aggrevated by supersonic flight.)* Here is an important factor of fatigue for aircrews.
>
> Indeed, with jets, the human body is transported, in a short time, from the cold to the heat, then again to the cold without the regulating centres having had time to adapt themselves. In the word "adaptation", lies the whole physiologically delicate problem of the crew's health. We must pay attention to thousands of adaptation problems which make the physiological daily life of the crew in the jet era subject to varied, indeed exceptional, conditions of work and existence in an aircraft. . . thus declared Dr. General Bergeret at Louvain in 1958.
>
> In the domain of sudden changes of climate, we are certainly sorry to see big thermic regulating centres upset without any management. These regulating centres, indeed, start up automatically a whole system of defense against cold as well as heat, against aridity as well as humidity. Thus, it is for these vital needs of the "inside milieu's" balance, increasingly to fight against thermic

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* parenthetic insertion ours

aggressions, that the regulating centres of transpiration, respiration, vasodilatation, etc., function vigilantly. There is no proof that these regulating centres can function in an anarchical manner; they respond faithfully and exactly to a given influence with precision, like electric commutators moved at will by a simple finger pressure. Taking into consideration the case of aircrews having to make several sudden crossings per month from cold to hot climates throughout the year, we must admit that here is a medical and physiological problem closely linked with that of fatigue, and which must be studied, checked and evaluated."

If the problems associated with climate changes are severe then special consideration may have to be given to facilities for crews if they are to merely layover and then take the aircraft back to the city of origination.

4.1.1.1.3 Psychological Stress

Unique psychological stress conditions may exist for the SST crew because of their increased responsibility and the severity of operating conditions. The crew's increase in responsibility will be due to such things as:

(a) The relative cost of the airplane -- something over $20,000,000 a copy.

(b) Increased number of passengers -- up to 220 passengers.

(c) The economic consequences of deviating from the flight plan.

(d) The almost certain requirement that the SST will have to land in "zero-zero" weather.

The severity of operating conditions will be due to such things as:

(a) The outside skin temperature at cruise is 500 or 600 degrees and any failure of the cooling systems would be disastrous for the passengers and probably for the crew.

(b) Any pressurization failure would result in almost instant death from ebullism and the lack of oxygen.

(c) Similar consequences are true for other factors such as radia-

tion and ozone concentration at cruise altitudes.

(d) Possibility of obscured vision in the cockpit by some sort of visor over the window. Will this produce claustrophobia?

(e) Collision avoidance, at least at altitude, will depend on air traffic control and not 'see and be seen'.

Juin (ref. 26) also reports on psychological factors as follows:

> "These (psychological factors)* hold an equally important position in the study of the causes of fatigue in aircrews and they cannot be separated from physical factors, because they are very often closely linked, without its always being possible to say which of the two has the most influence on the other.
>
> If it is considered that, among all other subjects, real fatigue can be caused by doing work which needs real and prolonged concentration with a certain amount of brain work, we cannot infer from this the important psychological factor of fatigue of the aircrew.
>
> For a long time, the manipulation of complex machines demanded a prolonged mental tension with the necessity to concentrate constantly. Similarly, the subject found himself the object of many serious psychological aggressions such as frequent emotional phenomena, due to air work itself. Finally, there is no doubt that sensory stimulations--more and more rapid, frequent, difficult to translate and interpret--brought serious trouble and real fatigue, in the same way as the essential notion of safety before everything.
>
> It is evident that the use of jets has considerably aggravated all the inherent factors of flight especially by the enormous increase of the aircraft in operation. All the given factors of the problem are indeed upset, precipitated and multiplied: altitude, speed, acceleration, unevenness, weight of machine, and also increased responsibility. All sensory incitements are increased by frequency and intensity. Finally, the phenomena of mental tension and emotional factors increase among air-crews using jets"

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* parenthetic insertion ours.

4.1.1.1.4 Monitoring Performance

Stewart (ref. 28) has noted that consideration of the flight profiles of supersonic jets indicates that high standards of accuracy will be required in flight control and navigation. He has suggested that automatic control be used for these types of flight functions which require great accuracy, and that the human role should be to monitor the automatic equipment.

Marshall (ref. 29) states that "Supersonic flight is in fact only made possible by removing some functions from the human operator and entrusting them to automatic and powered systems." Marshall further enumerates as follows:

> ". . . Also flight under the conditions envisaged necessitates quite complex systems such as air-conditioning and pressurization, powered flying controls to supply the large control forces required, control of the centre of gravity of the fuel due to its disposition in the aerodynamic shape required, and electrical generation to supply the complex services and systems; all these systems require correct handling and monitoring throughout the flight. Hence the time available for the correlation of information and the reaching and implementation of decisions is greatly reduced on two counts, that of overall time available and that of the possible number of actions required in any one flight. Thus at any one time there will be a requirement for a number of processes to be going forward simultaneously. These processes will be of various types such as data measurement and formulation, data transmission and reception, forming decisions based on the correlated data and the implementation of such decisions. Both the number and complexity of these processes makes it impossible to use human faculties to perform them all with an economical number of crew members and hence a high degree of automaticity is required. The automatic systems must then be monitored to ensure their continued correct functioning. The monitoring actions are few compared to the processes being performed and in general will be well within the capacity of trained personnel. Hence a primary crew function on this class of vehicle will be that of monitoring the equipment which is doing the work."

But relegating the crew to a role of monitoring is not without its problems.

Leamer (ref. 24) discusses the problems that flight engineers have in subsonic jets as regards their monitoring tasks. The boredom and monotony of just sitting at a control board, watching gauges with very little opportunity of exercise from four to six hours, very little opportunity for conversation, having to remain constantly at the control panel, even during refueling stops, was a very fatiguing type of duty. These conclusions were supported by the results of Stutman (ref. 25).

If, in addition to the above, we consider what is known about vigilance tasks, performance accuracy may be very depressed on supersonic jets.

Stewart (ref. 28) discusses the problem of monitoring and reports on the results of other investigators as follows:

> "Howland has shown that the number of false reports in a monitoring situation, increases in the second part of a four-hour experiment, and it might be thought that with a total flight time of three hours, strict cognizance should be paid to results such as these, since a false report by a fatigued monitor may be as dangerous as an omission. It must, however, be stressed that such reported decrements in performance are usually a function of the experimental situation and the measures employed, so that both should be carefully chosen.
>
> What is not known is whether any decrement in performance in, for example, the cruise climb would be relayed to monitoring the descent and landing phases.
>
> Here Broadbent, discussing the effect of such interactions, clearly shows that much more work is required on the carry-over of effects from one type of task, performed under a form of stress, to a similar task with a change in the intensity of the stress. The experiments of Welford, Brown and Gabb on aircrew show a similar interaction between fatigue or stress and performance in

that subjects learning a task when fatigued, also perform badly on the task when returning to it afresh.

It is well known that any tasks demanding vigilance also show a decrement in performance with time, which is characterized by the occurrence of lapses in perception, lasting for 1-2 seconds and resulting in the missing of infrequent signals. A great deal of work has been reported on this subject and with certain kinds of tasks, the reduction in performance may occur in 30 minutes (Mackworth). One might thus expect that with an unvarying sensory environment, as again in the two hours of cruise climb, there might be a decrease in vigilance, but the relationship between the form of tasks, monitoring and vigilance is insufficiently clear from previous work, to state that vigilance will be of importance in this type of flying. Certainly in any task, such as watching dials, with or without reaction to significant signals, there may be shifts in attention such that central dials are observed best immediately after the stimulus of an observed signal, but are less well monitored than peripheral dials, after an interval without a signal.

The major lesson to be learnt, from the consideration of vigilance, is to avoid in the design of the crew tasks, the isolation of any crew member physically or in terms of work, remembering that Coastal Command radar watchers showed a decrement in performance after 30 minutes, even if a member of a large crew."

If it turns out that the SST crew will be performing a considerable amount of monitoring tasks careful attention should be given not only to the allocation of tasks but to the design of the interface between the crew and the vehicle. There appears to be a tendency to develop "over simplified" monitoring interfaces, i. e., make the monitory displays much simpler than the complexity of the task. This may be poor interface design if the operator has to take over as primary controller in the event of failure of an automatic system. The operator may not be psychologically or physiologically set to take over a complex task if he has been monitoring it with an oversimplified display.

4. 1. 1. 2 Performance Limitations Arising from Vehicle Characteristics

4.1.1.2.1 Thermal Factors

The following discussion of thermal factors has been abstracted from reference 30 by Steinkamp, Berry, and Hawkins.

Thermal factors in the environment include infra-red radiations, air density and movement, and humidity as well as air temperature. The effect on man's physiology may be determined by various combinations of these variables. The human body is capable of some rather remarkable compensations for deviations from thermo-neutrality but cannot cope with the extremes encountered in the stratospheric altitudes with which we are concerned.

In the 50,000 - 70,000 feet area we are above the troposphere with its declining temperature (2 degrees per 1,000 feet). This stratospheric area is iso-thermal at virtually a constant -55 degrees centigrade. Even though the air density is low and thus heat transfer rates are slowed, the low temperature and the high airflow rates make this an undesirable thermal environment. Generally it has been found that cold predisposes to dysbarism, and heat to motion sickness and diminished tolerance to acceleration. The important factor in maintaining a comfortable thermo-neutrality in the aircraft cabin is the effective temperature index. This index is determined by relating the three important thermal variables -- temperature, humidity and air velocity.

> "Humidity control has been a continuing problem in present-day aircraft. Complaints of drying of the mucous membranes are frequent in current aircraft. The presence of smoke and high air temperatures accentuate these complaints. This would imply that effective filtration of the air is important. The current jets have tried to use air only once, but in supersonic liners recirculation of air will almost have to be used due to its scarcity at the operating altitudes."

4.1.1.2.2 Pressurization

The following discussion of pressurization has primarily been abstracted from reference 30 by Steinkamp, Berry, and Hawkins.

The most obvious environmental change at high altitudes is the tremendous reduction in atmospheric pressure. This low pressure is not sufficient for man's physiological needs and several important problems can be created by exposure of man to these pressure levels. In the order of occurrence these are: (1) decompression with its physical effects, (2) the resulting hypoxia and/or anoxia, (3) dysbarism and ebullism. These will be discussed separately in the paragraphs which follow.

Physical damage resulting from decompression is a function of the pressure differential between cabin and outside, the size of the cabin and the size of the opening through which the cabin is decompressing. Massive structural failures, as in the Comet would obviously be disastrous but new design techniques have greatly reduced the possibility of this occurring. The principal physical effect of decompression is the expansion of body gases. The two important factors in estimating the hazard are the relative gas expansion and the time of decompression. The initial quantity of gas is of great importance in such situations for the large quantity in the intestinal track could produce great pain. Small amounts expanding in very sensitive or critical areas would also pose a problem.

Hypoxia and anoxia--oxygen comprises 21% of the available pressure at sea level and therefore has a partial pressure of approximately 159 mm. of Hg. When this pressure drops below 109 mm. of Hg (found at 10,000 feet) there is not enough force to drive the oxygen across the lung membrane in sufficient quantity to maintain the body's needed supply. This results in hypoxia. The physiological affects of this condition are well known to airmen and are not consistent with flying safety. Blurring

of vision, diminished night vision, faulty judgment and poor coordination, headache, dizziness, and eventually unconsciousness result. Current jet liners have automatically produced oxygen masks available for passengers and the crew has constantly available masks. The critical effect of hypoxia is the time of useful consciousness which decreases rapidly with altitude. Generally speaking at altitudes over 40,000 feet personnel must have their mask on if they are to avoid hypoxia in the event of decompression. Even experienced personnel have difficulty donning an oxygen mask and usually suffer some impairment of their capabilities at this altitude even when they are ready for decompression. At 50,000 feet the partial pressure oxygen is only 18 mm. of Hg. Of even more importance, the total barametric pressure is only 87 mm. of Hg and in the lung alveoli this is occupied by carbon dioxide (40 mm.) and water vapor (47 mm.) to the total exclusion of oxygen. Thus exposure to this altitude results in anoxia. The time of useful consciousness would be limited to the circulation time of lungs to brain, or eight to twelve seconds. It is quite obvious that ordinary mask presentation will be of little value at this altitude unless the decompression rate can be slowed so that passengers will never be exposed to the full effects of the altitude.

Dysbarism--dysbarism may be defined as the symptom complex resulting from exposure to reduced or changing barometric pressure. It is an entity totally apart from hypoxia and may occur at altitudes where the individual is well oxygenated by the use of current protective equipment. The principal dysbaric symptom is trapped gas involving the ears, sinuses, teeth or abdomen.

Ebullism--this could be simply defined as the "boiling" of body fluids without the addition of heat. At 63,000 feet the total pressure is equal to that of water vapor, and thus the only deterent to body fluids boiling is the pressure exerted by body tissues. The actual altitude may vary due to body temperature in the solutes and the fluid.

In view of the foregoing it is obvious that total decompression of the supersonic airliner must be designed out. We can no longer depend on a rapid descent to a safe altitude.

> "It should also be obvious that crew members of any supersonic air transport must receive detailed physiological indoctrination including exposure in the altitude chamber." (ref. 30)

Juin (ref. 26) has noted in connection with the problem of barometrical depressurization:

> ". . . it is important to know and bring to light factors of serious fatigue like digestive troubles experienced by the crew as soon as they are in a pressurized atmosphere, because pressurization only brings the cabin pressure up to the pressure of a still higher altitude. Thus, most of them suffer from dilatation of gas found in the closed cavities of the body, leading to often very painful troubles of abdominal distension which are themselves a source of neuro-vegetative disorders. We have often come across these digestive troubles among aircrews, notably increased among those of jets."

There is no question that the human limitations with respect to pressurization are severe and that the possibility of a catastrophic depressurization must be designed out. There are techniques for reducing the severity of this problem such as eliminating windows in the passenger compartment, environmentally isolating the crew, or having the crew (and for that matter passengers) wear "pressure suits". These techniques are unfeasible, however, when we remind ourselves that we are working with commercial air transportation. Just like any other commercial free enterprise, - the customer must be satisfied.

4. 1. 1. 2. 3 Toxicants

The following discussion of toxicants has been abstracted from reference 30 by Steinkamp, Berry and Hawkins.

Another important area is man's reaction to exposure to toxicants. Toxicants may exist from exhaust, various hydraulic fluids, sealants, solvants, fire extinguishers, items in baggage and various items exposed to fire. There is no simple definition of the amount of impairment allowable under these circumstances consequently it is best to consider that any impairment will jeopardize flying safety. It should be remembered that certain agents are more toxic at altitude. This is true of carbon monoxide. The combination of a toxic agent and the hypoxy of altitude could be lethal.

One of the best known atmospheric toxicants which is a current matter of concern is ozone. Spectographic measurements both in this country and in Germany have revealed an area of increased ozone content greatest between 70,000 and 100,000 feet with a maximum concentration at about 85,000 feet. This ozone is produced by the action of ultra-violet light in wave lengths less than 2,000 angstroms on ordinary oxygen. There appear to be great individual differences with respect to ozone sensitivity. The primary symptom of exposure to ozone is irritation of the respiratory track. The toxicity of ozone is graphically illustrated by comparing the maximum allowable concentration (for an 8-hour daily exposure for a year) with that of other known toxicants. Ozone is 0.1 ppm while carbon monoxide is 100 ppm and phosgene and chlorine are 1 ppm respectively.

At least one industry spokesman (ref. 51) shows some concern over the effects of ozone:

> "The ozone content in the air at SST flight altitudes will vary from 5 to 10 parts per million parts of air. One tenth part of ozone per million parts of air is considered a desirable upper limit. The effect of ozone on the health of passengers and crew is still controversial.
>
> In the Lockheed SST, ozone will be controlled by the combination of heat and catalytic material and instrumentation will be provided in the airplane so that ozone content

in the air can be monitored along with the other cabin air conditioning parameters."

Leder (ref. 27) states a caution:

> ". . . With respect to toxic exposure, we must not adopt standards written for one purpose applied to another. As an example, the present Maximal Allowable Concentration (MAC) for ozone is 0.1 parts per million in inhaled air. This was written for the worker working eight hours per day, forty hours per week, for fifty work weeks per year. The MAC for an airline pilot flying eighty hours per month may be much more providing acute toxic symptoms are not produced."

4.1.1.2.4 Vibration

On the subject of vibration, Juin (ref. 26) has reported:

> If simple vibrations, in the proper sense of the word, are already less strong on jets than on ordinary piston machines, we must consider the eventual action of ultra-sonic vibrations, if only to attempt a "rectification", after numerous theories and numerous opinions--often contradictory and advanced over several years by numerous authors. However, on looking back over the past, it seems possible to form a reasonable opinion. Among the most recent rectifications, we quote that of Bugard (Paris). It coincides entirely with what we have tried to prove in parallel works.
>
> There is no doubt that ultra-sounds exist intensively in the acoustic spectrum of the aircraft's propellers. Van Gierke has been able to calculate that the ultrasonic quantity produced by a jet corresponds to an energy equal to 1/300 of total energy. On a 5-ton jet, that is equivalent to an acoustic power of 30 to 50 kW.
>
> Without entering into the enumeration of all the theories and all the mechanisms of action of ultra-sonic vibration, it can be said as a physiological reality that ultra-sonic disturbances emitted by jets spread across the solid body of the cabin, the under-carriage, next penetrating the body by feet, seat or hand. Naturally, these ultra-sounds are considerably deadened, and thus produce

in human bodies only "non-specific effects" as opposed to "specific effects." These non-specific effects are important in the physio-pathological domain. Thus, Chauchard and his collaborators have shown experimentally an excitation of nervous motor fibres with a diminution of "chronaxia". This effect of excitation is seen equally on sensitive fibres, the muscular systems, the heart, the cardio-vascular system and the intestines. Finally, real disturbances have been observed in connection with the autonomic nervous system, and the endocrinological and metabolical systems as well as disturbances in the blood.

For ourselves, we do not wish to dismiss ultrasounds as causes of fatigue in aircrews. Our aim is to discover and consider all interferences caused through the machine used, in order to try out a prophylactic medicine and draw up a healthy policy for the maintenance of the crew in good physical order."

4.1.1.2.5 Radiation

Human limitations to radiation are somewhat uncertain as well as is the radiation environment of the SST. There seem to be a general feeling of "we don't know quite what the radiation environment is but we don't think it will hurt you".

An excellent technical discussion of radiation and the SST by Mohler, Director of the Civil Aeromedical Research Institute, FMA is provided in reference 31. Dr. Mohler concludes:

"To sum up, then, we may say that the matter of the exposure of supersonic transport occupants to ionizing radiation at cruise altitudes of 60,000 to 80,000 ft consists largely of two considerations. One is a value judgment based on the known degree of biological effects of ionizing radiation components other than heavy nuclei. The other consideration is at present somewhat baffling, and revolves around the fact that we do not know much about the biological effects of those heavy particles, which, for the SST occupant, will constitute a sort of microscopic "ack ack" or "flack" environment."

For reasons given here, the present state of the art in ionizing radiation shielding does not yet of itself give us a complete solution to this last situation, but the problem is apparently not insurmountable. Various approaches, integrating scheduling with biochemical and atmospheric protection, are available and should produce an acceptable solution."

Mohler's article also includes a table of acceptable exposure levels which was prepared by Foelsche of NASA.

TABLE 7

"ACCEPTABLE LOADS OF EXPOSURE BY SST CREWS TO IONIZING RADIATION*

Solar Minimum Year

Galactic Cosmic Rays

Over-all Ionization - Below 0.033 rem/week

Nuclear Stars - Below 0.002 microcuries (expressed in terms of radium)

Heavy Primary Thin-Downs - Below 0.007 microcuries

Solar Cosmic Rays

Inapplicable

Solar Activity Year

Galactic Cosmic Rays

Over-all Ionization - Below 0.024 rem/week

Nuclear Stars - Smaller than in solar minimum year

Heavy Primary Thin-Downs - Smaller than in solar minimum year

Solar Cosmic Rays

Below 8 rads/yr.

* Based on 10 hr/wk of flying over polar routes at 75,000 ft, with no precautions taken. Estimates by Foelsche."

Steinkamp (ref. 30) has suggested that " . . . while aircrews have expressed concern about radiation exposures, they should receive no significant injury from either cosmic, atmospheric fallout, or microwave radiation in flight at the contemplated altitudes. . ."

However, Marshall (ref. 29) has observed that some form of reflecting or absorptive screen may be required over the windshield at cruise altitude to protect the pilot's eyes from infra-red radiation from the hot outer surface of the transparencies. It is conceivable that this latter requirement could eventually be met by material which could absorb or reflect infra-red while transmitting in the optical range. Another factor to consider however is that in early and late summer there will be a "sunset flight" from London to New York during which the aircraft will fly almost directly into the sun which will appear to remain at a constant elevation above the horizon. This feature might necessitate an opaque or semi-opaque screen.

Juin (ref. 26) has agreed with Marshall. He writes:

> "In the domain of eventual effects of radiation, we know very well the actions of radiations like ultra-violet and infra-red, not absorbed or imperfectly absorbed at great heights. This problem has been studied for a long time and the means of protection seem to be tested. However, the problem must not be considered as solved. A number of ophthamologists, such as Henry Calvet in Paris, being brought in to treat ocular lesions among aircrews, have again put questions in this domain: Is the protection given really sufficient with new machines flying at high altitudes during the whole of their flight?
>
> Beside these "Celestial Radiations" (excuse me for this expression) we may put down radiation from machines used on certain aircraft as factors contributing to fatigue in some circumstances; for example, radar and the microwaves emitted by such equipment. This study is continuing but in this connection we must refer to the interesting Italian contribution of Busco and Serafini, revealing the existence of non-negligible blood disturbances among 35

users of radar (sensitive diminution of erythrocytes with increase of lymphocytes), at the same time as violent headaches frequently occurring among the same persons. It appears important to us that the study of the biological action of microwaves emitted by radar has been seriously carried out, because the multiplicity of techniques, and therefore of machines, used in new aircraft, can multiply physiological troubles."

Reedy from Lockheed (ref. 51) speaking of SST crew problems says:

"There are two types of radiation in the atmosphere that we are concerned with. One, cosmic rays that cause ionization of the atmosphere, and two, high energy protons emitted from solar flares.

We do not expect any hazards from cosmic radiation, based on U-2 experience and from the Mercury Project.

Solar flares produce infrequent radiation conditions which could require restriction or rerouting of SST flights. These conditions are accurately predicted and evaluated, and solar flares of this intensity occur infrequently -- usually several years apart.

Generally speaking, radiation is no worse than at 40,000 feet. However, radiological monitoring in the cockpit may be desirable and if so the SST will be suitably instrumented."

Lederer (ref. 27) cautions that we must not adopt standards written for one purpose applied to another. He discusses this for ozone and radiation . . .

"The same applies for ionizing radiation exposure. The average allowable whole-body radiation exposure for the average person is set at 0.5 REM per year. For monitored people like radiation workers, x-ray laboratory technicians, it is ten times that, or 5.0 REMs per year. It is anticipated that, by the time the SST becomes operational, we will have a world-wide radiation monitoring system in operation. In addition, we anticipate on-board monitors to warn of heavy ionizing radiation (solar flare influence) in the atmosphere. This device will act like

radar to warn the pilot ahead of time so that evasion tactics can be smoothly accomplished."

4.1.1.2.6 Acceleration and Deceleration

Steinkamp, et al., (ref. 30) has suggested that there is really no limit to the speed which can be endured in straight and level flight. Under normal operating conditions, supersonic flight will offer no problem and there is no reason to believe that it will be necessary to produce extended changes in linear velocity on take-off and landing of a magnitude which could alter man's functional ability. Obviously the effects of abrupt linear changes in velocity such as collisions or severe turbulence will lead to reaction forces of inertia for which the body has a sharply limited tolerance.

Disorientation should not be a problem in supersonic commercial flights under normal conditions. It is possible it could be induced in passengers as well as crew in a high G field on pullout from an emergency descent or during a high-speed turn. Disorientation of this type may not be critical in passengers but is obviously critical for the crew and they should be well briefed on this phenomenon so that they understand what is happening and how to avoid it.

On the other hand, Juin (ref. 26) states:

"As for the problem of acceleration, this is not of much concern in the domain of commercial aviation where sudden acceleration and deceleration are uncommon, on principle, in order to give maximum comfort to passengers. This cause of the crew's fatigue cannot be set aside because even if these phenomena are less frequent and intense than on certain military planes, they nevertheless take place at certain times. Their repetition is a cause of real fatigue. If the crew undergoes many times in the day several sudden acceleration and decelerations (on medium sectors), their bodies are strongly disturbed by these repeated aggressions. As this is repeated many times over months, it is impossible to neglect this source of physiological aggressions, and, therefore, of fatigue."

Anticipated accelerations for a "normal" SST flight profile should present no problems to the crew or passengers. There will probably be slightly higher accelerations during takeoff and possibly during descent than is experienced in present jet transports. The problem associated with acceleration is the potential for adverse accelerations in case of "off design" performance. For example, it is possible to over accelerate during climb and to over decelerate during descent. It is also possible to obtain mean zero g in those cases where the SST must nose over from a high climb angle such as for noise abatement after takeoff, transition to supersonic speed and transition to cruise.

4.1.2 SYSTEM PERFORMANCE WHICH REQUIRES CREW PARTICIPATION

Generally speaking man is required to participate in systems for one of two reasons, viz., (1) he is mandatory or, (2) because he excels or is simply best in some system situations. The difference between these two is of course where a man is mandatory there is no option for automation and where man excels there are options but a manned solution may be the best option.

Even though man is not mandatory, many systems will include man's performance because that solution excels with respect to automatic performance. The areas in which man excels are quite diversified and difficult to categorize and discuss. A more detailed discussion of these areas will be presented in the final report.

As far as the supersonic transport crew is concerned the roles in which man is mandatory are not so controversial but what is subject to controversy are those roles in which man is not mandatory but may be used. This, of course, is basically a consideration of the automation problem and what should be automated and what should be left to the skills of the crew. This problem is by no means resolved and the material

in this part of the report is included to give some of the general thinking which exists today.

4.1.2.1 Man is Mandatory for Crew Performance

In general man is mandatory to:

1. achieve a satisfactory system reliability;
2. perform management and control tasks which require judgment as opposed to decision making;
3. perform non-system oriented tasks; and
4. increase the diversity of missions which the system is capable of achieving.

4.1.2.1.1 Tasks Requiring Judgment as Opposed to Decision Making

As has been true in all preceding commercial transports, the crew will be required to provide continual judgment as to whether to continue the flight, abort the flight, or proceed to an alternate destination. This has been stated in a more scientific context in a report entitled An Approach to Functions Analysis and Allocation, Shapiro, Rappaport, and Ericson. They assert: "in any system (or function) of human design, man is necessary whenever the assumptions concerning relationships between inputs and outputs are subject to re-examination and restructuring in the operational context." Because of its importance, let us take one more look at this criterion by stating that man is mandatory in any systems where all of the alternatives in the operations of that system cannot be anticipated in advance and thus cannot be pre-programmed into automatic equipment. Obviously in the command and operation of a supersonic transport, or for that matter any commercial transport, all of the possible situations which may occur during a flight cannot be anticipated in advance, and thus certainly cannot be pre-programmed even if we could afford to carry the automatic equipment on board capable of doing this.

4.1.2.1.2 Achieve System Reliability

A second situation in which the crew is mandatory in commercial air transportation is as a means of operating the aircraft if all else fails. While indeed the crew may be the primary means of aircraft operation, they must always be some secondary or tertiary means of operation of the aircraft. No matter how many orders of magnitude they are removed from primary operation of the aircraft, the crew will ultimately be the final backup system for operations. The British, for example, are considering triplicated systems for their all-weather landing in which one might say that the crew is a fourth order backup to three orders of automated equipment, but the point is that the crew is included for the final backup no matter how many orders of automation precede it.

4.1.2.1.3 Public Acceptance Factors

Another factor enters into the mandatory inclusion of the crew in supersonic transport which may not be active when considering military or space systems. This factor may be deemed the public acceptance factor. The public has a deep-seated fear of air transport that is independent of objective safety data, and therefore may be termed irrational. Mr. Jerome Lederer, Managing Director of the Flight Safety Foundation, Inc., recently stated (ref. 32) -- "We can safely assume then, I believe, that fear is a factor in the public acceptance of aviation." This irrational fear will not disappear in less than a decade, and must therefore be a constraint in the design of civilian aeronautical systems. The proof of the existence of this fear is the fact that, as we enter the space age, the vast majority of Americans have still not ridden in an airplane.

To partially cope with this fear, the airplane must be under the control of a force which the public will perceive as competent. Today's public will not so perceive a machine, regardless of the objective facts, which is the reason for terming the public's attitudes in this area a design constraint. Furthermore, this attitude will require a manual backup,

i.e., a co-pilot, and therefore a minimum crew of two, as the public is aware of man's ephemeral nature.

4.1.2.1.4 Non-system oriented tasks

The crew is required in the system to make a variety of observations, and to perform some tasks, which are not directly related to the function of the system (aircraft) itself. Two examples come to mind. The first of these is in-flight weather observation and reporting. The SST will fly high and fast. The reliability of in-flight weather data is notoriously low. However, if SST pilots observe and report in-flight weather, they can thereby enhance the reliability of this information for other SST aircraft. An example of a non-system oriented task arises out of the fact that operation of the SST will be a commercial venture, presumably a money making proposition; further, competition will be keen. Thus services to passengers, such as informing them of flight progress, weather conditions at the destination, and explaining unusual occurrences or phenomena may be very important to the competition. These are non-system oriented tasks, where the system under consideration is the aircraft.

4.1.2.2 Roles Where Man Excells

Three general roles of man in a system configuration have emerged:

1. Contributing to system effectiveness through the operation of system equipment. This may include starting and stopping, continuous control, adjusting, trimming or correcting, overriding part or all of a subsystem, switching to a standby or backup system, testing, and initiating and accomplishing emergency or non-routine procedures.

2. Contributing to system effectiveness through substitution for system equipment. This includes such things as programming, sensing,

selecting, storing information, monitoring system equipment, and performing manipulative actions unfeasible to mechanize.

3. Contributing capabilities not possible with an automatic system such as observation and recording of ephemeral information, anticipating failure, decision making and in general contributing in situations, the alternatives to which cannot be specified in advance, and thus, cannot be programmed in an automatic system.

Within the context of these three roles, several generalizations of the kinds of things man excells at may be made.

4.1.2.2.1 The Recognition of Patterns in Noise

Man is able to recognize and use information redundancy. Further he can use such redundancy, or patterning, in the context of considerable noise and distraction. An example is the recognition of the aircraft identification call for radio communication. The experienced pilot can recognize a call intended for him in the context of considerable static and distraction. A similar example is the recognition of weather patterns, other aircraft, terrain features, etc. within considerable background noise on a radarscope.

Pattern recognition machines exist, but they are very expensive and not so efficient as man. Further, machines perform well only in a clean environment. There are also limitations to man's ability to perform in a noisy context as after a short time his efficiency and reliability is greatly reduced.

4.1.2.2.2 Related Action Tasks

Man has excellent long-term memory for related events. This capability can have relevance in two kinds of situations with respect to the SST. Consider a malfunction which could be reduced by local troubleshooting and maintenance procedures. Most troubleshooting

tasks are sequences of related actions. Further, if the original cause of the malfunction had occurred some time earlier to its discovery, observation of that event could lead to anticipation of the malfunction and to more immediate reduction of the malfunction.

A second example would be the initiation of emergency procedures in a given situation. Since emergency procedures consist of a related sequence of actions, each occasioned by a given event. The occurrence of that event can lead immediately to the initiation of check procedures to verify the emergency and then to the emergency procedures per se.

4. 1. 2. 2. 3 Transient Overload Tasks

Man performs well under transient overload, his performance degrades gracefully. Machines generally have a maximum load point, beyond which they fail. Man's ability to function at an adequate level--as opposed to an excellent level--is exemplified by some present day communications problems.

4. 1. 2. 2. 4 Tasks Requiring a High Degree of Flexibility

Man can learn to develop a high flexibility for task performance. For example, if there are alternative modes of maintaining flight path along the ILS, man can utilize, or monitor, the preferred mode. If this mode should go out or malfunction, man can switch to a second preferred mode and so on.

As a second example related to maintaining the ILS glide path man may be monitoring an automatic system which was designed to fly the aircraft, and if the pilot should have reason to believe that the aircraft was not going to make the runway - he could take over and go around. Such an event could occur in the case of a malfunction of automatic equipment, or if a mistake were made in setting up the equipment for the approach.

Man can override his own actions should the need arise. This capability is the basis for alternative routes to a goal. For example, if the SST were climbing out and had to hold at a given fix, the information to hold at that fix at specified altitude may come too late and the aircraft may overshoot. The pilot may report that the aircraft is overshooting and request an alternative fix at a new altitude -- to be specified by him.

Man complements the machine in the sense that he can use it in spite of design failures. For example, if the hydraulic system for rudder control should malfunction and render the rudder useless, the pilot could still land the aircraft in a crosswind by using differential engine thrust.

Man complements the machine in the sense that he functions as an aid in sensing, decision making and output evaluation. This is essentially man's role as a monitor of equipment with the responsibility for evaluating the adequacy of the output.

4.1.3 SYSTEM RELIABILITY AND THE CREW

Given the decision to include man in any system context, because he is mandatory or because he excels the performance of the machine in any particular, there is still the question how man should be included in that system context. Within the constraints of time and cost, man should be included in a system in a manner which enhances the reliability of system performance. This means that reliability requirements must be established in the context of the operational situation. These reliability requirements are then used to evaluate automated performance, man-machine interaction and the overall system output. In addition meaningful reliability requirements provide a background for the selection and training of crew members. Without the reliability requirement there

is no system oriented way of determining whether the crew is adequately trained.

Man contributes a large component of consistency to the output of a system. Krendel and Bloom (ref. 41) have summarized the literature. They observe that:

> "On an intuitive basis it might appear that the performance of machines would always be more consistent than that of men. Interestingly enough, with complex equipments, the opposite is more often the case. Even such relatively simple devices as radar equipment often exhibit surprising variability compared with their human operators. In an unpublished study cited by Chapanis (1959), variations between individual radar sets of the same model were found to be much larger than differences among operators. Indeed, in his studies on detectability on radar scopes, Williams (1949) found so much variability in cathode ray tubes that he could not use electrical measurements of circuit parameters as the independent variables. In the case of entire aircraft systems the machine variability is, of course, substantial. As a matter of fact, pilots tend to characterize certain of supposed identical individual craft as "mushy" and others as "touchy." In a similar vein, Bray (1958), reports on experiments on interceptor gunnery performances as measured by actual firing on targets. Variability between pilots was normally of little importance compared to variability within and between aircraft; he goes on to state:
>
> > 'In other words, the hardware varies within itself and from one item of hardware to another so greatly as maintenance and adjustment are normally carried out that the pilot matters little, if at all.'
>
> "The significant value of man in terms of his ability to increase system reliability -- measure of consistency of system output -- has been dealt with by McRuer, Ashkenas, and Krendel (1959), in connection with the current manned vs unmanned space craft controversy; and Anderson (1958), has presented a quantitative discussion of the increased system reliability afforded by the use of manned space vehicles in comparison with

unmanned vehicles.

"Thus it appears that consistency of system output is not only an appropriate measure in terms of insuring validity of measurement but is a performance measure particularly appropriate to the human operator in the man-machine complex. For it is man by the exercise of his peculiarly human attributes who contributes to overall system output consistency.

"To examine the underlying human skill which results in consistency of system output we shall refer to industrial work measurement data. Whitehead (1938), in reporting the Hawthorne experiments noted that the production rates of experts were more stable than the production rates of novices. Loveday and Munro (1920), noted similar findings in reporting that highly skilled workers had more uniform production rates than other workers. Elton (1922), in studying the time required for each of a group of weavers to complete a series of warps concluded that:

> '. . . considering the large number of causes at work which affect output the consistency of these figures which have been taken at random and have not been specially selected is remarkable. '

"McRuer and Krendel (1957) examined a number of tracking studies including those by Benepe, Narasimhan and Ellson (1954) and Elkind (1956) and concluded that variability in tracking tasks without controlled element dynamics was dependent on both task and degree of subject training. For our purposes, level of skill and degree of training may be considered to be correlated.

Shaw (1958) in a study of automotive driving skill tested three groups of drivers: skilled police patrol-car men, skilled civilian drivers, and below average civilian drivers (the assessments were made by an experienced police driving instructor). He found highly significant differences in consistency of performance with the police drivers exhibiting higher consistency than the skilled civilian drivers and the latter in turn more consistency than the unskilled civilian drivers. Shaw suggests that not all consistency is indicative of skill, 'for obviously bad habits can be acquired' but that perhaps all inconsistency is indicative of lack of skill."

Major General O. J. Ritland (ref. 42) has published the following graph, showing the unmanned Regulus 1 recoverable missile and the manned F8U-1 aircraft. The two vehicles are quite comparable, except for the manning variable.

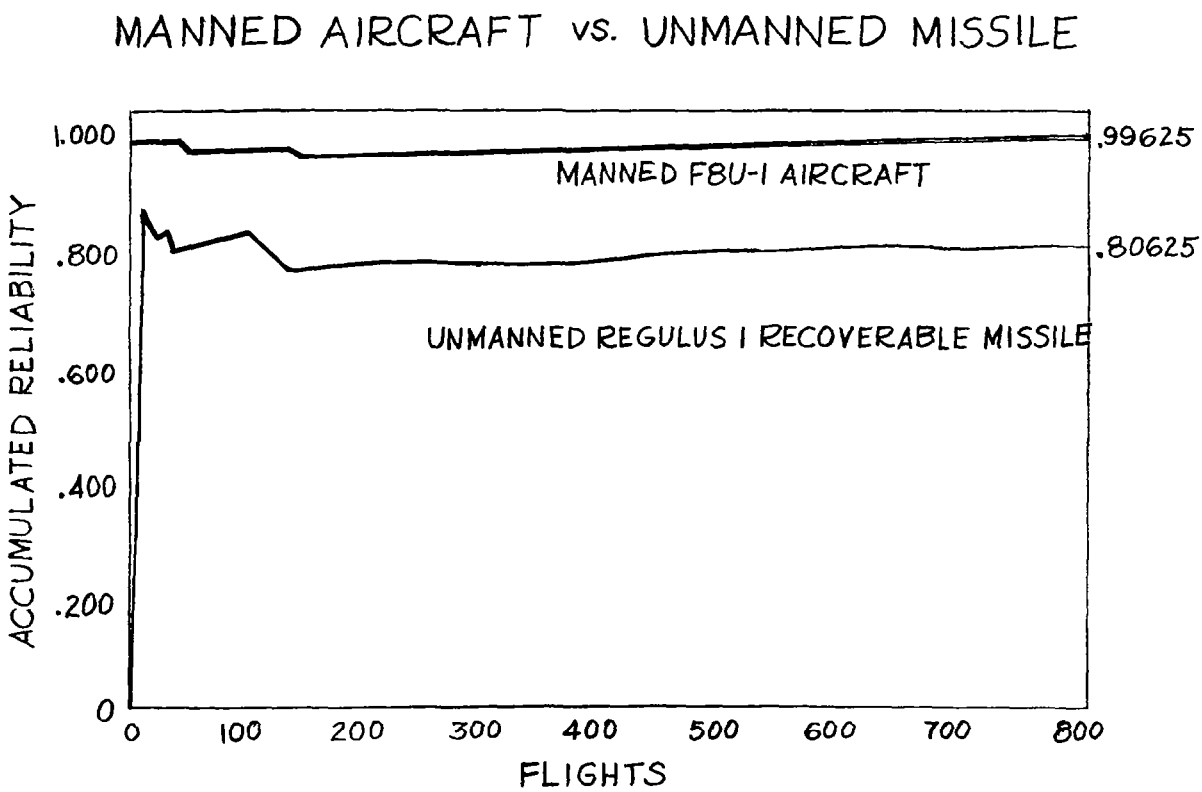

Figure 8. Comparative Reliability Curves Based on Total Losses of Each Vehicle for their First 800 Flights (Manned Aircraft vs. Unmanned Missile)

It is in coping with contingencies that man is irreplaceable by machines. This is the essential meaning of human flexibility.

"Production machines pose a problem rarely posed by tools since they replace man in doing a job. They are not perfect and tend to break down. When they break down they do not do the job. One must always then take into account the criticality of the job for the system. If the job is critical, the system should so be designed that man can serve as a manual backup to the machine. Although he will then not do it as well as the machine, he still can do it well enough to pass muster. This is another aspect of human flexibility -- the ability for graceful degradation. Machines can either do the job as specified or they botch up; man degrades gracefully. This is another example of complementarity."

Majendie (ref. 20) also has published a list of the conditions under which man or machine should be used.

The use of an automatic system is justified:

(i) When it is necessary or desirable to deploy more effort in time and space than can otherwise be achieved.

(ii) When a high standard of continuous, or repetitive, performance is required.

(iii) When the nature of the task is easily predictable.

In contrast it is necessary to retain the services of a human being:

(i) When extreme flexibility is needed in the fulfillment of the task, and when the latter cannot readily be predicted ahead.

(ii) When discretionary intervention may be needed for reasons not connected with the actual task itself.

The consideration of system reliability and the SST crew is particularly important when it is realized that human reliability can be enhanced. Thus, with a crew, we should consider not only what the crew should do but how we can enhance their reliability in performing their assigned (or designed) tasks. Detailed discussions of methods for enhancing crew reliability are beyond the scope of this report, but it should be considered that total system reliability will be related to crew reliability particularly where the crew is directly involved in control functions of the SST. In general we may say that human reliability can be enhanced in several ways which include:

1. Selection of an optimal task performance means:
2. Selection of operators;
3. Training selected operators;
4. Motivation of the operators;
5. Optimization of operator attitudes toward the means of task performance;
6. Utilization of social mores to achieve task performance;
7. Optimization of the task performance situation.

4.1.4 EFFECTIVE USE OF AUTOMATION

A considerable degree of utilization of machines exists already in the modern subsonic jet aircraft. One need mention only the hydraulic systems through which the pilot manipulates controls, the autopilot, control of the environment, many monitoring systems, etc. Marshall (ref. 29) has stated that:

> "Supersonic flight is in fact only made possible by removing some functions from the human operator and entrusting them to automatic and powered systems. However, this technique must not be taken too far, not even to the limits of technical feasibility since it would raise problems of maintenance and hence aircraft utili-

sation. As systems are made more completely automatic they tend to become less flexible since there tend to be fewer alternative methods of operation and hence the aircraft is more likely to be grounded due to a minor fault which renders a system inoperative. Co-operation between engineering and medical personnel in this field of the optimum combination of automatic and human functions can contribute substantially to the economic efficiency of a supersonic aircraft design."

A spokesman for Quantas airlines (ref. 43) has pointed out further examples of the automation of operational functions.

"Many examples already exist of encouraging accomplishment in automating relevant operational functions. Such may be found in the Hustler's (B58) navigation system, in electronic log keeping in the same aircraft; in a fuel and cruise control calculator being applied by Convair in 880 and 990; in automatic landing devices being tried and tested by the Blind Landing Experimental Unit of the R. A. E. and others; in automatic space control and selling apparatus; in automatic data links. These developments must be developed and used to the fullest extent."

Majendie has discussed the implications of automation in reference 20. He points out that:

"It should be clear that the basic decision between man and machine is not whether to employ human effort, but how to employ it. The application of a machine to a task does not remove the human content from that task. The principal involved is that of separating human actions from their effects. The fundamental advantage of any automatic device is not that it removes the human element, but that it allows the carrying out of human actions long before their effects occur. Three important consequences arise on this account.

"First, there is no operational limit to the extent of the human effort which can be deployed, either in number or in time, however concentrated and compressed may be the application for which the automatic device is required. Secondly, it makes possible the application of

human effort in situations beyond the limits of the unsupported human being. This can apply to environment, to perception, and to sheer muscular output, limited as it may be by force, precision, reaction time, or fatigue.

"The third consequence arises primarily on account of the separation in time between the design of the automatic device, and the operational circumstances in which it is actually used. This introduces the element of prediction into the process, which has already been examined. This is probably the most seriously limiting fundamental factor in the development of automatic systems for advanced operational applications.

"The machine is not, therefore, competing against the man, but is just a different tool available for his use. The real problem is in deciding which tools to use for a particular job. This issue can only be settled by taking a much closer look at the way they are applied in fact. It is necessary, therefore, to examine further the functions of control and of monitoring, before a practical consideration of the application of automatic landing to passenger transport aircraft."

Price (ref. 44) adds to the above observations that:

"the decision to essentially automate a complex man-machine system in many cases makes the role of man qualitatively more demanding. Recent advances in the state-of-the-art in engineering have produced machines with tremendous capacities and speeds which may require fewer personnel to operate, but which also may place increasingly more difficult tasks on those personnel who must install, maintain, monitor, override, and program these systems. If the task complexity of personnel performances in a highly automated system is to be reduced to the point where highly skilled personnel are not required (or at least reduced) then the burden of responsibility lies with the human engineering of the interface between the automatic machine and the human monitor or operator. In this way, training costs and time for personnel can be kept to a minimum. The general advantages of the automated system apply to the extremes of any performance continuum. For example, monitoring functions which either do not change over long periods of time, or change extremely rapidly in time, are best performed automatically. Those monitoring functions

that are in the middle of the continuum may well fall within the capabilities of a human monitor and be performed with as much reliability and accuracy as the machine at much less cost. Another major consideration in the decision on the degree of automation is the extent to which all the alternatives can be identified and programmed. Where all the alternatives can be identified in advance a fully automatic machine function is superior to a man-machine or man function. Where all the alternatives cannot be programmed, a man-machine or man function is probably better. The man-machine function in this case may be considered semi-automatic. The danger most commonly encountered in this situation is where man is required to some extent to operate or program the system, but the relatively high degree of automation precludes provision for the necessary displays and controls, and often leads to equivocal situations."

Jordan has discussed the role of machines in reference 45.

"Machines serve man in two ways: as tools and as production machines. A tool extends man's ability, both sensory and motor; production machines replace man in doing a job. The principle underlying the complementarity of tools is as follows: man functions best under conditions of optimum difficulty. If the job is too easy he gets bored, if it is too hard he gets fatigued. While it is generally silly to use machines to make a job more difficult, although this may be exactly what is called for in some control situations, tools have, since their inception as eoliths, served to make a difficult job easier and an impossible job possible. Hence tools should be used to bring the perceptual and motor requirements of a task to the optimum levels for human performance. We have had a lot of experience with tools and they present few, if any, problems.

"The problem is more complex with machines that do a job in place of man. Here we can return with benefit to the commonalities underlying the Fitts list. To the extent that the task environment is predictable and a priori controllable, and to the extent that activities necessary for the task are iterative and demand consistent performance, a production machine is preferable to man. To the extent, however, that the environment is not predictable, or if predictable not controllable a priori, then man, aided by the proper tools, is required.

(iii) When the effort required to solve the problem by automatic means would not be justified on economic grounds.

Price, Smith and Behan (ref. 21) have discussed the tradeoff considerations between using machines and using men. They assert that:

> In considering a tradeoff between man and machine, where performance capabilities are not at issue, one should consider:
>
> 1. The population from which system operators will be drawn;
> 2. The specific characteristics of the machines under consideration;
> 3. The costs of selection and training of humans should be compared with the costs of design and construction of equipment;
> 4. The costs of potential continued training for humans should be compared with the costs of potential modification and reprogramming for equipments;
> 5. Special environmental requirements of man and machine;
> 6. Space requirements of man and of machine;
> 7. Weight and power requirements of man and machine;
> 8. Reliability (motivation) and preventative maintenance;
> 9. Cost of maintenance and repair.

One other important consideration relative to the effective use of automation is the crew's attitude toward or acceptance of automated

systems. Price, Smith and Behan (ref. 21) state, in part, about automation and acceptance:

> "Automated systems are man-machine systems in which some tasks are performed by machines. These systems all include manual tasks, although they may be performed at a remote time or place. Where man is a system component, he must be designed into the system in an optimum manner, like any other system component.
>
> "Current automatic methods for implementing tasks frequently do not solve the problems they are designed to solve, and, in fact, create new problems. For many years to come automated systems will be man-machine systems that, at a minimum, will require man to initiate the machine functions, monitor them, and decide when to disengage and override them. However, if all man-machine interfaces are not optimum, system effectiveness cannot be optimum, as the system will be under-used and/or used improperly, either covertly or overtly. Traditional human engineering, usually performed after the system has been designed and the breadboard equipment developed, has been applied as if man were rational and it were only necessary to consider such aspects of man as his perceptual and motor capabilities. In actual fact, however, it is equally important to consider man's fears, anxieties, aspirations, etc., as part of the design efforts.
>
> "Acceptance problems created by lack of confidence in the effective and reliable performance by hardware of automated functions must be considered independently of whether in fact the hardware is effective and reliable."

4.2 OPERATIONAL CONSIDERATIONS AND THE CREW ROLE

4.2.1 OPERATIONAL ACTIVITIES

There will be, of course, many specific activities, functions, and tasks necessary for operation of the SST. The program being conducted under this contract will derive SST operational activities and functions during the next phase. For the present, however, we can consider the operations of the SST as occurring in one of the five operational activity groups below:

1. Flight Management Activities
2. Flight Performance Activities
3. Interior Subsystem Activities
4. Exterior Subsystem Activities
5. Emergency -- Non-Routine Activities

The flight management aspects of the flight are some of the most important functions performed by the crew. Their successful accomplishment of the tasks involved will determine whether SST flight will be economically realistic. The crew's primary role will be to plan a flight as close to the optimum as possible taking into consideration all outside influences. Distance of flight, number of passengers, baggage, weather conditions, and air traffic will all affect the optimum flight profile and must be considered. Advances in weather prognostication, closer coordination with air traffic control, and theoretical flight data make it very easy for the crew to allow for marginal weather conditions, to determine suitable alternate air terminals if needed, to find an optimum flight route consistent with proposed and actual traffic, and to determine flight parameters, i. e., take-off distances, climb speeds, cruise speeds, fuel control, reserve fuel, and landing roll out distances. These planning activities indicate whether the flight, within allowable

safety limits, will be economical. Flight management must be considered all during the flight, although the actual execution of the original flight plan will be accomplished prior to take off. Many unforseen events such as bad weather or a mandatory change of flight level can cause a change in the original flight plan and it will be necessary to manage the flight accordingly. Flight management activities are directly related to crew responsibility.

Flight performance activities consider the actual skills involved in taking the aircraft from one geographical location to another. Broadly defined flight performance activities encompass all of those activities required to control the aircraft in both the horizontal and vertical plane while it is airborne. The SST will have the basic flight controls found in any other aircraft and in addition it may have some unique configuration controls which affect the geometry of the aircraft. Powerplant control for affecting the speed of the aircraft and fuel consumption will also be part of the flight performance activities.

Those areas of activity which are not directly related to the actual flight of the aircraft, but are necessary for the health and comfort of both passengers and crew concern themselves with interior subsystems. Examples of these systems include air conditioning and heating, pressurization, radiation control and monitoring, ozone suppression and ventilation, etc. These subsystems do not affect the flight as such, but any malfunction of these subsystems places restraints on the operating efficiency of the SST. Therefore, the crew must be aware of the effects of these subsystems, and monitor them so that malfunctions may be anticipated and handled to alleviate the resulting restraints.

Any activity which necessitates interaction with a facility or organization external to the aircraft may be considered as an exterior subsystem activity. These interactions do not directly affect flying of the

aircraft. Navigation, communications and ATC procedures are examples of exterior subsystems which influence the activities of the crew. Many of these activities will be performed automatically and will only require monitoring to insure proper operation. If a malfunction occurs it will be necessary to perform additional tasks. Suffice to say that sufficient training in these areas is still necessary so that the added work load caused by any malfunction can be absorbed by the crew without seriously impairing their operating performance. For example, the crew must still be able to navigate even if the internal and external subsystems fail.

Activities under non-routine and emergency conditions will depend on the seriousness of the problem. Malfunctions of subsystems usually pose no danger to the flight, but rather only increase the work load of the crew. Emergencies usually require immediate action and prompt landing to alleviate the danger to both passengers and crew. In both cases a new stress factor has been introduced into the system and how well the crews are prepared to meet these situations will determine the overall performance efficiency and the resulting safety.

As was stated earlier, the next phase of this study will be concerned with deriving SST activities and functions, and the foregoing description of operational activity groups is provided for general orientation purposes. Since this section is, in general, concerned with presenting some viewpoints on the different potential roles of the crew, we shall briefly discuss "role" variables before presenting a discussion of potential crew roles.

4.2.2 ROLE VARIABLES

In a previous study (ref. 21) for the Ames Research Center, Serendipity Associates developed a rationale for the philosophy that there is an optimal manned design solution for any system requirement, i.e., there is an optimal role for man in any system. The optimal manned solution may not however be the best over-all system solution when cost-effectiveness criteria are used to evaluate all solutions. The reason for introducing the concept of an optimal manned solution is to bring attention to the variables which were used in the study (ref. 21) to evaluate man's role. An optimal manned design solution was defined as "one in which man has the most responsible/authoritative/acceptable role which he can perform while also being protected and sustained." These three variables, i.e., responsibility, authority, and acceptance are useful to describe different potential roles for the SST crew with respect to major operational considerations.

4.2.3 OPERATIONAL RESPONSIBILITY

Responsibility refers to the criticality or effect of role on mission performance and safety. Thus responsibility, as used here, does not relate to the number of activities in which one is involved; rather, responsibility relates to criticality of those activities in which one is involved. The responsibility variable of the crew's role is directly related to their accountability for critical activities.

There is a tendency to jump from the doubt that the human can adequately manage some of the tasks in a system to the conclusion that all tasks should therefore be automated. For example, an FAA document (ref. 18) has stated:

"In order to safely and efficiently utilize the super-

sonic vehicle, system management, i. e., control of the aircraft and its systems, must be coordinated and executed in the correct sequence. Due to the speed of the vehicle, even a minor mismanagement of the systems - for example, a small heading deviation - can result in a navigational error of many miles before recognition by the crew. Improper fuel management may result in instability of the aircraft. There is doubt as to the ability of even the most competent crew to perform all the functions required efficiently. Consequently, it appears that management of systems may have to be accomplished automatically. Means are available within the current state of the art; however, much must be done to achieve reliability necessary for civil transport operation.

Conclusion: Automation of all aircraft management functions appears possible within the current state of the art. The question as to the extent of this, as related to the vehicle as a safe civil air transport, has not been determined.

A study program should be undertaken to determine the extent of automatic control that can be performed for safe operation."

Such a position may mistakenly assume that automation removes man from the system, and therefore all of the consequences of human frailties are thereby removed from the system. On this point Majendie (ref. 46) has been specific. He writes:

"Now the first point I want to make in discussing the relationships between human and automatic pilots, is that they are both in fact human. The automatic pilot is itself just as human as is the pilot who switches it on. At every stage in its design and development it has been conceived and fashioned by human beings. It completely reflects their capabilities, and shortcomings. We do not remove the human element by fitting an automatic system, and few more dangerous fallacies than this exist today.

"What we in fact achieve by fitting an automatic system is a separation between the human effort and the task which it has been deployed to meet. This separation exists both in space and time, and has three impor-

tant consequences.

"In the first place there is no operational limit to the extent of the human effort which can be deployed, either in numbers or in time, however concentrated and compressed may be the application for which the automatic system is required. Secondly it makes possible the application of human effort in situations beyond the limits of the unsupported human being. This can apply to environment, to perception, and to sheer muscular output, limited as it may be by force, precision, reaction time, or fatigue.

The third consequence arises primarily on account of the separation in time between the design of an automatic system, and the operational circumstances in which it is actually used. This introduces an element of prediction into the process, and is probably the most seriously limiting factor in the development of all automatic systems for advanced operational applications.

In order to design such a system one has first to define the task which it is intended to perform, and the operational circumstances and environment which it will encounter. If in service actual conditions are met which were not foreseen at the design stage, the performance of an automatic system is no longer determinate, and unexpected failure may occur. The really difficult part in design of an automatic system is in establishing an overall operational requirement for its application, from which nothing significant has been missed.

In the past automatic systems on conventional, subsonic aircraft have been provided mainly to ease some part of the workload on the human pilot, rather than to extend his capabilities. This has meant that failure of the automatic system and reversion to manual control has not posed too serious a problem. In fact the risks of failing to recognize the malfunctioning of the automatic system have generally been of greater significance than have the risks of the pilot taking over himself."

A second problem with this position is that the trade-off between men and machines is couched only in terms of human vs. machine capability for performance. The arguments ignore two other variables which

are equally important. One of these is the social milieu within which the ultimate system must operate. The step to automation frequently creates acceptance problems because it changes the role of the human in relation to the system output. Social, economic and related problems may thus be created. The second of these variables is that automation changes the nature of the human tasks in the system. Typically, the humans who perform these tasks are required to possess much different types of skills than were required prior to automation. Thus the responsibilities of the humans in the system change. These responsibilities are no longer system output oriented. These responsibilities have to do with monitoring, servicing, troubleshooting and maintaining the automatic equipments.

Such an approach has another strong disadvantage. It precludes an empirical attempt to determine how the job could be done best, manually, mechanized or by automatic equipments. One of the points mentioned in reference 18 was that improper fuel management may result in instability of the aircraft. In this context, the Air Force has been studying man's ability to perform military missions in space at General Electric Valley Forge space station simulation facility. One of the results of these tests was that:

> "In a navigation experiment in which the Orbiting Astronomical Observatory (OAO) stabilization and control system was used to fix the aircraft on certain stars, the pilots manually operated the system as well and better than the automatic OAO system. OAO project engineers at G. E. said fuel conservation was "significantly better." In controlling the space craft through complicated maneuvers, the men's performance was so good that it was determined that the type of equipment - such as the stick - was not up to the rate the pilots could perform by 50 to 100%."

It should be observed, in connection with this quote, that better automatic equipment might be built - which would out perform the pilots.

However, the point is still valid that automatic equipment is not necessarily superior to human performance.

4.2.3.1 Responsibility in Automated Systems

Responsibility refers to criticality or effect of function on mission performance and safety. Majendie (ref. 20) argues for the full acceptance of the automatic system - again in the context of the all-weather landing problem and super (hyper) sonic flight. He states:

> "At the present time we are just on the threshold of moving into an entirely new era in the use of automatic landing systems for genuine all-weather operation, we are providing a capability beyond that of the pilot. It seems certain that such ultra-human systems will become generally accepted within the current decade. Clearly, in the event of a serious malfunction of such a system under the most critical conditions, no reliance could be placed on the ability of a human pilot to intervene successfully in avoiding disaster.
>
> How then are we to make such a system safe, and what is the proper function of the human pilot in a situation over which he is not capable of exercising direct control? Are we prepared to accept a situation such as this at all?
>
> These questions are tremendously important. If we refuse to accept dependence upon fully automatic systems in the future, and insist upon direct manual control as an essential emergency mode for all phases of the operation, we are tying ourselves forever to the limitations of the capability of a human being working "on location" and in real time. Such a capability is extraordinarily limited in comparison with the team effort which can be devoted to the design and development of a fully automatic system.
>
> The automatic landing systems which are now under development for civil aircraft have come about in an evolutionary manner. The complete complex of instrumentation and control in current transport aircraft has evolved one step at a time over many years. However, with the forthcoming introduction of super-

sonic airliners, to be followed by hypersonic craft, we may well be forced to become dependent on automatic systems for operational tasks about which we really know very little, and our experience of which is extremely limited.

Everything will then depend on the accuracy of the assumptions made by the designers of the system about the circumstances in which it will have to operate. The methods needed to monitor the system are not then necessarily concerned primarily with its correct functioning, but may need constantly to check the validity behind the underlying design criteria. If these criteria are false, correct functioning of the equipment can still lead to disaster.

If the automatic system is already handling a situation beyond the capability of the human pilot (i. e., an ultra-human task), it is clearly impossible for the latter to take over complete manual control. The overall design must therefore provide an escape route, capable of being initiated by the human pilot in time to avoid disaster. Such an escape route can only be provided in two ways. If the dangerous situation is only due to malfunction of one element of the complete system, it may be possible for the human pilot to control this one element directly, whilst leaving the remainder of the automatic system undisturbed.

Alternatively, and if this is not possible, the complete system must be diverted to a new task, of such a nature that false design criteria cannot co-exist both in relation to it, and also at the same time in the preceding situation. This needs a very much more sophisticated approach to the design of complete systems than has been the practice up till now.

In order to achieve efficiency in the design of this system it is essential to make the very best use of the potentialities both of the automatic and of the human pilot. These are two alternative ways of deploying human effort, and they need to be set into proper relationship with each other if either is to function effectively."

The essential conflict is that from a legal point of view the pilot has the responsibility and he cannot delegate that responsibility to an automatic equipment. He must be able to monitor the performance of

that equipment, be in a position to decide whether he must take over, and if he has to take over, have the capability of performing the task in either a manual or a mechanized mode. Majendie would have the pilot monitor the conditions under which the automatic equipment is employed. He says:

> "The first thing to recognize is that such a system (automatic landing system)* must have virtually complete authority over the aircraft's controls, in order to cope with turbulence, cross-wind, shear, etc. If such a system should malfunction at its full rate of authority close to the ground, no pilot could be quick enough to effect recovery in time to avert disaster, whatever monitoring information might be provided. Some form of auto-monitor must therefore be included in the system to protect against gross malfunction.
>
> Two courses are then open. In the first we totally disconnect the system when failure occurs. We have then to provide sufficient control intelligence to the pilot to enable him to extricate himself, either by completing the operation or by aborting it, as may be most feasible. In future systems this solution may not be possible owing to the task proving too difficult to handle.
>
> The alternative course is to provide sufficient redundancy in the complete system so that the element causing the malfunction can be detected and suppressed, without destroying the total capability of the system as a whole.
>
> Once the latter course has been adopted, it is perfectly feasible to provide a malfunction rate for the automatics much smaller than that capable of achievement by a fallible human pilot. It is then obvious nonsense to talk of the pilot monitoring its correct functioning. But he still has an important role to fill.
>
> In the first place, and owing to the predictive element in all forms of "historic control", such as this, it is essential to ensure that the system is not being asked to perform in circumstances outside its original design criteria. The pilot must therefore monitor not its per-

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* parenthetic insertion ours.

formance, but the circumstances of its application.

> Secondly, reasons of motivation may arise unconnected with the actual fulfillment of the particular control task, and demanding an urgent alteration in the pattern of the operation: only the pilot can make this type of decision."

The question of responsibility is definitely related to the question of automation and the consequent monitoring required of automated systems. There will be some functions or subsystems the performance responsibility of which will still reside with the crew no matter how automated the systems or functions are. For example, the landing function is certainly the crew's responsibility whether an automatic landing system is operating or not. The crew is essentially in parallel with the automatic landing system and must be able to land the aircraft just as effectively as the automatic system. This type of role for the crew has implications on the monitoring requirements as the crew must not simply be informed that something is wrong but must be given information and controls adequate for them to complete the operation.

On the other hand dissipation of heat is not a direct responsibility of the crew. If fuel is to be used as a heat sink then the automatic system that transfers heat to the fuel is responsible for heat dissipation. The crew is essentially additive in this situation and will be expected to properly follow emergency procedures in the event of failure of the "heat dissipation" system but they are not responsible for dissipating the heat per se. Monitoring requirements where the crew is additive are also different as the crew need not be given information to take over the operation and therefore need not be prepared in the same psychophysiological sense as they must be to take over the landing function.

Anticipatory information is desirable in both cases but again different for both cases. In the case of an automatic landing system

the crew will be interested in anticipatory information for both malfunctions and planned performance. For example, the crew would not only like to be forewarned of an impending failure in the localizer receiver but would also like to know in advance if the automatic system is "planning" to flare and when (or where). The same would not be true for the heat dissipation system in that the crew would only be interested in anticipatory failure information and not in what the system was planning to do with the heat.

4.2.4 OPERATIONAL AUTHORITY

The means for man to exercise control over his areas of responsibility or the manner in which he is assigned to manage his operational responsibilities constitute his authority. The SST crew will get a great assist from the design of the airplane and its systems in a variety of areas of responsibility.

At this point it will be desirable to distinguish between manual, mechanized and automatic task performance.

Manual task performance implies that a man performs the task; generates or accomplishes whatever power, energy or energy transduction required; and controls the application of power or directs the utilization of the given energy. No assumptions are made about the nature of the task. It may involve the utilization of human receptors or effectors, or both. The definition does not preclude the use of tools, e.g., a chart, a lever or a telescope. The tool merely extends man's raw capabilities.

Mechanized task performance implies that a man performs the task; a machine generates or accomplishes whatever power, energy or energy transduction required; a man controls the application or directs

the utilization of the given energy. Again, no assumptions are made about the nature of the task. In this case the tool does more than extend man's raw capabilities. Examples are the powered flight controls, search radar, a bottling machine or a desk calculator.

Automatic task performance implies that a machine generates or accomplishes whatever power, energy or energy transduction is required; a man controls the application of the power or directs the utilization of the given energy. In automatic task performance man plays a more remote role. He may determine what is to be done, and perhaps how, as in the use of a digital or analog computer. He may set the limits for an automatic control like a thermostat. He usually monitors the output to determine whether it meets certain minimal standards or accuracy. He initiates and may terminate the operation of the automatic device, as in the use of an autopilot or a record changer.

Operational authority, as used here, is very much concerned with the degree of automation of all activities which the crew is responsible for since authority is essentially how it will be done and what part the crew will play. Specific means of performing specific functions will be the objective of the next phase of this study but for the present some opinions of cognizant authorities are presented in this section.

4. 2. 4. 1 Flying Characteristics

Reference 40 which was presented by Mr. J. J. Tymczyszyn, during a symposium on the SST sponsored by the International Federation of Air Line Pilots Associations discusses the design characteristics of the SST which will support the pilot in carrying out his mission. Since Mr. Tymczyszyn is the FAA representative for the SST in the Western Region, his views are most cogent and are presented below in large part.

"Let's look at the areas in flying characteristics of the SST that are known or expected to be different (from the subsonic transport)*.

1. Flight Envelope - Altitude - "q" Mach

It is quite obvious that the flight envelope is expanding at a phenomenal rate compared to the previous steps in either commercial or military aviation. The cruising altitude of the SST will be nearly double that of today's subsonic jets. The "q" or dynamic pressures involved will also increase a substantial amount. The Mach number may be more than three times as great as today's subsonic transports - depending on the final choice of cruising Mach number for the American SST.

The very nature of these changes would infer cause for concern about the flying characteristics of the SST. It should be pointed out, however, that much of this area has already been thoroughly explored by military and research aircraft and the SST need only adapt the lessons learned to its own use. This paper will concentrate, therefore, only on those areas that are considered worthy of discussion from the viewpoint of the airline pilot.

2. Performance Variation - Drag rise versus Mach

The SST, no matter who builds it, will still be subject to certain basic laws of physics which will impose predictable and controllable variations in drag and thrust throughout the flight envelope. These can be summarized simply by saying that the SST will have areas of performance capabilities which can be expressed in terms that pilots understand - longitudinal acceleration or climb gradient - which will vary depending on the design that is chosen, engine size and characteristics, inlet and nozzle characteristics, and operational techniques. In most cases the SST will be a "going machine", but it may have "low spots" in performance in three probable areas:

(a) Takeoff performance resulting from consideration of high gross weight takeoffs and possibility of engine failures, inadvertent configuration errors, and/or variations in takeoff techniques.

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* parenthetic insertion ours.

(b) Transonic acceleration from approximately Mach 0.9 to 1.3.

(c) A small band of cruise climb performance deficiency area, especially on a hot day, somewhere around 50 to 55 thousand feet.

The need to reflect on these areas of possible performance deficiencies is intended to make us realize that a performance deficiency can aggravate handling qualities and performance is therefore mentioned in this light. Obviously these deficiencies must be minimized. What then can be done about them?

(1) Proper "scheduling" of flight profiles with respect to airspeed, Mach and altitude. Proper "scheduling in this case meaning simple and obvious control of configuration, thrust, attitude, and trim.

(2) Development of engine inlet/nozzle configurations and fuel controls to result in maximum capabilities in these areas. This will undoubtedly be a fully automatic system which can be easily monitored by the flight crew.

(3) Good speed and attitude stability so that the airplane "q"/M/altitude schedule can easily be followed. The basic stability of the airplane will undoubtedly have to be augmented as in all present military fighters to insure good "manual flying" capability. In addition, autopilot development of IAS/M "hold" has already been developed in the late subsonic jets to take the "dogwork" out of flying an optimum cruise/climb profile.

The effect of performance variation on flying qualities must also consider performance "excesses" as well as the marginal areas discussed above. Pilots seldom complain about excess performance since superior performance generally enhances flying qualities as well as increasing the overall level of safety. The subject is considered here, however, in order to point out the phenomena which will occur at high cruising Mach numbers if the airplane is upset and allowed to dive. The rate of thrust increase due to inefficient inlet compression may exceed the "drag rise" and result in unwanted acceleration. The obvious solution is an automatic "q" and/or Mach control of the engine fuel control which will result in a relatively "dead-beat" stability at maximum cruise. The mechanics of this type of control are

see errata

readily understood and present no real problem to the designer.

Another phase of excess performance that has been grossly exaggerated in recent literature is that of leveling off at cruise altitude. One article published recently even suggested an acrobatic type of half roll, inverted level-off to an upright half roll to solve this "problem." It is true that performance climb potential at the top of the cruise climb will be very high and our piloted simulator studies have indicated considerable altitude and Mach overshoot if the pilot were to fly the airplane with old-fashioned instruments and handle the thrust controls all by himself. But transports are not flown "solo" and the solution in the simulator studies was simple: smooth automatic or manual thrust reduction as level off is approached and the airplane instruments supplemented by a simple Mach or "q" command indicator to provide the pilot with better instrument reference.

3. Speed Spread - Slow Down

A very important consideration of flight characteristics is to provide the pilot with the means to decelerate at controllable and predictable rates and to have sufficient margins between operational and limit design speeds. Many of the subsonic jets were generally considered to have rather marginal-slow down characteristics owing to structural limitations of wing spoilers and considerations of buffet on passenger comfort and handling qualities. In the case of the SST, there is every reason to believe that smooth thrust reductions will provide the pilot with any degree of deceleration that he considers necessary in the supersonic region. In addition, there is every reason to believe that the inlet/nozzle and fuel control will also provide a potential for greater deceleration capability in the subsonic region or in fast descents. The SST is again fortunate in that it can be the recipient of the latest developments of in-flight reverse thrust and "no buffet" spoilers if the designer feel this capability is needed in his particular design. The need for limiting trim changes and control variations during decelerations is well understood and there is every reason to be optimistic that the designer will provide this feature in the airplane by means of a relatively simple Mach Trim System, supplemented by stability augmentation - if this is also needed. Ironically enough, variations in stability para-

meters in supersonic flight are smaller and are more consistent than those that plague the high subsonic cruise region. Obviously, the design will have to provide "fail-safe" means of handling transonic trim changes but there are many ways to handle this problem and it is one that has been solved in every modern military supersonic airplane.

4. Takeoff and Climb Out

A great deal has been said in the recent past relative to the "problems" facing the supersonic transport in areas pertaining to takeoff handling characteristics and performance. This is obviously not a problem new to SST, but rather an awareness of the deficiencies of the subsonic jet transports and of the continuing efforts to improve the overall characteristics and performance of transport aircraft. There is no doubt that poor handling qualities in critical phases of the takeoff contributed to the poor takeoff record of the subsonic jet transport.

The accident record of the subsonic jet transport in takeoffs is well known. What is not readily apparent, however, is the tremendous progress made in the science and art of understanding and performing the takeoff and climbout manoeuver. Literally thousands of "emergency" takeoffs have been conducted during certification and development testing of the subsonic jets and a great deal has been learned. In addition, these lessons are being supplemented with research programs in piloted simulators and research aircraft to predict and solve any unknown areas that may be characteristic of the SST configurations being considered. We feel that this is a commendable effort and one that should take much or all of the mystery and accident potential out of the takeoff problem. The results of the developments and improvements in today's subsonic jets and of the many research efforts should provide you - the airline pilot - with an airplane that can have the best takeoff characteristics of any transports to date . . . today's transport. With this thought in mind, let us enumerate the individual features or characteristics available to the SST to achieve "superior" takeoff characteristics:

(a) Configuration Guarantee - It is considered imperative that the configuration of the airplane in takeoff position be "guaranteed" in the sense that flaps, trim, inlet/nozzle controls, anti-skid, weight and c. g., are known and verified either by a foolproof check list and

warning system, or other simple methods.

The trim setting should be so adjusted that average pilot takeoff technique will yield near optimum performance regardless of weight, c. g. or runway condition. In addition, this trim setting will produce an airplane that is "in trim" for the initial phase of the takeoff climb out. This trim characteristic is already a part of one subsonic jet transport and makes the transition to instrument flight much less of a chore.

(b) Minimum Control Speed Consideration - V_{mc} problems in the past were usually associated with the takeoff case where airspeeds were low and thrusts were high. The subsonic jet has expanded this problem well into the takeoff transition where reduced rudder effectiveness (to protect structure) dictated special procedures for "cleaning-up" the airplane to the enroute configuration. Two engine out landing approach speeds also had a tremendous influence on minimum control speed considerations and some thought was given to providing some performance capability in this case. Fortunately, the subsonic jet transport has given us an insight into the V_{mc} problem of the future and we are now considering V_{mc} as an integral problem throughout the entire Mach - speed - altitude range. In the case of the SST, this problem will have to be examined from the start of the takeoff roll until the landing is complete. The transition from takeoff to subsonic climb, then to supersonic climb and cruise, will undoubtedly result in configuration changes and control system features requiring careful consideration of the V_{mc} problem during the entire flight profile. Again, thanks to the subsonic jet transports, we have encountered and solved many of these problems and the results of these lessons are "available" to the SST. For example, the advantages of a well-designed rudder pedal steering system now means that the airline pilot needs to be equipped with two hands during the takeoff roll instead of three. If you recall, you as the pilot, are required to monitor nose wheel steering with the left hand, the throttles "until you reach V_1" with your right hand, and the control column is to be monitored by your "third hand" - which function, in most cases, had to be performed by the co-pilot. The concept of rudder pedal steering had been worked out to a very high degree on one of our subsonic jet transports and is now being adopted by other manufacturers. Federal Aviation Agency is giving partial credit for this refinement in their performance rules and will help to produce an airplane with much

easier and more predictable directional control on takeoff, and not depend at all on the auxiliary nose wheel steering control (which will still obviously be used for slow speed taxiing).

The consideration of engine failures at supersonic speeds is one that is also receiving very careful attention by every designer and research organization. Many of us have had the opportunity to investigate engine failures at supersonic speeds in the NASA 5° Motion Simulator at Ames Research Center, and it is quite obvious to the evaluation pilots that the dynamics of sudden engine failure at high supersonic cruise speeds would be beyond the capability of normal pilot reaction without stability augmentation and/or yaw and roll rate and displacement limiters. These are relatively simple devices, however, and the manufacturer has many choices in providing this feature. Additional protection may be provided for by automatic control of engine thrust by varying fuel control, inlet/nozzle geometry, and some device to reduce engine drag after initial failure. (Roughly comparable to autofeathering). The end result of the V_{mc} phase of this discussion is that industry, together with the related regulatory and research organizations, are aware of this problem area and are working hard on the solution of these problems. There is every assurance that the airline pilot will be provided with the necessary control features that will minimize problems of handling qualities resulting from engine failure during <u>any</u> phase of flight.

(c) Takeoff Rotation - A great deal has been learned during the flight tests of the subsonic jet transports to reduce the hazards associated with variations in pilot rotation techniques. The lesson learned in the subsonic jet transport flight tests, together with FAA sponsored simulator studies with NASA and under Federal Aviation Agency contract with North American Aviation, will yield the information needed to guarantee an airplane that is more predictable in takeoff handling qualities than ever before. Whether this characteristic will be achieved entirely by improvements in handling qualities and better control of trim and attitude, or with the assistance of some type of computer using acceleration and angle of attack inputs into a simple pilot display for takeoff rotation attitude, we cannot yet predict. There is every reason to believe, however, that this problem is receiving full attention of industry and government. The end result is that the airline pilot will have an airplane that is not temperamental in terms of rotation technique even though we do not yet know what

the final SST takeoff configuration will be.

(d) Takeoff Monitors - A great deal of time and effort had been spent in the case of the subsonic jet transports in evaluating takeoff monitors. A certificable monitor has not yet been produced. There are many competent people who are continuing to work on this problem and there is again every reason to believe that a very simple and reliable takeoff monitor will soon be available for reliability testing in subsonic jets well before the SST comes along.

(e) Configuration Changes - The problem of guaranteeing optimum performance in takeoff climb-out is one that is receiving a great deal of study on today's subsonic jets and in SST performance profile studies. If the SST is to be a "delta" or low aspect ratio fixed geometry airplane in which the stall speed is not a finite number such as the "1 g" stall is in the subsonic jets, then you may be assured that the regulatory staffs and research agencies are working toward a better understanding of this type of "lift curve" in order to provide sufficient margin in takeoff and rotation climb-out speeds, and have a more meaningful and safer maneuver than you have today. Today's aviation world realizes the controversies involved in the definition of stall and takeoff speeds in the subsonic jet series. The lessons being learned in industry, NASA, and FAA flight and simulator studies will mean that the airline pilot will be supplied with more meaningful climb speeds and attitudes than you have ever seen before. This will be true whether the airplane is variable wing sweep, or of a fixed geometry. This assurance is rather obvious if you look at the tremendous increase in performance and handling qualities of the subsonic jet transports in the last five years. In a way, the SST is a lucky airplane. It is the recipient of a great deal of know-how from many sources, coupled with the present appreciation of the interrelation between performance and handling qualities in critical flight conditions. The inference is not that you will have additional instruments and "gadgets" to watch, but that all of these considerations will have been built into the airplane/instrument/pilot "loop."

(f) Aborted Takeoffs - The other half of the takeoff "problem" is the accelerate-stop or takeoff abort case. Few people realize or appreciate the tremendous advances in aircraft deceleration systems that have been developed

on commercial transports in the last six years. Brake and anti-skid systems are getting better. Hydraulic systems are getting more reliable and more foolproof. Spoiler systems and characteristics are being improved. Engine thrust-reversing systems are receiving careful attention by many segments of industry and government. Even the technology of building aircraft wheels and tires has come a long way in the last few years. All of these developments will be thoughtfully incorporated into the SST. The benefit to the airline pilot will be obvious. He will have a more predictable airplane to stop, if he has to stop, and there is every reason to believe that the occasions to abort will be minimized by the "configuration guarantee", and the greater performance capability of the airplane in normal and emergency conditions.

(g) Related Takeoff Parameters - The intimate relation between performance and handling qualities has never before received such careful attention. Obviously the airline pilot wants low lift-off speeds and excellent crosswind capability. These are assured, in a sense, by the requirements clearly stated in the Federal Aviation Agency Request for Proposal that the SST designs must provide for lift-off speeds of 160 knots or less and that a runway length of 10,500 feet be sufficient on a 15°C. "hot day" at sea level. The stated crosswind capability in a 90° crosswind is specified at 30 knots. These related parameters, coupled with the considerations previously stated, will probably result in takeoff characteristics superior to today's intercontinental jets.

5. Supersonic Cruise

It must be appreciated that military supersonic airplanes have produced tremendous improvements in flying characteristics in the supersonic region. This in spite of the fact that consideration had to be given not only to Mach and q, but also to limiting total temperatures. This has not been possible through aerodynamic "shapes" alone, but has also necessitated development of reliable stability augmentation and damping systems. It is also axiomatic that the commercial transport must have redundant SAS damping systems if the basic flight characteristics require them. The SST need only to capitalize on these developments and extrapolate or project them to whatever cruise speed is selected. The concern of the airline pilot to be assured that he will be a part of the control loop in cruising flight as well as all other phases of flight - if and when he wants to - is receiving a great deal of thought and study.

Much has been learned in developing the "pilot in the loop" concept by pilot input into any airplane control axis that he deems necessary. It is not the purpose of the regulatory agency to influence the final control configuration, but it is obvious that the designer will have many excellent choices in providing a control system that will ensure an airplane that you will, in a sense, "fall in love with."

"Special problems during cruise flight will include the important consideration of "speed spread" and slow-down capability. Every supersonic pilot knows that reduction of thrust is the best slow-down device ever developed and it follows that the problem of preventing inadvertent airplane upsets must receive adequate consideration during the research and initial design phases. Each designer has his own solution to this problem, but the variables are known, and there is every reason to believe that adequate speed controls of a relatively simple and reliable nature will be incorporated into the SST to make it a comparatively easy airplane to fly in the supersonic region. . . . there is every reason to feel that the airplane will have constant and predictable flying qualities at whatever supersonic cruise speed is chosen. In like manner, it also follows that the descent and approach handling qualities are being thoroughly studied and satisfactory solutions to this phase of the flight are available to the designer. Ironically enough, handling qualities in supersonic cruise will generally refer more to considerations of stability and "turnability" to desired headings without tendency to gain or lose altitude. After all, what else do you want to do at 25 to 30 miles a minute but "point and go" with as little "wiggle" as possible?

One set of facts is hard to dispute: American military supersonic airplanes alone have flown over 100,000 hours at supersonic speeds, and this includes over 2,000 hours at or near Mach 2 . . . and there are very few complaints about flight characteristics from the pilots who fly these airplanes! The development work involved in producing these fine characteristics may not have been easy (especially in the early days at low supersonic speeds), but now the results are quite apparent - fine handling qualities at supersonic speeds; and that "know-how" is available to the SST.

6. Landing and Low Speed Flight Characteristics

The design objectives pertinent to the landing phase of the American SST competitions, as stated in the FAA

Request for Proposal, may be summarized as follows:

(a) The required runway length shall not exceed 8,000 feet under wet runway conditions with the aircraft at maximum authorized landing gross weight.

(b) Landing approach speeds shall be in the order of 135 knots or less over the runway boundary or threshold.

(c) A crosswind capability of 30 knots, direct crosswind component, is required, with average pilot ability.

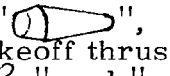
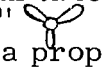
(d) Cockpit visibility shall conform with current FAA and SAE S-7 Standards.

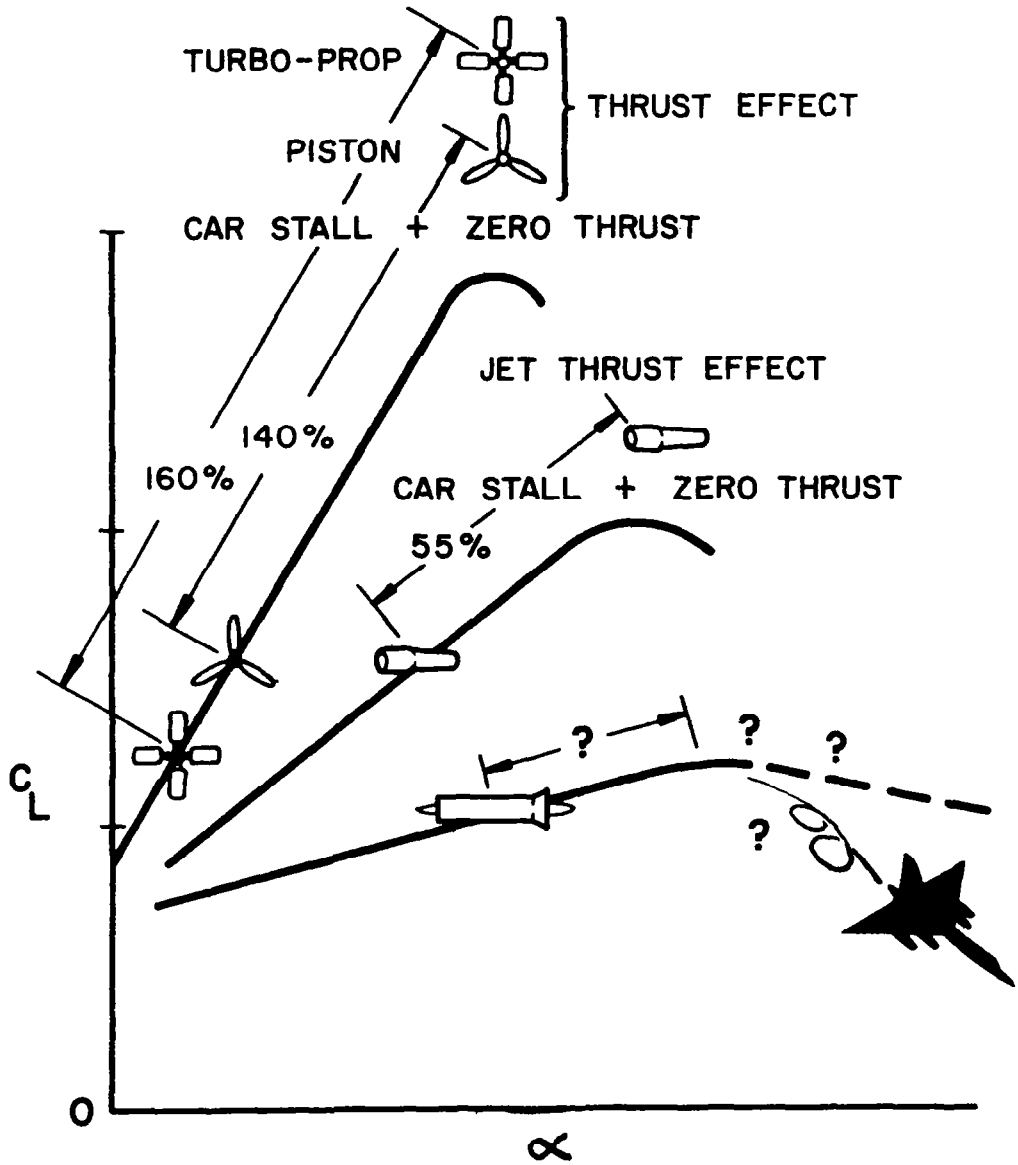
These objectives, together with the presently stated or proposed regulations, virtually assure the airline pilot that the landing characteristics of the SST will be at least as good as today's jet transports. In addition, the tremendous efforts being expended in present research flight and simulator programs may well contribute to landing characteristics clearly superior to those of the subsonic jet transports! It would be redundant to enumerate the various programs and efforts now under way to achieve this objective. It would be pertinent, however, to list the present status of the goals sought in these programs. In addition, it would also be pertinent to review briefly the conclusions reached in several research areas, and to illustrate again the manner in which the SST will be the "happy recipient" of these efforts:

Stall or Minimum Reference Speed

It would be difficult to discuss takeoff or landing characteristics and performance without immediately becoming involved with stall speeds and related reference speeds and their relation to the landing approach and touchdown speeds. Reference speeds in common use during the past several decades have been based on the CAR minimum or "stall speed." Regulations prescribe a very exact manner in which this reference speed has been determined. The growing dissatisfaction with this reference speed and its inadequacies resulted in a thorough exploration and appreciation of the "1 g" stall speed concept for airplanes with a "finite" lift curve break. Several research programs are now beginning to yield fruitful answers for definition of minimum reference speeds for low aspect ratio or delta plan

airfoils which do not have a finite lift curve "break." One such flight test program recently completed on the Douglas F-5D delta wing fighter was especially useful. In any event, the trend is towards a more meaningful reference speed which will have greater application to normal flying than the present CAR minimum speed.

Several of the basic differences between landing speeds and characteristics may be seen more readily from Figure 9. Reference to this figure shows that one of the differences is that the lift curve slope is getting "flatter" as we progress from the DC-6 and Constellation series of transports to the present family of subsonic jets, and it appears that the SST configurations - as presently envisioned - are getting flatter. The significance of this point from the pilots 'or flying qualities' viewpoint is that the control of airspeed on final approach becomes more difficult as the slope decreases. This would then infer that greater margins are needed between approach and "stall" speeds. This can best be determined again by reference to Figure 9, where the certificated value of $C_{L_{MAX}}$ is compared with the predicted aerodynamic values. The symbol " + " refers to the current CAR definition of stall or minimum attainable speed obtained by decelerating at 1k/sec. The portrayal of the "extra C_L" available is due to transient lift effects obtained at the expense of deceleration (corrected to zero thrust). The symbol "  ", denotes the increment of lift available with takeoff thrust for jet aircraft. Likewise, the symbols "  " and " ", denote the increment of lift available for a propeller-driven piston engine airplane and turbo-prop, respectively. The minimum landing approach speed presently specified by the CARs is the arithmetic factor of 1.3, denoting an approach speed incorporating an excess lift of $(1.3)^2$ or 1.69 - equivalent to 69% excess lift as a minimum required by the regulations. A comparison of the actual excess lift available for the subsonic jet family with that of older piston-powered transports was made by Messrs. Moss, Gannett, and Patton. This analysis showed the actual excess lift to be in the order of 142% for older piston-powered transports, but only 45% to 65% for the present subsonic jet transports. Further study reveals that present turbo-propeller powered transports have an excess lift in the order of 160%! So the magic of the 1.3 factor loses its significance! We find that it has no real aerodynamic merit, and the published approach speeds for the present family of jet transports are generally considerably less than the actual landing approach speeds in order to allow



LANDING APPROACH SPEED VARIABLES

Figure 9. Landing Approach Speed Variables (taken from ref. 40)

for gusts, wind gradient, or any number of undefinable handling quality factors which force the pilot to either aim for or accept a higher speed than the published minimum. Now let us examine the lift curve for a possible SST configuration: the slope is much flatter; $C_{L_{MAX}}$ is less definable, and we are not sure what factor to apply between the landing approach speed and certificated value of $C_{L_{MAX}}$ - if we are to apply the present concept of the Civil Air Regulations. We are sure that this analogy will serve to explain the problem that the aviation world is facing in SST landing approaches - and one which is currently being studied very seriously by the industry and government.

This analysis in itself would be rather discouraging if certain other factors were not considered simultaneously. Principal among these considerations is the fact that this characteristic has been inherent in shipboard navy fighters and these airplanes are considered to have rather favorable landing characteristics when auxiliary means of improving speed control (such as angle of attack indicator) are provided.

Another major consideration is the probability of flying on the "back side" of the thrust required curve in certain SST configurations. This, coupled with consideration of longitudinal dynamics, would tend to indicate a rather poor outlook for the SST landing characteristics if it were not for the fact that each of these problems is being analyzed in piloted research simulators, variable stability research airplanes, military supersonic fighters, and in manufacturers' design studies. The results of these efforts are encouraging and warrant an optimistic viewpoint for either the variable sweep or fixed geometry airplane. The important fact is that the potential problems in landing characteristics were recognized early enough to allow time for effective research and design solutions to be incorporated into the SST designs being considered.

Several phases of the landing "picture" are immediately more favorable. One of these is the higher thrust/weight ratio available for "go-arounds." A second is the recognition for trim compatibility for the missed approach. The third is the reasonable assumption that wing loadings will be reduced for landings. And finally, is the awareness of the aircraft industry to the need for excellence in landing characteristics.

7. Lateral/Directional Handling Qualities

One of the major deficiencies in the handling characteristics of the subsonic jet airplanes was the generally poor Dutch Roll and lateral "wallow" characteristics. A tremendous effort is being exerted on these problems and the results are beginning to show - not only in augmented flight, but in basic characteristics as well. It should be borne in mind that this too is a problem of the subsonic jets and not unique to the SST. Efforts to improve yaw dampers in today's jet transports, for example, have even yielded "fall-out", providing for better co-ordination in turn entries resulting in greater ease in holding or turning to headings. This very simple, but important, "improvement" is being incorporated into one of the newest jet transports and simply serves to illustrate the fact that the subsonic transports came about perhaps a little too abruptly for the State of the Art. In the case of the SST, the aviation world has been alerted to the problem areas early enough to offer a solution in the prototype airplane. It is well recognized that if the SST is to make its debut into world aviation with a safety record at least as good as the present subsonic jet transport, it will be necessary to have an airplane that is initially a better airplane, in terms of flight characteristics than did its predecessors during their aviation debut. It is well recognized that the pilot of the SST airliner must have an airplane that is not only easy to fly in terms of all the expected operating problems, but also be predictable and consistent in all normal and emergency situations."

The foregoing is an excellent description of the potential authority the crew may have with respect to flying the SST. Many specific functions will have to be considered in developing the crew role but at least three more general areas are considered worthwhile to discuss now with respect to crew authority. These are (1) communications, (2) navigation, and (3) all weather landing.

4. 2. 4. 2 Communications

Reference 47 which was presented by General Precision, Inc., at the IATA Symposium on Supersonic Air Transport in 1961 includes the following discussion of communications.

"Voice communications will still serve during the time period of interest as the basic back-up communication capability in all aircraft. There is a continuing need to handle generalized non-routine messages of advisory or emergency nature by this method. Aircraft, especially of the general aviation class, will certainly use voice as their prime communication facility. Air carriers, business, and military aircraft will carry a form of automatic communications equipment.

"A refinement of voice communication is the incorporation of SELCAL equipment. This provides for automatic call up where a specific flight can be alerted that a voice communication is being addressed to it. CALSEL equipment provides for the transmission from aircraft of an acknowledge signal upon interrogation by a properly coded SELCAL signal. This provides a means for reducing the voice communication associated with routine in-flight reporting.

"This has been considered as only an interim stage between the area of voice communication only and the area of a complete automatic communication system. However, the CALSEL capability can be used for other purposes such as ground-based position determination to be discussed later.

Automatic Communication System (Data Link)

"An experimental automatic communication system has been delivered to the Federal Aviation Agency for evaluation. This system, Air/Ground/Air Communications System, is being used to evaluate the modes and speeds of transmission necessary to ensure reliable communication under all atmospheric and interference conditions. Some studies have also been carried out to determine the types of messages and operating procedures to be used with an automatic communication system. Also, studies have been performed covering the problems of integrating the automatic communication systems with the ground-based processing and display systems. Resulting from these studies and from the experimental work, a final automatic communication system will be developed and standardized well before the time period of the supersonic transport. Such a communication system will be an operational requirement for this aircraft. This communication system will be used primarily for the delivery of clearances and other routine messages to the aircraft and the transmission from the aircraft of identity, altitude, and position. (Requests for changes in clearances, emergencies, and other non-routine messages will be handled by voice communications.) The

automatic system will be completely ground controlled as far as the interrogation cycle is concerned, and will probably not make use of a routine roll call. It will be integrated with a ground-based processing and display system. It will also be used for providing weather advisories to the aircraft. To minimize the channel switching requirements for the supersonic transport, the communication system will be of a fairly high-speed type, probably of the order of 750-1000 bits per second. Time and frequency multiplexing could provide up to 14 bits in parallel on separate subcarriers, with characters in serial, and used with a high-speed tape printer of the Xerographic type in the aircraft. The final form will depend on the evaluation results of the present experimental systems. For smaller aircraft, low-speed variations will be provided, using a mechanical printer. To minimize the channel switching problem for these aircraft, automatic channel switching capability will be provided. It is expected that by 1970, regular users of the air traffic control system will be required to carry some form of automatic communication equipment as a basic part of the airborne equipment complement.

Summary of Communications Factors

"The supersonic transport will use as its basic communication system some form of data link compatible with the types of flight involved. For use over the continental United States, the aircraft will use VHF and, possibly UHF, as the communication frequency. For oceanic operations, either single sideband HF communication or forward scatter VHF communications will be employed. Experiments are being planned presently for a VHF forward scatter system to cover the North Atlantic to provide direct controller/pilot communication on VHF over all segments of the North Atlantic routes. Similar possibilities are available to cover a large fraction of the short service routes as well, although certain portions of these routes may have to be covered by HF communication links. In all probability, over the routes to be serviced by the supersonic transport, direct pilot-to-ground control communications will be available. The data link will be an absolute necessity to provide up-to-date position and altitude information to ground control at all times, and to provide to the flight crew clearance information and weather information as necessary. The back up system for the data link will be voice communications, using some form of SELCAL to alert the flight crew to messages directed to them, and minimize the necessity

for them to constantly monitor all communications on their channels."

4.2.4.3 Navigation

Powell and Willis (ref. 48) who are the Chief Navigator and Assistant Chief Navigating Officer of Trans-Canada Airlines respectively present a discussion of SST navigation and crew role.

> ". . . what about civil supersonic navigation? Frankly we believe it impossible to specify the optimum equipment until the industry in general knows much more about, and has reached broad philosophical agreement on, several other factors.
>
> The heading input is a good example. Our engineering staff expects no significant improvement in performance of present systems. Even so it can be shown from our results that if errors (due to compasses alone) in the doppler (or any doppler radar) system are to be kept below five miles at supersonic speeds, the necessary free gyro mode compass management could be handled manually. Is a crew member with the required training to be available for a task of this general order? If not, more accurate heading information could be supplied from a relatively simple stabilized platform, but it would be erroneous to believe the heading problem would then be solved. Celestial checking will still be necessary, and especially if manual change-over from magnetic to grid reference is necessary in flight (see data and comments on initial unslaving errors in the San Diego paper). In this connection the possibility of retaining grid reference during departure and landing phases warrants attention, though the necessary studies would involve many areas. At supersonic speeds the checking equipment may have to be stabilized, but again the crew complement may determine whether this equipment must be an automatic star tracker or a sextant linked to the stabilized platform which will in any event be required for other flight control functions.
>
> If the sextant is not stabilized, apart from coriolis considerations, care must be taken (as on present aircraft) to measure a bearing while the aircraft is not turning. Whether it be intentional or sensed and made by the co-pilot

system, a turn requiring 5° of bank causes an 8.5° error in the measured bearing of a body ahead of the aircraft at 60° altitude. Errors of this magnitude would also be expected in the measured bearing if compasses were checked while magnetically slaved in some areas due to rate of change of grivation.

The question of a basic sensor may be simpler, with the choice limited to inertial, doppler, and astro, or a marriage somewhere within that group.

Inertial vs. doppler

There are doubtless many valuable places for a full "inertial navigator," but we do not believe there is one in civil aviation. The gap between present serviceability performance and that required in civil aviation is tremendous. In-flight failures, particularly those in the vertical system, don't just degrade the results; they make them useless. Both initial and maintenance costs are discouraging. So is the allied problem of keeping enough skilled technicians in the right place at the right time. But, perhaps above all, an inertial system, and any hybrid system involving inertial components, would still require in-flight monitoring and the use of back-up aids. Inertial systems might well give increased accuracy for considerable periods, but not enough accuracy plus reliability to permit their performance to go unchecked.

Doppler sensors enjoy an extensive operating background. It is reasonable to expect some refinements in both airborne and ground checking equipment. The incidence of airborne failure is significant, and probably always will be, but it can be minimized by a dual installation. It seems certain that doppler sensors will supply drift and groundspeed for civil supersonic systems, but from everything said so far it is also certain that monitoring and back-up capabilities must be provided.

Study is therefore needed to determine the relative merits of (a) greater automaticity and simplification of display to minimize human errors, and (b) provision of better fixing facilities for updating the self-contained system. As shown, with doppler operating we currently find a 20-30 minute fixing rate necessary to keep track errors wholly within 30 miles. If this rate must be compressed significantly without inviting more human error there will be a requirement for a ground-based aid giving more complete coverage of high density areas than present

consol and loran. In the light of past experience we must assume the necessary international agreement for specification and adoption of such an aid may take some time. There is place for a technical recommendation stating which would best meet our needs. In any event such an aid will probably be required as a means of back-up navigation.

The astro tracker

The potential role of a day-night astro tracker is also interesting. Position errors of the order of 10 miles have been quoted, probably over-pessimistically. But even so a manually or automatically applied limit of this magnitude on doppler errors would meet all forseeable requirements. Perhaps especially valuable would be the heading control feature, again usable manually or automatically. It has been indicated that this task could be performed with a (stabilized) version of present equipment, but the necessary skill is not always acquired quickly. To attain uniformity of results this feature of the astro tracker, even if not the full fixing function, merits attention.

One practical comment on an astro tracker: the ability to use it manually in the event of mechanical failure would avoid carriage of otherwise necessary heading check equipment. Depending again on crew complements and ability it could also save carriage of dual long-range fixing equipment.

The actual number of navigation boxes which could be available for civil supersonic flying is not large. The various combinations and degrees of complexity do, however, make the optimum selection difficult, not least because the delicate question of manpower is involved. Decisions taken in this area are often irreversible.

In order to make these decisions wisely the industry needs the results of studies already suggested as well as several others which will doubtless be pinpointed during this symposium. Perhaps above all, a thorough technical analysis is needed to show what probable cost, accuracy, and human skill requirements are involved in each forseeable combination of equipment.

Few, if any, airlines have facilities to pursue all of the necessary studies, and our individual answers might in any event be suspect. By applying any available resources

to them and to the correlation of the several studies already undertaken, the Institute, and this University, could render an invaluable service to the industry at large.

Winick (ref. 49) of FAA in a paper concerned with "The Navigation Ground Environment for the Period 1965-1975" states the requirements for automatic navigation to assist the pilot.

> "All of the navigation systems proposed for the supersonic transport involve an airborne digital computer of some sort, from a fairly simple type, such as the ASN-24 now being considered for the C-141, to the B-58 variety, and on to the complexity of a Polaris-type system. The question is, are such central digital computers ready for civil airline use? Will the electronics envisioned be ready for the supersonic transport? Should we take this for granted? What may be suitable for the B-58 or the F-106 may not be satisfactory from a reliability point of view for a civil supersonic transport aircraft. Certainly there is a need for automatic computations, but these automatic computations must be designed as aids to the pilot, and must be provided with redundant manual channels to assure a very high order of operational reliability without relying on the extremes of component reliability in the design, extremes which are very expensive and still don't seem to be able to produce wholly satisfactory results. There can be a simplified approach to performing the functions of the ASN-24, as an example. As a matter of fact, what better way is there of accomplishing its major function in a simplified manner than to relate doppler and VORTAC fixes on the same display? There is much work yet to be done on airborne electronic navigation configurations, and it is dangerous to borrow completely from the B-58 or the F-106 and feel that this type of configuration will necessarily be suitable for the civil supersonic transport. There must be the least possible degree of sophistication consistent with relieving the pilot of routine tasks, and there must be provision for redundant information channels. Finally, there must be a very high order of electronic reliability. Military aircraft can achieve performance reliability for single missions by careful optimizing. Civil aircraft must have this capability day-in and day-out. Such performance can be obtained through both simplification and a relaxa-

tion of requirements which strain at achieving performance limits."

4.2.4.5 All-Weather Landing

There seems to be no question that SST will have to have an all-weather landing capability, however, there is a question as to the distribution of authority to the crew and automatic equipment. Some aspects of automatic landing have been discussed in section 4.2.3 in the context of crew responsibility. The material here is oriented more toward crew authority.

Reference 20 in discussing all weather landing and the role of the pilot states:

> "An automatic landing system will always therefore be additional to the currently accepted normal crew complement, at least for the forseeable future. As the machine cannot replace the men, but can increase the overall operational capability, the two must learn to live together if progress is to be assured. But such progress will not be achieved if our attitude is to regard the automatic system as something which can and should be overridden by human intervention in routine operation and for purely technical reasons. This outlook can only freeze progress at the current level.
>
> The automatic system can be, and must be, designed so that it takes care of the flight technical problem at a higher standard than can the pilots. Our current single channel automatic landing systems already achieve this in consistency of touchdown performance: longitudinal scatter for example being better than half the figure obtainable by manual means. If we add to this an in-service reliability at least an order better than the human pilot, there can be no case for intervention on the basis of the pure performance of the equipment.
>
> But the pilot must always be allowed to dictate where he lands, and whether any particular landing should be continued, or overshoot action taken. Reasons for such a change of decision cannot be entirely foreseen, and must therefore be left to be handled at the level of human discretion.

In order to initiate changes of operational plan the pilot must be provided with adequate situation intelligence from suitable displays, including as far as possible trend and prediction elements. In order to keep him closely in touch with the developing situation, particularly when it is generally of a somewhat routine nature, means must be provided of enabling him to have effective participation in the regular routine. The most important function of the pilot, apart from decision taking, will be in monitoring the operational circumstances in which the automatic system is being applied, to ensure that no unforeseen abnormalities are present, which might endanger its use by not having been included in the design specification.

The overall system design should be such that adequate time is provided for the pilot to make decisions at critical phases, and the necessary information content must be severely curtailed when time is short.

A practical example of such an arrangement can be drawn from the system being developed for the Belfast. This provides a full triplex version of the S. E. P. 5. automatic landing autopilot. Before becoming committed to a landing the pilot is expected to check that the design state of the equipment is as intended. This is mainly done from a special System Panel. However, once the landing proper has started the only indication of malfunction provided is by the main red master-warning system, and then only if complete control is lost about any one axis, or of the throttles. Throughout the final stage of the manoeuvre the pilot need only be concerned with the situation displays.

Finally if he should decide to initiate a new programme of action, there is great scope for the further development of automonitoring systems to assist in making safe and sound decisions. These could provide valuable protection from lapses due to inattention or oversight when under stress, also from simple human blunders.

A possible "fly in the ointment" with this approach is that the pilot may be both psychologically and physiologically unprepared to take over a complex task if he has been monitoring this task by observing over simplified displays. There is reason to believe that monitoring should be accomplished in the same dimensions and similar order of complexity as the performance task if the human is to be able to take over effectively.

Another commentary on all weather-landing is presented by reference 49.

> "The last area to be discussed here is that of all-weather landing. We all take it for granted that the supersonic transport will contain an all-weather landing system. In this case we must introduce a word which I have very consciously left out of many past discussions on the subject. As you notice, the terms used here is all-weather landing system, not automatic landing system. In the case of the supersonic transport the automatic becomes more important than perhaps even the all-weather. This is not a new thought, since experience in the military some years back with high-performance jet aircraft indicated that many landing accidents occurred in good weather, and that an automatic landing system could do a better job of landing the aircraft than the average pilot. With the supersonic transport there is little doubt that automation in the cockpit must come into its own, and that the pilot must be relieved of many duties during the landing maneuver. We in the FAA Systems Research and Development Service have made some important decisions concerning landing systems recently. We feel that the landing system which will be used by civil carriers will be a flare-out landing system as an extension of the ILS. Feeding the flare-out computer and providing vertical guidance over the last hundred feet of altitude will be a radio altimeter since this equipment is now available. There may be other sources of vertical guidance inputs to the flare-out computer, some of which have been discussed recently in considerable detail, but they are not advanced sufficiently to be considered acceptable for system choice at this time.
>
> A question yet to be resolved is whether the profile of the supersonic transport will need some newer method of providing vertical guidance information, rather than the standard ILS and radio altimeter flare-out. Therefore, let us examine a typical profile being considered.

SST descent profile

It appears that the aircraft will make a steep transition from 45,000 down to 10,000 feet. Here there is a navigation problem, that of providing vertical guidance and speed control through this descent. It seems that a vertical guidance computer would be ideal for this function.

One which will utilize DME at extended ranges and barometric altimetry could perform this function quite readily. The next question is, what happens from 10,000 feet to the outer marker of the ILS system? It would appear that here again a steep descent angle, perhaps about 5°, would be in order. Now that the aircraft is at the outer marker, what will be the final approach angle? There have been many discussions on the need for a higher descent angle than the nominal 3° of the Instrument Landing System with high performance aircraft. However, the requirement to maintain proper attitude for possible go-around, and the need for speed control, will limit the final approach angle of the supersonic transport, just as it does that of any other aircraft. Therefore, there is a good possibility that the supersonic transport will make its ILS approach perhaps with a longer final than the current 6 to 8 miles of the outer marker, but still at a descent angle very close to 3°. If this turns out to be the case, the standard ILS will suffice. If not, it may be possible to set the standard ILS at a higher approach angle specifically for the SST, although this will present some obvious difficulties.

The final portion of the automatic landing will be accomplished through the use of the flare-out computer. For the supersonic transport, it does appear that more flexible vertical guidance devices, other than radio altimeters, will be of benefit. This is one of the main reasons why newer developments are being kept active in our program. They are definitely behind radio altimetry in the development cycle. However, there is no reason to believe that they cannot meet the supersonic transport time scale.

Since automatic functions become very important in the control of the supersonic transport, pilot monitoring can only be used as the method of assuring a safe go-around at some critical altitude rather than continuing the landing by manual means in case of failure of the automatic system. Therefore, the requirements of autopilot reliability are much higher in the case of the supersonic transport than is the case for subsonic turbojets. This greater emphasis on automatic control may be considered the major difference in the landing system between the two categories of aircraft."

4. 2. 4. 5 Emergency and Non-Routine Situations

A general statement of crew operating problems with emphasis on emergency and non-routine performance is presented by Bennett (ref. 50). He states:

> "The workload on crews has reached maximum permissible limits with current jet transports. When aircraft fly twice or three times as fast, crew members must be much more closely integrated into the overall man-machine system and given only those tasks which they are able to perform more efficiently than mechanical or electronic elements. Information on the progress of the flight must be presented by integrated instruments, so that indications as to whether progress is normal or abnormal can be rapidly and simply assessed. In certain cases, time factors may make it desirable that where an abnormal condition is shown, there should also be an indication of the preferred corrective action. For example, in collision avoidance, space myopia and problems of dynamic visual acuity at high closing speeds preclude absolutely a reliance on visual observation. The use of simple proximity-warning radar may facilitate ATC positive separation procedures, but will give inadequate warning at closing speeds of 5000 m. p. h. , and an indication of the preferred deviation, or even automatic initiation of deviation, may be required."

Stewart (ref. 28) introduces the concept of in-flight preparation for the servicing of faults.

> "The question of in-flight preparation for the servicing of faults is, in its application, new in conception.
>
> This could add a great load on the crew, particularly in view of the complexity of interactions within the aircraft control and navigational systems, where, for example, a fault in the central computer could have widespread repercussions. Since this is obviously a problem of identification and memory, and since the memory capacity of the human brain is far larger than any computer, it may well fall into the tasks of a flight engineer or an air electronics officer. It is again not possible to describe the memory capacity in arithmetical terms as one can for a computer, and it is also known that the selective order of power of recall may change under conditions of stress.

It may therefore be a matter of evaluation whether the diagnosis of faults in complicated interacting systems could not be aided by an additional computer, into which various short codes could be fed.

According to the code fed in, it should be possible to make this computer examine every order it receives from any part of the main system and so to determine the correctness of the structure of the orders. With different short codes, it could thus examine any discrepancy."

4.2.5 OPERATIONAL ACCEPTANCE

Man-machine system design has typically utilized data as to man's sensory, perceptual, cognitive and motor capabilities in allocating functions to man or machine, and in designing interfaces. However, man's motivational system (i.e., acceptance) has not been systematically included in man-machine system design. This is a serious error as a highly motivated man can compensate to a considerable extent for poorly designed equipment to maintain system output. Conversely, a man dissatisfied by a machine function, due to status, economic, survival fears, or simply a desire to perform the function manually, because it is a function man enjoys, may not properly use equipment which has been designed to fit all other criteria. Consequently, the system output may suffer. Acceptance factors are most critical, and will have a maximum effect on system effectiveness, in the role area. As the design of man's role is a major output of System Design, it is most important to include acceptance factors. Acceptance factors should also be considered at the later design efforts, but they become less and less critical as Task Design is approached.

Acceptance or more correctly non-acceptance by the SST crew of flight deck concepts and equipment can also represent a serious economic problem. If costly equipment is designed and installed on SST but is not used (or at least not used effectively) it is certainly a waste of good money. Some current work by Serendipity Associates concerned with "Pilot

Acceptance Factors in the Development of All Weather Landing Systems" (Contract NA32-1346) substantiates this. A part of this study was directed towards determining pilot attitudes toward present day ILS Auto-Pilot Coupler systems. Generally speaking there was "negative acceptance" toward the Auto-Pilot Coupler and it was not used or used ineffectively[3]. Without question, acceptance by the flight crew of their role and the equipment they must interact with will definitely impact the effectiveness of SST operations.

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[3] The data from this study is in publication

4.3 CREW VARIABLES

The composition and qualifications of the SST crew is a problem as complex as many of the engineering problems associated with SST. It is one of the intrinsic purposes of this study contract to develop a basis for making objective analyses of the crew variables of composition and size and a later report (Interim Report III) will be directed toward this problem. The final decisions concerning the crew will undoubtedly have to be based on empirical as well as analytical research results. For the present, some authorities have expressed their views and these together with some of our own are presented for consideration.

4.3.1 COMPOSITION AND SIZE

One point of view shared by many people who have to do with the SST is well expressed by D. E. Kinkel of Pan American World Airways, who states (private communication)

> "Our general impression of the plans to which we have been exposed is that the crew requirements will be similar to present day transports except that the navigation function will be supplied by a self-contained guidance system and the Flight Engineering function may become a combination engineer-electronics device operator."

Mr. J. T. Dyment, Chief Engineer, Air Canada, has strongly expressed the opinion that commercial aircraft should be designed so they may be completely and safely flown by one man from either the left or right hand seat. This philosophy emphasizes the point that should an emergency arise he does not feel that team work should be required to prevent a catastrophic situation from developing. Mr. Dyment further states (private communication):

"We do not wish to suggest the number of crew members that should be carried on an SST, but, we feel very strongly that regardless of the crew complement the cockpit and its controls must be designed with sufficient simplicity that the airplane can be flown by one person in either the left-hand or right-hand seat and whichever person is in charge of flying the airplane must have the ability on encountering any emergency to make the decisions on the desired action and to take the action himself. We feel it is essential for the cockpit to be designed to make combined action of two human elements unnecessary under any circumstances.

Under normal conditions we would expect that the airplane would generally be flown by the combined actions of its crew but such combined actions must not be necessary to maintain safe flight. We would also expect that it may be necessary for a person not in command to take certain clean-up actions after the emergency has passed. However, as stated, throughout any emergency one person must be able to make the decisions and take the actions to recover.

In discussions with personnel in other international airlines I have found them to be in complete agreement with this basic philosophy in spite of their not agreeing on the actual number of persons who should comprise a crew."

J. A. Wahle, FEIA-SST Committee Chairman has expressed the following views in a private communication.

"While the SST will have fully automated flight capability, we have seen that reliability considerations and public and pilot acceptance factors will require provision for manual flight path control throughout the operational envelope. Therefore, at least one pilot will be manipulating or standing by the flight controls at all times. Since all humans are subject to sudden, unexpected, physiological incapacitation, minimum safety consideration will require first order redundancy or a minimum of two pilots immediately available to the flight controls.

Given this irreducible minimum of two pilots for commercial flight operations, we consider now the effects of crew task allocation. One of the two pilots is designated "pilot in command" and is assigned flight management responsibility. The remaining pilot crew tasks (flight path control, navigation and communications) are

navigation equipment is aborad, along with an autopilot, (2) warning devices are installed which provide the air crew with required malfunction information, (3) three-axis electrical trim is available, (4) some semi-automatic backup equipment is available for use in unexpected emergency conditions or extended operation.

A more detailed analysis is necessary before a firm crew size can be determined. Factors which include SCAT operations, equipment cost and reliability, air crew capability and training, and the operational environment must be thoroughly considered in this study. It is expected that the operation of SCAT will impose stringent demands, both physical and psychological, upon the crew.

Such aspects as age, physical condition, reaction time, and vision should be considered as they affect normal and emergency system operational requirements."

The crew task allocation from the above included:

"The pilot is the aircraft commander. He is responsible for the crew, passengers, and all decisions concerning operation and safety.

His primary operation tasks are flying the airplane and monitoring all automatic flight equipment operation.

Copilot

The copilot is second in command. His primary tasks are radio communication and navigation. He serves as a backup pilot and assists in flying the airplane as required by the pilot.

Flight Engineer

The flight engineer is the subsystems operator. His primary tasks are environmental control and monitoring engine operation performance. He also monitors and controls other subsystems (e.g., electrical, hydraulics and fuel) and serves as an assistant in general cockpit operation (e.g., logs and maintenance reports). He provides assistance to the pilot during emergencies."

assigned among the pilot in command and the copilot by the pilot in command.

At the present time, these piloting functions, when allocated among two average line pilots will tax their capabilities to an extreme degree under high traffic density, low visibility conditions. Even considering projected advances in navigation aid technology, instrument presentation, traffic control and communications procedures, it is not expected that the pilot workload will be reduced much below the maximum tolerable limit.

Consequently, the inclusion of any other tasks into the crew workload will require the inclusion of another crew member to accomplish them. Now, it appears certain that the increased importance and complication of the SST subsystems will make subsystem monitoring, analysis and control an extremely vital crew task. So we see that piloting tasks will require an additional minimum of one flight engineer. Thus the basic minimum crew of pilot in command, copilot and flight engineer. This minimum basic crew will be augmented from time to time by the inclusion of extra relief crew members when fatigue conditions are such that the minimum crew is unable to perform its functions safely and adequately for extended periods of time."

Reedy (ref. 51) of Lockheed has stated:

"Current SST designs are laid out for operation by a three-man crew for both domestic and international operations. A crew of three is considered satisfactory for international operations since trip times will rarely exceed three hours."

Brown, of United Airlines (ref. 52), says about crew composition:

"Now if we may return to the basic problem of crew composition, I believe that we can dispatch this area in fairly short order. As yet we do not know what the design of the airplane will be. If the supersonic transport requires the very narrow plan form of some of the present models, it may be necessary to limit the cockpit space and thus the number of crew members that can be accommodated. Depending on the time that it requires to develop this aircraft, we can look forward to improvements in automation. With miniaturization, it is possible

to increase redundancy in automation which will extend the fail-safe automatic mode of operation considerably beyond our present concept in many important phases of flight and systems operation.

Until we know at what point the operator must take over to assure fail-safe completion of flight, we will not know the number of operators or pilots that will be required to make up the crew.

It is reasonably certain that present-day automation in the fields of navigation and radio will generally eliminate the need for special positions in these two areas.

Improvements in radio communication have long since replaced the radio operator in the majority of operations. Some of our airlines are now replacing the navigator with automation. It is reasonably safe to say that we will move farther in this direction.

It appears certain that the industry will need to weigh the long-range potential savings against development and equipment costs if they are to decrease further the number of flight officers below the two pilot and systems operator concept now governing crew composition in our present jet transports. Furthermore, we will be dealing with the impact of FAA regulations and present-day union agreements in any further considerations in this area. This does not, however, rule out the possibility of moving farther toward complete automation if this route is feasible and more economical in the long run.

As you can see, there are many unknowns. It will be some time before we have sufficient information to determine the composition of our future supersonic crew without injecting many suppositions. We can only assume at this point that there will be little change in the basic three-man crew."

Reference 23 presents the results of an initial study of crew size for SST:

"The estimated work load curve indicates that a three-man air crew is adequate. The preflight through climb-out to cruise altitude phase imposes the greatest crew work load. The approach and landing through engines-off phase requires a total work load nearly as great. It is assumed that: (1) accurate, reliable automatic

Reference 23 closes with a few remarks about the problem associated with life support:

> "Life Support. The flight engineer is assigned the responsibility for monitoring the cabin environment and other life support parameters. Adequate and timely information must be displayed to facilitate accurate and rapid response under all conditions to an abnormal system operation or emergency. Display and control requirements must be derived and validated.
>
> Provisions are included for rapid egress of the crew after ground or water emergency landing. Space is available for systems to allow direct descent by crew members from cockpit to surface. Required pieces of reliable, easily accessible emergency equipment, such as automatic radio beacon and life rafts, have space allocated.
>
> Some specialized life support training for SCAT is required. This may include physiological high-altitude indoctrination and training in emergency procedures and operation. Simulators will be an important aid in this area."

White, (ref. 53), asserts that in his opinion the SST would be complicated enough to require three crew members, and he considered that it would be good design philosophy to have the two pilots able completely to handle the aeroplane. This would mean that the new panel for the engine inlet system would certainly have to be in view of the pilot and co-pilot, and the manual control back-up systems for the aeroplane available both to them and to the third pilot or flight engineer.

Baxter, et al., of the Australian Aeronautical Research Laboratories, (ref. 54) performed a study of "Three Pilot Operation of a Jet Transport Aircraft." The study was performed with respect to operation of the Boeing 707, and also included some conclusions relative to SST. Although these conclusions concerning SST are apparently not based on any extensive study they are interesting and worthy of consideration.

"The change to supersonic aircraft, with a two to three-fold increase in block speed and much the same payload as the present aircraft, will increase the productivity of each aircraft, expressed in ton-miles per annum, by a factor of 2 to 3. The size of aircraft fleet and the crew strength required to maintain a given service should decrease by a smaller factor, and this opens up interesting possibilities for crew organization.

With smaller numbers of crew to handle and shorter times away from base on international operations, the rostering arrangements associated with operating as complete crews could be simplified to the point where this would become practicable.* The gains in effective crew coordination with arrangement should be very significant. Each crew would train together, operate together and have its periodical checks together; they could, in fact, be checked as a crew, rather than as individual pilots, and one of the criteria in their assessment could be their standard of teamwork. It is envisaged that the crew complement would only be changed when a man had a long term illness or was transferred or promoted. One disadvantage, however, would be that all members would have to agree to take leave at the same time.

An alternative arrangement, which would confer some of the benefits of complete crew operation and yet allow more flexibility in rostering, would be to divide the crews into small 'flights', each consisting of four or five Captains, First Officers and Second Officers. Each flight would have a Senior Captain, who would be expected to assist in developing the potential of his junior pilots by taking a personal interest in them, and each crew would be rostered from the members of a particular flight. This should develop a better standard of crew co-ordination than generally applies at present. In fact it would be a similar situation, in many respects, to that prevailing among the London based crews, where a high standard of teamwork and mutual confidence was observed and commented on by the pilots themselves.

It is recommended that this alternative arrangement should be considered for the present generation of aircraft. It would imply, as part of the establishment of a San Francisco based flight, that a few Second Officers would be based in that area. This should greatly improve crew co-ordination in an area where close teamwork between the Second Officer and the two senior pilots appears to be needed, but for very understandable reasons has not

* It has been reported in the technical press that Aeroflot mans its jet aircraft with complete crews at the present time; if one number is medically unfit, the whole technical crew is changed.

been fully developed.

It seems likely that the crew complement of the supersonic transport will include three pilots as at present - one being concerned primarily with the control of the aircraft, one with communication and navigation and the third with overall monitoring and administrative duties. It is probable that, with the shortening of flight times, improved presentation of navigational data in the cockpit, and reduction in the relative magnitude of wind drift, a Navigator will not be needed. However a Flight Engineer of high calibre will undoubtedly be required to monitor the complex systems and rapidly rectify faults when necessary; his duties will presumably include fuel management and performance checks. The employment of an engineer trained to diploma or degree standard would seem appropriate in an aircraft of such complexity. If the stage has, by then, been reached where the junior pilots have been professionally trained at an institute of technology or a university, the Flight Engineer could be a junior pilot. The technical crew would then consist of four pilots, with the two junior members alternating between Second Officer and Flight Engineer duties. This arrangement would provide the junior pilots with a very sound background for future promotion to captaincy and would also lead to a high degree of mutual understanding between the men performing pilot and engineer duties.

Considering the relative seniority of the three men performing pilot duties, it seems logical that the man in control in the left hand seat should, at least in critical sectors, be senior to the man handling communication and navigation in the right hand seat. On less critical sectors there would, of course, be some interchange between these two men to keep them both in current practice. It remains to decide on the seniority of the man in the rear seat, who is engaged in monitoring and administrative duties.

At present in Qantas he is the Second Officer and is less experienced than the other two. With the increasing emphasis on flight management and the need for the monitor to detect any errors in navigation or handling very quickly, and to ensure their immediate rectification, there is a strong case for considering the 'Captain as Commander' concept. With this arrangement the Captain would maintain overall command from the rear seat, the First Officer would control the aircraft from the left hand seat and the Second Officer would navigate and communicate from the right hand seat. The advantages would appear to be these:

(1) It would place the monitoring of the overall operation in the hands of the most experienced member of the crew, who would be most likely to recognize deviations from good flying practice at any early stage. He would also have the authority to demand a rapid correction of the situation.

(2) It would give the Second Officer a more active flying role and greater job satisfaction, and this would assist the development of his potential.

(3) In view of the smaller demands on the manipulative and flying skills of the Captain, his considerable background of knowledge and experience could be available to the company until a later age than is presently considered appropriate for retirement.

(4) All of the pilots could have a longer working life which would be of mutual economic benefit to the company and the pilots.

(5) It would give the First Officer more flying from the left hand seat. The resulting increase in his interest and job satisfaction would assist in developing his Captaincy potential.

Possibly the main objections to this arrangement would result from:

(1) The impracticability of the Captain retaining command of the situation in the event of a sudden emergency during take-off or landing, such as an engine failure at about V_1 speed. In such a situation there would be no time for verbal instructions; the First Officer would have to make his decision and act immediately.

(2) Less manipulative flying experience for the Captain. For his new role, continuous flying as a pilot en route should not

be necessary, but presumably he would need to have sufficient flying in a training situation to retain a license and some degree of proficiency.

(3) Reduced promotion prospects for First Officers. Possibly this could be compensated by some salary adjustment since there would be some economic gain resulting from the longer working life of the pilots.

Seen in the light of past and present aircraft types, the most serious of these objections appears to be the first one. With continuing development of pre-programmed subsystems, the emphasis, even in critical conditions, is likely to shift from manipulative to managerial skills, so this should be less of a problem in the supersonic transport. With a crew functioning as a team, it would be accepted that the Captain's function would be a long term overall command, with the First Officer solely responsible for manual control and associated emergency decisions in critical conditions.

In view of the finding from the interview material that, of the recallable incidents in present aircraft, those attributable to lack of adequate monitoring and checking far exceeded all others, the 'Captain as Commander' concept certainly merits serious consideration for the faster tempo operation of the supersonic transport. This raises the question of whether an evaluation of this crewing technique should be made in the present generation of aircraft before the supersonic transport arrives. It is understood that a leading European airline is planning such an evaluation in their operating environment. This would be of great interest, although the results would not necessarily apply directly to operation over longer stage lengths or in other areas."

Baxter, et al. further state

"Comments by Boeing 707 pilots on incidents in the past related to cockpit co-ordination, revealed that most of them were due to inadequate monitoring and checking. Considering this along with the increased need for close monitoring in the supersonic transport, a case can be made for making monitoring the primary function of the most experienced pilot - the Captain. This suggests a Commander in the rear seat with the First and Second

Officers doing the flying. Possibly this crewing technique should be evaluated in the present aircraft.

To improve crew co-ordination in the supersonic transport, the organization of pilots into complete crews, or into small flights out of which crews are chosen, would seem advisable. Possibly the arrangement of small flights could be introduced with advantage in the operation of the present aircraft. "

One very important consideration as regards crew size is the additive-multiplicative crew role mix. If man is to have mostly--or only --an additive role, then there can be a crew of minimum size. However, as the multiplicative role for man grows, then so does crew size--to a presently unknown upper limit.

In connection with considerations of crew composition and size, crew interchangeability should be investigated. At present the pilot and co-pilot are usually thought to be interchangeable. However, as regards flight planning this may not be so. That is, the pilot and co-pilot are really interchangeable only insofar as flight performance is concerned. What degree of interchangeability is desired in the SST? Radical crew interchangeability may lead to a revolutionary as opposed to an evolutionary approach to the manning for the SST.

4.3.2 QUALIFICATIONS

The SST crew qualifications are dictated by the operational and functional role each crew member must play, and how well each applicant satisfies all the performance requirements. These performance requirements in turn represent the capability the crew must possess. From a human factors point of view there are, in general, four ways in which performance capability may be obtained (this is assuming that we already know <u>what</u> the crew will do and we are now concerned with <u>how</u> we can obtain the necessary performance from them):

1. Selection
2. Training
3. Job guidance or mechanization
4. Human Engineering

Selection and Training are familiar techniques but a word might be said about job guidance or mechanization and human engineering.

Job guidance and mechanization will always be required to some degree. The Job Guide--is valuable in cases where the system operation is of long duration, there is relatively high personnel turnover, skill requirements are relatively low, task performance can be specified in detail and a large number of system personnel are involved. Checklists are a good example of a job guide. Mechanization may be thought of as extending the human's capability in the job situation. Powered controls or flight computers are examples of mechanization. Automation and mechanization should not be confused -- mechanization keeps man in the loop but makes his performance easier or more effective.

Human engineering can be used in two places. The first is to fit the equipment to the human being. This is what is usually meant by the term, e.g., type and arrangement of knobs and dials, working posture, work space arrangement and lighting, task sequencing, etc. The second sense in which human engineering can be done is to modify the human emotionally and intellectually to help achieve the most reliable performance possible. Man is capable of learning, being motivated to perform well, adapting to changing conditions, developing attitudes toward specific work conditions and of changing his attitudes.

Crew qualifications then are those performance characteristics of the crew which we can expect to obtain through selection, training, job guidance or mechanization, and human engineering.

4.3.2.1 General Qualifications

Considerable speculation exists as to whether the SST crew must possess unique qualifications or similar qualifications to today's airline crews. The general statements which follow and specific assertions in subsequent paragraphs represent the viewpoints of some authorities today.

J. J. Tymczszyn of FAA (ref. 55) has stated:

> "Existing performance regulations (SR-422B) require a finding that the operating procedures can be consistently executed in service by crews of average skill, and that allowance shall be made for such time delays in the execution of the procedures as may be reasonably expected to occur during service. The determination of "average pilot skill" with respect to the level of skill anticipated from the airline crews during certain emergency situations, coupled with the accountability for realistic "time delays" has been an area of considerable difficulty and controversy. Many of these difficulties are due to the large number variables involved in the airplane and cockpit design, and to uncertainty in predicting human characteristics. For example, in the case of an engine cut, the pilot's reaction time and corrective action will depend on his state of vigilance, the design of the seat and controls, control force required, and the seat adjustment and pilot's foot position before the event."

It is reported in reference 27 that J. G. Brown, Director of Training for United Air Lines has asserted:

> ". . . the average jet-qualified flight crew will transition to the SST with less difficulty than was experienced in advancing from the piston to the jet. This presupposes a continuation of proficiency training to retain and enhance pilot skills and a high degree of personal application in keeping abreast of technological changes. Experience has shown that flight officers who continue to develop their professional potential have little difficulty in transitioning to jets. The same should hold for the SST."

Reference 27 further asserts:

". . . if we were assured that the pressurization system of the SST were as infallible as the wing structure, we could right now, except for take-off and landing characteristics, write a ticket for admission to the flight deck which could include most of the jet airline crews now available.

If we were assured that the SST cockpit area would not act like the end of a fishing pole, if jostle or buffeting is not a factor in the take-off or dive maneuver, we could again state that any highly motivated, now-existing jet flight crew member could be a candidate for this aircraft. This is some of the critical information needed."

It is also important that the crew members have characteristics which instill confidence in the public. This is probably why flight crews wear confidence-instilling uniforms which remind us of high-ranking military officers. For this reason, the captain will have to be at least in his 30's, despite other factors which might favor a younger man. The public believes that a young man and a powerful, fast vehicle are a dangerous combination.

4.3.2.2 Selection

Brown (ref. 52) states the following concerning SST crew selection.

"In much the same void we must consider the factors which will affect crew selection. Perhaps we first should consider whether it is desirable or possible to employ an effective selection process. Why shouldn't we follow a straight seniority system in crew assignment in the supersonic era? I believe we can answer this question rather quickly with reference to the subsonic transition period. Without an exception, domestic airlines have knowingly or unknowingly been selective in their final assignment of crews to jets. European operators have been much more obvious and have generally practiced some form of selection prior to assignment for training in the jet age.

In our domestic operations we have all gone along with the seniority system in the assignment of individuals

to a training program, but from this point on each airline has followed slightly different courses of action in determining who would or would not fly the airplane in schedule. On the other hand, at least one airline in the United States has advised trainees who have demonstrated serious problems in making the transition to the jet in the flight-simulator phase of transition to discontinue training. This has been done before any large training costs were involved as a result of flight training. Other airlines have taken the same questionable type of trainee on through endless hours of flight training at an expense ranging upwards to $50, 000 per captain, only to find that the trainee cannot pass his rating or meet the standards required on the line.

A survey of the major trunk airlines involved in jet transition indicated that without an exception training organizations found it necessary to eliminate certain pilots as a result of inadequate progress in training or the inability to meet required standards for qualification or rating in the aircraft.

Several months ago United conducted an experiment in which one of our instructors, with a very positive attitude toward the use of flight simulators, completed an entire transition to the Caravelle in the flight simulator. Although this instructor was recommended for a rating without any actual airplane time, regulations being what they are, it was necessary to conduct a practice rating prior to the actual successful rating. The practice rating check clearly indicated that the check could have been passed without any previous flight time in the airplane. I only mention this incident to point up the need to reorient our thinking toward the value of the tools we have available for training and selection. I feel certain that the proper use of the flight simulator will allow us to select pilots for supersonic transition who will complete the flying phase within an economically acceptable period of time with a very high degree of predictability.

If we may accept the fact that cost alone may require increased attention to selection of those individuals who are economically trainable, either before or through training, we should now return to some of the other factors which also may have a bearing on the screening of applicants. For example, as we find out more about the nature of the job to be performed in the supersonic airplane, we may find that through automation and improved design concepts, the supersonic airplane may require no greater flight skills for normal flight than present-day

airplanes. However, in unusual, abnormal, or emergency situations, it is quite possible that skills of the highest order may be required. Regardless of skills required, we can be fairly certain that decision making most likely will be a critical factor in the operation of these aircraft. Owing to the high rate of fuel consumption of an aircraft of this type at lower altitudes, decisions must be final and completely accurate. They must leave very little need for change after one has been committed to deceleration and descent to the lower altitudes. Increased speeds will simplify the weather problems, and with progress in automation many decisions may be assisted through ground control, thus somewhat decreasing the demands on the crew for critically important and rapid-fire decision making.

THE ENVIRONMENTAL PROBLEM

In the area of environment, however, it may not be as easy to design around the present-day man. In flying at altitudes between 50 and 70,000 ft., we will be exposed to pressure differentials in the order of 9.86 psi, which, during a complete decompression, would expose the human body to a change in gas-expansion ratios from the present 2.5:1 to ratios of 12:1 at 60,000 ft. and 80:1 at 80,000 ft. It is obvious from the literature that the human body cannot withstand such differentials without the assistance of some outside environment control such as pressure suits or automatic capsulization. The alternative to these protective devices is a guarantee through design that rapid, unexpected depressurization will never occur.

Our designers are already considering methods of combatting decompressions for the passengers through such media as eliminating windows or providing separate capsulization for sections or individuals in the passenger compartment. The idea of no windows or separate capsulization for the crew members seems hardly feasible as far as the flight crew is concerned. As Colonel Steinkamp has mentioned in his unpublished paper, "Human Factors in Supersonic Air Transport":

'There has been an unhealthy dependence on rapid descent and a constant attempt by both military and civilian air crews and the agencies to go ever higher with less and less protective equipment in use or immediately available. This trend must be reversed, for there is <u>no</u> room for error at altitudes of 50-70,000 feet.'

I believe that if we take the necessary steps to protect the passengers from the effects of depressurization,

which we must, we must then be ready to accept and educate the traveling public to the need for necessary flight crew protective measures which will assure safe completion of flight. Live passengers with a dead crew at 70,000 ft. would not be a perpetual situation. We cannot rule out the possibility that pressure suits will be a requirement for our flight crews, and accordingly, training including practice in the use of such gear under simulated depressurizations to these predictable extremes. This factor alone may require a re-evaluation of the physical conditioning and age limits for personnel being selected to participate in the supersonic flight crew.

If emergency situations may result in conditions requiring unusual flight skills and judgment, or if the environment control at high altitudes cannot guarantee "shirt sleeve" operations under all conditions, it may be necessary to consider selective screening through such factors as:

Relative or Physical Age. All factors which may affect the productive usefulness of the crew member in the supersonic transport must be considered and not chronological age alone. Owing to the cost of training supersonic crew members, it would be advantageous if medical science were capable of predicting with reasonable accuracy that the individual will continue to have the physical requirements necessary to continue in these operations for a reasonable period of years.

Mental Acuity. The crew member must think ahead of the requirements of his airplane under all conditions, emergency and normal. It is quite probable that this requirement can best be evaluated in the early phases of training.

Physical Conditioning. Crew members must continue to maintain physical capability to handle the airplane under all unusual conditions and for the duration of time required. It may be necessary to educate crews to accept voluntarily, or through requirement, a program of physical fitness.

Positive Attitudes Toward All Phases of the Program. Past records of performance may be important in determining professional attitudes toward maintaining skill levels, accepting and adapting to changes, and so on.

Ability to Function as a Member of a Crew. Crew integrity or the ability to function smoothly as a single entity is becoming increasingly important in air transportation. It will be even more vital in the supersonic transport. Therefore a highly standardized and coordinated set of operating procedures must be developed and men selected who will be willing to function accordingly. A maverick cowboy in a 50 million dollar sky rocket with passengers seems hardly compatible."

4.3.2.2.1 Standards for Crews

Reference 30 asserts,

". . . to discuss the physical standards for supersonic flight, one must approach the problem from two standpoints: (1) crewmembers; and (2) passengers. Consideration must be given to our basic requirement for complete structural integrity; however, one cannot ignore failure and the consequences discussed previously.

The complexity of a supersonic transport together with its pattern of flight profile will demand a higher degree of mental and physical response than is needed in our current aircraft. In our opinion, then, one must consider the possibility of an age limit. It is a known fact that deterioration in complex performance occurs usually in the fourth decade of life. It is also granted that older persons, through time and experience, do develop a greater degree of judgment. In weighing these factors one still must favor the ability to respond more quickly in the younger age group of pilots, as a deciding point.

When one considers the possible effects of dysbarism, thought must be given to the exclusion of pilots who are obese and in a generally poor state of physical conditioning. Poor physical condition is a definite factor in susceptibility to dysbaric symptoms. This can lead to complete incapability of crew members to perform their duties."

Reference 10 indicates that "although it is expected that the aeroplane will be under automatic control a great deal of the time, the human pilot must be capable of flying it in all phases of flight. Great alertness and very quick reactions will obviously be required. It is not yet possible to say whether the selection of personnel for pilot

training will involve higher medical standards and more stringent tests than are required at present."

J. A. Wahle, FEIA-SST Committee Chairman has stated in a private communication.

> ". . . Minimum flight crew qualifications will be established by the concerned government agency. At the present time, these minimum qualifications are as follows:
>
> Pilot in Command: Air Transport Rating (First Class Physical)
> Copilot: Commercial Pilot, Instrument Rating (Second Class Physical)
> Flight Engineer: Flight Engineer License (Second Class Physical)
>
> The public interest suggests that these minimum standards be increased for copilots to the level of the Air Transport Rating, and for the flight engineers by increasing the scope of the flight engineer certificate to include an aircraft type rating and to require a mechanical background commensurate with the level required for the present Airframe and Powerplant Mechanic's Certificate. Unfortunately, because of management pressures, it is unlikely that any such increase in minimum statutory standards will be achieved in the foreseeable future. In view of these rudimentary legal minimum crew qualifications, experience indicates that management and the flight crews themselves, through their unions, would be well advised to establish a rigorous program of initial and recurrent training to enhance these minimum standards."

Reference 51 reports:

"Dr. C. I. Barron, M.D., Lockheed-California Company's Medical Department Head, advises that he does not anticipate any requirements for special physical or mental attributes for SST crew members. This opinion is shared by our top piloting personnel.

Age should not be a factor, but just as was found in training for subsonic jets, aptitude does count and shortens training time when other variables are eliminated. Experience with the Mach 2 F-104 and other supersonic military aircraft indicates that the speed factor itself is no

different whether you fly at 100 MPH or 2000 MPH.

Acceleration and rotational stresses at takeoff, and acceleration during transition from subsonic to cruise speed, may be mildly different experiences than some current crews are familiar with. However, there should be no problems in this area. The takeoff acceleration and rotational feel might be likened to a lightly loaded Electra.

It is understood that the FAA is not assuming any different medical requirements or new physical standards for qualification and selection of SST crew personnel.

It is possible that more physiological training will be required for more complete understanding of how to cope with anoxia in emergency and for orientation to new visual experiences."

Reference 27 states:

"Let us look at some of the other vagaries for SST operating crews which are quite apparent even at this time. . . .

We assume that the flight crew member is an intact, healthy human being when he enters the cockpit. We assume that his heart, brain, and special senses are functioning at a physiological level capable of good performance. This is ascertained by clinical testing at stated intervals using some stress test techniques. The present requirement of one or two comprehensive company examinations and two minimal FAA examinations performed per year seems adequate. If deviations from the normal are detected, surveillance can be carried out at more frequent periods. A word of caution here--the airline pilot is perhaps the most often examined individual in any professional capacity. We can overdo this if we are not careful.

If we provide a stable physiological environment of an 8000' cabin altitude or below, adequate function is assured. If we introduce no new noxious elements to an acutely toxic degree, such as ozone, the oxides of nitrogen, or acute radiation effects, he should continue to function well."

It would appear that the general concensus of opinion is that the SST crew will require no unique physical or mental standards to effectively operate the SST.

4.3.2.2.2 Technical Skills and Knowledge

Technical skills and knowledge will be obtained primarily by training rather than selection although the minimum technical entry requirements for candidates may be higher. Selection will, however, be important for screening candidates on their capacity to learn new technical skills and knowledge required for SST. The following discussions represent some thoughts on the kind of technical qualifications which the crew will be expected to obtain.

Reedy of Lockheed (ref. 51) has asserted:

> "With respect to the question of flight crew skills and abilities required, it is the opinion of our top Engineering Flight Test -- and Flight Operations people -- that the SST could be less demanding than subsonic jets from the standpoint of overall flight handling characteristics and fatigue-creating factors. Stability and control characteristics are expected to be better than on today's subsonic jets. There should be no loss of control power or effectiveness at high speed.
>
> The degree of skill required to operate the SST should not differ much from that required for subsonic jets. Several of our people are of the opinion that it is going to be easier to transition from the present jet aircraft to the SST than it was from the piston engine aircraft to the jet.
>
> Based on experience in supervisory training of initial pilot checkouts for the United States Air Force and Consortium Countries on F-104G Mach 2.0 fighters, it appears that the SST will not require any special skills not now possessed by the average subsonic jet pilot."

Baxter, et al., (ref. 54), do not seem to agree with Reedy (ref. 51). Baxter asserts:

> ". . . Should there be a system malfunction in flight, the time available to rectify it will be very short. This will

lead to an increase in the number of automatic changeover mechanisms; that is greater technical complexity. Also, the pilots will have to be more highly trained in technical matters, to give them a greater facility for identifying system faults without prolonged study of manuals."

Both the growing traffic density of present aircraft and the increase in performance of successive generations of aircraft are tending to place more emphasis on technical management rather than on manipulative skill. Critical decisions can only be made in the context of technical competence backed by a full understanding of the systems and underlying principles involved. While it will be necessary to maintain present standards of actual flying skill, there will be an increasing need for a more extensive basic training in subjects such as physics, mathematics, subsonic and supersonic aerodynamics, aircraft and engine performance, electronics and communication.

Academic training to university degree standard for pilots has been the practice for some time in many air forces and there is already a trend in civil aviation overseas towards the setting up of institutions of similar standard. This need might be most readily met in Australia by extension of the facilities of an existing university or institute of technology. An effective course will require a close integration of the practical flying and academic training."

The ICAO (ref. 10) seems to agree with Baxter (ref. 54) as they state:

". . . the greater complexity, and in some cases greater importance, of the various aircraft systems will necessitate a correspondingly greater technical knowledge on the part of the pilot and any specialized members of the aircrew."

4.3.2.3 Training

SST crew training will undoubtedly be complex and costly, and plans for training should begin early. Certainly, Flight Simulators will play a very important part in training and since they will undoubtedly be expensive, every effort should be made to see that they are effective.

Brown of United Air Lines (ref. 52) states as follows about SST crew training.

> "Before we close this discussion, I would like to look carefully again at the tremendous costs that will be involved in training and, paradoxically, the lack of training of flight crews. The cost of training in the supersonic airplane itself has been variously reported as costing in multiples of 5 to 1 upwards to 20-1 of that of the present jet aircraft. Using our present airplane times for jet transition, we are talking in terms of a change in the range of costs for airplane time alone from the present $12,000 to $60,000 per crew to $60,000 to $1,000,000 per crew. The latter is ridiculous, and one such error can pay for a lot of preparation.

MAINTAINING COMPETENCE THROUGH TRAINING

High airplane training times in our present-day jet programs have resulted from two factors which we must overcome in the supersonic era. The first of these is the wide range of individual differences in pilots with respect to their current abilities and professional day-to-day attitudes toward staying on top of their job -- maintaining current professional competence in the whole field of flying. The second of these factors is adaptability to change and attitudes toward training, including the use of the flight simulator.

The wide range of difference in abilities and professional attitudes toward the job is most probably a current problem of every airline. Through recurrent training these differences should be minimized. Those individuals who continue to display an unprofessional attitude toward maintaining current competence should be earmarked for special handling.

Attitudes toward training, and particularly the role of the flight simulator, must be improved and policies for the role of the simulator established long before we enter the supersonic transition period. Some individuals have been retained in our training programs, and particularly in the airplane phase of transition, to an aggregate total of airplane hours exceeding four times that of the more apt trainee. This is an unacceptable penalty to pay, particularly in the supersonic transition program. Both the operator and the pilot groups must accept the fact that performance in the flight simulator

can be used to demonstrate reasonable assurance that the flight training can be completed in the airplane in an economically reasonable number of hours. Thus, the flight simulator phase of our training programs must be accepted as a screening and selection device for the supersonic era. This will require a real change in attitudes and acceptance of this device.

TRAINING MUST COVER ALL ASPECTS OF OPERATION

Finally, it will be necessary for all operators to make a more detailed analysis of the required tasks. We must be absolutely certain that all relevant details and components of each task are defined and covered in training. We cannot afford to uncover shortcomings in our training programs as a result of costly accidents. We must have these complete facts if we are to design our training programs to assure thorough training with efficient use of the time available. Furthermore, if we are to use the flight simulator to evaluate performance and to determine whether a man will continue to progress upward in his chosen career, we must make certain we are evaluating his ability to perform in areas that are essentially relevant to the job he must perform in the airplane.

It would appear from the foregoing that we have a great deal to do before we are ready to enter this field of supersonic flying with all of its responsibilities and exposure, both to cost and safety. It is quite appropriate and timely that we take this opportunity to reflect seriously upon our responsibilities and to begin the action that will be necessary to assure a sound embarkation upon the inevitable step into supersonic commercial air transportation."

ICAO (ref. 10)assert:

". . . as far as can be seen at present, the supersonic aeroplanes will require much the same crew complement as subsonic aeroplanes and the specialization will be much the same as now, although training in each specialty may require particular emphasis. However, the present aircrew functions, other than those of the pilot, have evolved historically with the development of the aircraft itself, and it may be found that a re-grouping of some of these functions will be needed for the efficient and economic manning of the supersonic aeroplane.

The maximum possible use of simulators will be made to provide training on the ground, but it is expected that the simulators will not avoid entirely the necessity to undertake some checking of crew competency in flight. Because the aeroplane will normally be under automatic control for the greater part of its flying time, pilots will need frequent refresher courses to retain their skill in handling it. Simulators will be used as much as possible in these refresher courses as well as in initial training. The opinion has been expressed that special flights made exclusively for the training and instruction of crews will no longer be possible because of considerations such as cost and noise involved, and that, therefore, any training necessary in flight should be conducted on board aircraft engaged in regular flights."

Baxter, et al., (ref. 54), have suggested that a training program oriented more along a college or university program would be appropriate.

"The supersonic transport is likely to place higher demands of a managerial nature on its crew. It will require a more precisely pre-planned operation with a severe compression of the time scale, and the penalties for any divergence from the optimum flight profile or any delays in rectifying malfunctions will be greater; this will place more emphasis on close monitoring and technical skill on the part of the pilots.

This is almost certain to lead to the training of future transport pilots and flight engineers at institutes of technology or universities. It may be found convenient to have two junior crew members with academic training in engineering and flying to share the Flight Engineer and Second Officer duties. The technical crew would then consist of four similarly qualified men; further mechanization of navigational equipment seems likely to eliminate the need for a Navigator."

4.3.2.4 Job Mechanization

Effective planning for job aids, i.e., extending man's capability rather than replacing it has been expressed in reference 56.

"There has been some interest voiced by IFALPA members on the floor and also by Mr. Tymczyszn on the

workload problem in supersonic transport cockpits, brought about by a much shorter flight time and also by the need to monitor the performance of the increased number of automatic systems, such as the engine intake controls.

In this connection the use of an off-line digital computer appears to be worthy of detailed study.

It is important to stress that a digital computer can be extremely useful in an off-line capacity. That is to say, it would not actively switch switches, move controls, open and close valves, etc. Rather it would accept information from the basic systems and perhaps displays of the aircraft, and then process this information to give the crew data which they would normally spend some time deriving from instruments, charts, flight manuals, etc.

Perhaps the most readily seen example of this is in the navigation system. Our own work on supersonic military aircraft navigation systems, which appears to be supported by B58 experience, is that some form of automatic derivator of aircraft position, and perhaps steering information, is necessary at speeds in the region of 20 miles per minute. A digital computer could provide continuously or on demand aircraft position both in latitude and longitude, and also relative to check or reporting points, together with ETA, course to steer, etc. Moreover, if fuel contents and fuel flow information is supplied too, it can provide continuous "how goes-it" information, range remaining, diversion range remaining, etc. Since the computer will have a stored knowledge of the aircraft's performance characteristics, currently contained in cruise control and flight manuals, it can indicate to the crew on demand optimum flight conditions for the particular ambient atmosphere at the time.

All of this type of information gathering and processing and system performance monitoring is currently done by the crew and the proposed use of the computer is merely a means of removing the chores of frequent sums and reference to charts and tables which might otherwise be necessary.

But please note all the systems and information remain directly accessible to the crew so they can ignore any computer if they so wish and calculate their data in their present manner. Thus computer failure has only the potential effect of increasing their workload and does not incapacitate any basic systems.

My conclusion is brief. Many of the reference and computing requirements of supersonic transports can be met by equipment at present available but we are in an era of rapid development of equipment and operational requirements perhaps more so than in the recent past. This is likely to affect the SST throughout its life and equipment which is inflexible from the economic and development viewpoints will impose serious drawbacks on all aspects of the problem, and I think it is an equipment manufacturers responsibility to bear this in mind with great concentration."

The problem which arises with some such suggestion as this is how the information to be provided by the computer is to be displayed to the pilot(s)? As long as the pilot must still use the conventional sources of information, that provided by the computer is not of additional assistance, particularly when the data provided by the computer is based on the information contained in the conventional instrumentation. The computer could make a real contribution here if it presented information from a source independent of the conventional instruments.

A second problem is that it is not just a summary of information which is needed. There is in existence today no procedure for instrument panel scanning to most effectively utilize the information which is available in the conventional instrument panel. The scanning procedure used by each pilot is whatever ad hoc procedure he has fallen into as a consequence of his years of experience. An empirical investigation of the piloting task, the information required to perform this task, the rate at which this information is updated in ordinary flight and the reliability of the information presented could provide considerable information on which to base an information scanning procedure to optimize the acquisition of information for the manual (mechanized) pilot tasks. The same information would be valuable in the design of automatic equipment for information display.

Crew proficiency will be the resultant of inherent qualifications, past flight experience, and sufficient training in the new techniques required for optimum performance. The first two areas are nearly constant,

whereas the final area is variable and depends on the ultimate goals of the air crew. The training must be such as to give the crew the proper perspective as to their roles in the overall system and to instill in them the necessary confidence to fulfill their tasks and to fly the new system. Only with this type of training can the crew expect to react correctly in any "unnatural" situation. The final determination of flight performance proficiency can probably be made by comparing actual performance to planned performance, disregarding factors introduced by unanticipated or uncontrolled miscues in other systems. The ultimate performance will also be affected by whether or not an adequate orientation program into new and improved flight techniques, instrumentation, automatic systems, and cockpit displays is available. Archaic ideas will have to be "unlearned" if the efficiency of the subsystem activities is expected to approach the optimum.

4.4 FLIGHT DECK CONCEPTS

The planned introduction of supersonic transports into commercial aviation has, because of the complexity and high performance of the system, spawned many new concepts in the area of flight deck configuration, controls, and instrumentation. These new concepts range from the introduction of a few new instruments to be used concurrently with present systems to concepts which completely re-locate the "nerve center", re-assign basic responsibilities, and completely change the instrumentation. The purpose of this particular section to the report is not to recommend which concept should be used, but rather to present some of these concepts as they relate to SST, and to comment on their implications.

Authors' Note: An excellent paper by Flower and Flickinger (ref. 57) of PAA has been published concerning "Some Flight Deck Design Considerations for Supersonic Transports." Unfortunately the paper was received too late to be included in this report except as a reference. The paper is highly recommended to those concerned with flight deck design. It covers the following topics:

1. Location and Integration of Crew (Captain, First Officer and Flight Engineer)
2. Visibility
3. Comfort
4. Control Wheel Design
5. Instrumentation -- Communication/Navigation Control
6. Flight Engineer Position

4.4.1 FLIGHT DECK CONFIGURATION AND LAYOUT

The flight deck in commercial transports is typically located in the nose of the aircraft and the pilot and co-pilot are seated abreast of each other. These two seemingly simple requirements become somewhat more complicated in the SST. In order to minimize drag the SST will have a high fineness ratio (in the order of 13 to 1). This of course limits the fuselage cross-sectional area (particularly near the nose), and if the pilot and co-pilot must set abreast of each other they will be considerably further back from the nose than the approximate 5 feet or so that they are now. Instead of 5 feet they will be something like 25 feet from the tip of the nose. This location will pose unique visibility problems and some authorities have considered moving the flight deck. This has been discussed in reference 59.

> "The normal position for the pilot is in the front where he can see what is going on. Therefore, when the aircraft is landing, because the pilot is far from the center of gravity he received unreal motion cues--that is, physical sensations unrelated to actual aircraft performance. This has been no problem in modern aircraft transportation, but simulator results by the National Aeronautics and Space Administration indicate that this will be a problem in the supersonic transport.
>
> Another problem area for the pilot during the landing phase is the supersonic plane's body itself. Since the pilot is not at the very front of the plane, the heat-resisting portion of the aircraft may be in the way of what the pilot wants to view during landing. This could make it impossible to land a plane even in good weather.
>
> Three approaches to solving this type of problem are under investigation.
>
> 1. Bringing the pilot back to the plane's center of gravity to reduce his false motion cues.
> 2. Using television and optics (binoculars) to let the pilot "see" from outside the craft. This is necessary because the plane may come down at such a steep angle that most of the pilot's vision is obscured.

3. Using all-instrument approach (contact analog display). A display of this type would simulate the runway for the pilot.

Lockheed says (ref. 51) about its flight deck:

> " . . . the SST cockpit arrangements and crew facilities are not greatly different from current large transport aircraft, and that a number of improvements are provided. "

In any event even if the fuselage cross section at the flight were large enough to permit moving around the flight profile will require the crew to remain seated and strapped in during most of the flight.

J. A. Wahle, FEIA-SST committee chairman says (private communication):

> "Limited fuselage cross sectional area will impose severe restrictions on available flight deck space.
>
> The necessity for full time bodily restraint during the supersonic flight regime imposes an additional limitation on human effectiveness in that a crew member can effectively control only what he physically can reach. "

IFALPA (ref. 56) similarly agrees:

> "Cockpit space will be at a premium. It is assumed that the crew will be strapped in place for the duration of the flight and that no wandering around to read instruments will be possible. In the unhappy event that fully powered controls are mandatory then the wheel and yoke could be replaced by a small side stick, and the space made available by their removal used for the displays (pictorial navigation)* I have been describing as well as for providing work space. "

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* parenthetic insertion ours.

IFALPA (ref. 56) further discusses some flight deck problems:

"If it is agreed that responsibility and authority should once more be joined in one place, and if it is decided that this place should be the cockpit, then some changes will have to be made in the cockpit.

It is unsuited to the present, relatively leisurely pace of subsonic jets. I wish there were the time to demonstrate the point, but perhaps you can visualize the setting. The pilot is strapped in place behind the controls, wearing ear phones and the long cord that hangs from them, wearing an oxygen mask on his face or hanging against his Adam's apple with the supply tube tangled with the phone cord. He is approaching his destination. He has five charts, three of them the large, folding type on his lap or disposed about his person. He has route manuals and a cruise control book immediately available; in addition to the weather folder as originally issued, he has a notebook full of spot weathers and revised forecasts, clearances and revised clearances, on his lap or otherwise dispersed about his person. He has a set of "Notices to Airmen" containing the latest modifications to route and terminal facilities also located somewhere about his person or environment. And he doesn't even have a place to put a pencil, let alone a desk on which to use it! To suggest that some one can run a five million dollar business from such an "office" is preposterous. It is done, but no one ever figured out how. It must be changed."

The necessity for protecting the crew and their ability to see out also influences the positioning of the crew in the aircraft. Reference 60 has put it as follows:

"One of the major problems is, of course, pilot view. For cruising at Mach 3 a submerged windscreen is really necessary and a means of lowering the nose cone has to be developed to give adequate transparency for take-off and landing vision. This means that a periscope would have to be used for forward view in cruise. A suitably placed, remote viewing screen above the instrument panel is entirely possible for this regime. It is another problem which has to be worked out in detail from an

aviation medicine point of view."

The use of the periscope has not received much attention but the moveable nose has been incorporated in the Lockheed design. Reference 61 reports that the nose section of the Lockheed design can be lowered to two positions. A 10° down deflection is intended for takeoff and for maneuvering into the traffic pattern. Full down deflection is 15° for landing. Full downward nose deflection provides the pilot with a dead-ahead, over-the-nose down vision of 23 degrees, measured from a cockpit eye reference point, but the net down vision angle relative to the ground is reduced by the upward approach angle of the aircraft. With an approach angle of 8.5° a net down vision on approach of approximately 14.5° would be achieved, comparing favorably with today's subsonic jets. The Douglas DC-8 has a net down vision of about 14° with a 2° approach angle, and the Boeing 707 offers a net down vision of 12° with a 3° approach angle.

A NASA study (ref. 23) of an SST configuration made the following points with respect to vision:

> "The variables of major importance to external vision include visual field of view, range distortion, and depth perception.
>
> "Concepts for both direct and indirect vision during cruise, takeoff, and landing have been given preliminary examination for adequacy, design feasibility, and aerodynamic design. . . . An airline would more readily accept an arrangement that provides adequate, but not maximum, vision capability if the arrangement had a high degree of reliability. Variable geometry arrangements have less inherent mechanical reliability than fixed-geometry arrangements. . . .
>
> "Minimum aerodynamic drag penalty is achieved by variable-geometry arrangements which provide reduced direct forward vision during cruise. A translating nose scheme, . . . a retractable mirror arrangement, . . . and a ramp fairing shield. . . are arrangements which provide good

down vision for takeoff and landing but at the expense of reliability and increased weight.

"Other devices to aid vision (such as low magnification telescopes, periscopes and closed circuit television) are potentially feasible schemes but will require a considerable amount of study to determine the exact degree of their feasibility.

"The highly-swept windshield glass required for a fixed enclosure . . . is clearly a compromise between the pilot's vision requirements, the optical properties of the glass, and aerodynamics. The slope of the glass establishes incidence angles greater than used in normal practice; however, some testing of this has been done and the angles of incidence used are expected to yield satisfactory visibility for landing, takeoff, taxi, and forward vision. The good optical properties necessary are best achieved with flat glass which has the highest and most predictable quality. The panels were carefully tailored to minimize the frontal projected area and the angles of intersection between adjacent panes.

"The need for down vision coupled with the incidence angle limitation on the glass tends to raise the glass into the airstream. The configuration presented has a center panel slope of 70° measured to the vertical. This results in the pilot having a 68° incidence angle when observing a target in the forward horizontal location.

"Contours were placed as close to the pilot as possible to minimize exposed glass area. The reference eye position of the pilot's head is 10 inches minimum distance from the outside contour. Allowing for a 2-inch-thick glass envelope, the reference point is 8 inches from the inside contour. Local structure clearance is the same distance in the vicinity of the pilot's head. All other frame areas allow for conventional structural depth."

A second visual variable considered in the NASA report was visual range.

"Normal visual range is restricted by the amount of light (a) transmitted and (b) reflected by the windshield. Variation in reflected light from the object being viewed is caused by the varying angle at which objects are viewed through

windshield. Studies show that range loss will be very large for low light levels which occur at large angles of incidence of the line of sight with the windshield. SCAT aircraft with exposed windshields are expected to have slopes in the vicinity of 20°, be multi-layered and coated, and have an envelope thickness of approximately two inches. Large light transmission losses of approximately 60 percent can be expected. These losses will be combined with those due to variations in line-of-sight incidence angles. As indicated, these variations will also cause large light losses because most of the external vision will be at small angles relative to the windshield. The visual range cutoff point for landing and the correlation of the "LandoltC" test target with visual cues used in landing must be determined before a quantitative application of (studies) can be made to SCAT windshield design. Since the primary requirements for vision are taxi, takeoff, and landing, exposed windshields may provide adequate visual range. Taxi and takeoff can utilize short-range vision, and any range deficiencies can be corrected with external marking aids on runway and taxi strips. Extensive testing and evaluation of various windshield materials and configurations are required before landing vision adequacy can be determined. "

According to the report, other variables include distortion, depth perception and lighting. Distortion and depth perception requirements and their effect on windshield design require a detailed study. These variables will be important in determining the operational feasibility of exposed windshields.

Many of the organizations and individuals contacted expressed the viewpoint that the flight deck configuration and layout would probably follow the recommended practices of SAE Committees S-7. This new point is aptly summed up by J. A. Wahle of FEIA in a private communication as follows:

"All of the S. A. E. Standards and recommended practice documents within the purview of S. A. E. Committees S-7 (Flight Deck and Airplane Handling Standards Committee) and S-7 L (Flight Deck Safety Standards Subcommittee) are pertinent to the subject of flight deck concepts. Comprehen-

sive guidelines are set forth, covering flight deck layout, control location and allocation, instruments, switch and circuit breaker panel location and layout, warning systems, crew seats, visibility, escape provisions, flight handling characteristics, etc. Since these documents are continuously revised considering projected state of the art, they represent late and informed thinking on the subject of flight deck design.

"The scope of crew task and work load expected on the SST will require recourse to the S. A. E. Type III flight deck (two pilots and separate flight engineer). The basic concept which forces this selection is the principle of separation of duties. No extraneous task or distraction should be allowed to intrude upon the attention of the pilot engaged in flight path control. The reasons are obvious. All other systems operations considerations are subordinate to this principle."

4. 4. 2 CONTROLS AND INSTRUMENTATION

There appears to be general agreement that most of the SST cockpit controls will be more or less conventional (at least at this cockpit interface with the crew). The control mechanisms may be different but this should not have much effect on the crew. For example primary flight controls about all three aerodynamic axes will probably be a conventional configuration (wheel, and pedals). The means of control accomplishment will be more sophisticated, however, than those associated with present subsonic jet transports including stability augmentation and fully boosted control about all their axes.

Instrumentation on the other hand may not be so conventional. Some sources are advocating a revolutionary approach to instrumentation rather than an evolutionary approach. The pros and cons of either approach are numerous and will not be discussed here. However, the opinions of some authors regarding controls and instrumentation are presented for consideration. Reference 26 discusses the control concept for designs originally submitted by Boeing, Lockheed and North American.

"In all three designs, the control surface areas and the loads on them are so large that it is no longer possible to achieve manual control under any conditions. As a result all three proposals envision major change in flight control equipment. The controls are essentially irreversible hydromechanical systems with damping augmentation. In the event of failure of the automatic damping system, though, the pilot can still operate the controls.

Irreversible controls are nothing new, of course. The control wheels and cables, instead of operating the aerodynamic surfaces directly, operate through hydraulic valves and servomechanisms. The high-Mach military planes have been flying with such systems since the early 1950s.

The main problem is providing reliability; the solution, the designers say, is to use segmented control surfaces and to incorporate redundancy. On any given axis, such as pitch for example, there will be as many as three sets of controls completely isolated from one another. This means failure of one surface can not cause loss of control. In fact, present thinking is to design the equipment so that the plane could accept even two serious failures and yet have enough controllability for safe flight.

Computer quickens the response

Not the least of the flight control problem is the need for fast, accurate response under the much more rigorous conditions of the SST flight profile. The speeds, altitudes, pressures, vibration modes, etc., are more critical, yet far harder to measure, than in present jetliners. Under flight conditions, these parameters must be promptly corrected for such things as speed deviation, and the information processed to position the control surfaces. To do the job, then, the SST flight control system must depend on an air data computer -- probably quite similar to those used on high-Mach military aircraft at present. In addition to providing the inputs to the aerodynamic controls, the computer will also be used in the operation of other systems, such as fuel management, and for the automatic positioning of the variable inlet ducts for the engines."

A brief description of the Concorde control aspects (ref. 62) is also informative.

"Flying controls will be essentially completely power-operated, deriving their energy from the hydraulic system and employing tandem jacks. The precision required for actuation of conventional trailing-edge surfaces at high flight speeds creates very difficult demands on the system which transmits the movements of the pilot's hands and feet to the hydraulic actuators. Because of this, considerable attention is being paid to electrical signalling systems. These can be designed to have higher precision than mechanical ones, since they are less vulnerable to the effects of structural distortion and vibration.

An obvious problem is that they will have to have a reliability which is many orders higher than exists in any other electrical system to date. A mechanical reversionary system employs tandem jacks, which also provide autopilot actuation. The hydraulic systems also power artificial-feel systems, which are controlled by signals from air-data computers and the fuel c. g. control system."

"This leads us quite naturally into automatic flight control. This more embracing title is used nowadays, since we employ much more than what used to be a simple autopilot. Not only are today's autopilots far from simple in that they cover a wide range of control modes, but the reliability requirement is increased by the trend toward automatic landing. The systems are also improved in performance by autostabilization (or in American, stability augmentation) and automatic thrust control. Autostabilization works independently of the pilot, and operates to control the short-term behaviour modes of the aircraft. Automatic thrust control, or autothrottle, is used to provide speed stability in a number of flight conditions, of which the most important is perhaps the approach and landing."

Perhaps one of the more radical concepts concerning controls was discussed in a recent Aviation Week article (ref. 63). The author discusses the disadvantages of providing controls with an operational "feel". He states: "Another question a pilot rarely considers is why controls in the cockpit . . . must be made to move at all." "In the Piper Cub class of aircraft, stick and rudder pedals move cables that position the control surfaces. Hence, stick and pedals must be movable. But in modern fighters, such as the McDonnell F4H, pilot pressures actuate only electro-

hydraulic servos, which move the control surfaces. Bungee cords create a customary 'feel' for the pilot. Such a system burdens an aircraft with unproductive weight. In addition, room to move must be afforded the pilot, thereby wasting space in the cockpit."

As stated previously many different views on instrumentation are being expounded. The FAA in reference 18 recognizes that instrumentation is not a simple problem as evidenced by the following quotation.

> "Some of the instruments used in the supersonic transport may be similar to those used in present subsonic aircraft; however, additional refinements in the nature of improved presentations and increased accuracy and reliability will be necessary. Also, the reduced atmospheric density and pressure and increased temperature will present new problems requiring further research, development, and testing. Flight personnel may need a structural temperature indicator unit as a primary operating monitor much as the airspeed and machmeter are employed at this time. Accurate and reliable indication of speed and altitude, including the transonic acceleration phase, will be essential for efficient flight and traffic control purposes."

The FAA concludes that a comprehensive study program should be undertaken to determine the required instrumentation, individual instrument system parameters, and environmental and reliability standards.

Reference 27 relates instrumentation to crew workload.

> "Some of the cockpit instrumentation being planned for the SST may, in many ways, simplify the cockpit workload. The panels planned will give much more integrated information at computer level speeds. There will be less eye movement required and more emphasis on near vision than on far vision while in flight. True space myopia may be the rule rather than the exception. (Explain) The closing speeds with other aircraft will be so great that normal visual reception will be much too slow to be of value. Reliable electronic gear will detect other aircraft. Altimetry will be of a new variety. Radar altimetry is planned with a

flip-over mechanism for landing purposes accurate to within five feet, aided by a direct-vision camera showing runway underneath. In fact, the very thing which was the hardest part for the flight crew concerning the transition from props to jets, namely, "thinking ahead of the aircraft," may be solved by computer-type operation in the SST. It is not unlikely that the entire trip from take-off to landing destination may be thus handled even before boarding the aircraft."

Hughes Aircraft Company has been working on the concept of an integrated crew-computer idea for SST. They describe the concept in some detail in references 64 and 65 and a brief summary is presented here.

". . . a radically new concept of air transportation control, called the Central Electronic Management System or CEMS for short.

"CEMS system consists of two basic elements: a small, highly reliable, general-purpose digital computer--and a multi-purpose central display station. The computer ties together all of the various subsystems required by the aircraft for navigation, communications and flight control. It processes their output and controls them in accordance with instructions from the flight crew or--in some instances the ground controller.

"The second element of CEMS is the central display station, a TV-like screen which is the link between the computer and the flight crew. The display would include a cathode ray tube capable of presenting super-imposed electronic and optically projected displays. The presentation of optical and electronic information on the same screen eliminates viewing parallax (the apparent displacement or the difference in apparent direction of an object, as seen from two different points.) Symbols of aircraft present position and heading, fuel circle and homing points can be projected electronically, and navigation and instructional charts projected on the screen by an optical projection system.

"CEMS has the flexibility to perform a variety of basic and essential functions; such as: Takeoff Monitoring, Navigation, Automatic Position Reporting, Cruise Control, Terminal Navigation, System Check-out and Self-Test.

"The complicated CEMS computer will be similar in operation

to other Hughes-produced digital computers performing similar functions in advanced military aircraft. However, the CEMS computer will be radically different. Whereas present computers employ etched circuits and conventional circuit elements, the CEMS computer will employ thin-film circuitry. This circuitry has two outstanding "advantages: first, its extremely small size. The CEMS computer will occupy no more than one-half of a cubic foot. The second advantage of thin-film circuitry is its extremely high reliability. For every 100 planes flying regular schedules, it is estimated that no more than two computer failures will occur in 10 years.

"The other basic element of CEMS, the central display station, presents two somewhat conflicting requirements. It must present a tremendous amount of static information, charts, instructions, and it must present simultaneously a variety of dynamic information such as positions, headings, courses and ranges. The two requirements have been met by combining a slide projector with an electronic display tube. Static information is recorded on a 35mm film strip for optical projection, and dynamic information is presented by electronically controlling the beam of the cathode ray tube. The result is a single, integrated display of not only static, but also static dynamic information.

". . . the concept of CEMS was conceived by its investors as a specific solution to the operational problems of Mach-3 aircraft."

Reference 64 presents the position of the Bendix corporation with respect to SST instruments.

"We think that the flight director is going to get bigger, and will be a 5-inch instrument to incorporate monitoring of the commands for throttle; the horizontal situation indicator is going to have D. M. E. added to it--that will be distance whether on D. M. E. or on Doppler, Distance to Destination or Inertial Distance to Destination. We think that the major change that will take place will be on the altitude--Mach-airspeed group; if we add data link to the system, where we have to send out commanded altitudes or, if we are going to have a central computer, which is going to tell us what Mach number is optimum for the particular condition we are in, then the Machmeter will have to have not only its own indication but the desired Mach number; the

altimeter will have to show the desired altitude in addition to present altitude, and I'd hate to see that being a three-pointed instrument on top of a three-pointed instrument. In view of all this we think they are going to go to instruments similar to those in the B70, which are vertical tape type. They may not be exactly similar to those in the B70, they may be modular rise vertical tapes, but with these vertical tapes we can get color coding on altitude--we can have different colors and different shapes up to 10,000 feet, change it from 10 to 20, and so forth.

We can have radar altitude displayed on final approach --displayed alongside rate of climb or descent, so that we can see in the approach whether we are coming down properly. That, I think, would be the new instrument that pilots would have to get used to. All the others are pretty standard: we will still have the drift angle indicator, ground speed indicator and off-course indicator similar to those which we have in the aircraft today.

With regard to engine instruments there seems to be a difference of opinion between U. S. pilots and pilots in Europe; maybe we could get an IFALPA statement on this. Pilots in the U. S. seem to want to see all the instruments and make all the decisions; European pilots seem to leave it all to the Flight Engineer and have all the instruments at the back. In the U. S. we will have improved engine instruments where, instead of looking at twenty round dials to see if the engines are satisfactory, the SST instruments will have four tapes together for each reading so that any engine indication markedly dissimilar from the others will be immediately apparent."

A TWA captain expresses the general opinion that auditory displays might be considered as it appears that at least during final approach the co-pilot is frequently used as an auditory display in today's jet flying. For example, during final approach the pilot flies the aircraft while the co-pilot reads off final approach altitude to the pilot. In this case it is obvious that the co-pilot is being used really as an auditory display, i. e., he is taking the visual display information and translating it to an auditory display for the pilot.

North American (ref. 65) presented an instrumentation concept for the SST.

"With the advent of the triplesonic transport, new concepts of controls and displays are indicated. The crew compartment will be designed to maintain the highest degree of human performance. The control wheel and column has been replaced with a side control stick, since the controls are full powered. This eliminates the safety hazard of instrument panel obstruction, caused by the wheel, and allows the pilot to move further forward, increasing his field of vision and instrument reading ability. Artificial feel appropriate to one hand operation is provided.

The horizontal position indicator, located on the center pedestal, is coupled with an auto navigator and shows the pilot the horizontal projection of the flight data on any scale chart desired.

Considerable development effort must be accomplished on all of the flight crew stations in order to obtain the optimum means of display. This is an area where close cooperation between the government agencies, airlines, and manufacturers is necessary. Because of the reduction in flight time involved in the usual schedule of the supersonic transport, a number of changes in crew duty requirements may result. In the terminal areas for take-off and landing, crew duties probably will be increased primarily in the field of communications. The requirements for faster handling of voice communication with ground control when penetrating or leaving high density traffic zones may demand a change in the air traffic control systems and probably automation in airborne communication equipment. Increased speed also puts greater demand on crew vision, particularly with reference to collision avoidance. At the same time, it is apparent that pilot vision in the supersonic transport becomes increasingly difficult to obtain due to the requirement that windshield lines blend as closely as possible to the basic fuselage to obtain efficient high-speed cruise performance. Consideration must be given to aerodynamic heating and to solar radiation. Additional information must be gathered on these effects and on human tolerance levels.

Supplementary visual aids such as infrared or radar equipment may be required for use in detecting other aircraft in the area, as well as for terrain and weather information. Because of some of the limitations in instrumentation accuracy, it is not at all clear that vertical separation between aircraft is a satisfactory procedure for supersonic aircraft. The concept that we visualize is horizontal separation with ground vectoring of the aircraft by ground control and monitoring of the horizontal separation by the pilot

using airborne radar.

We expect some changes in the avionics equipment for commercial transports for 1970, independent of supersonic transport developments. Solid-state techniques will make the individual equipment smaller and more reliable. Advances in air traffic control will somewhat modify the communication and radio navigation complement. Doppler or inertial navigation systems, developed originally for missiles and military aircraft, will become sufficiently reliable for regular airline use. The basic requirements of the supersonic transport can be handled by the same equipment. However, some novel approaches to their utilization are indicated. The routine tasks of the crew, such as tuning in the successive radio communication and radio navigation stations, monitoring the flight and engine instruments, etc., will become more difficult when transports fly nearly four times their present speeds. It is anticipated that a completely automatic system with crew monitoring and manual override would be used for these flight management tasks.

The flight plan and other related data would be printed on a punched card. Copies of this punched card would be given to various air traffic control stations and other ground facilities concerned. One copy would be inserted into the airborne flight management computer. This computer would also be the primary navigation computer, possibly giving parametric data to the pilot such as recommended speed, climb angle, and altitude; would tune in air traffic control stations and navigation aids, automatically transmit flight data desired by the appropriate ground facilities, etc. In an emergency, such as an airport closure or a failure of one engine, it would display the recommended alternate destination.

It is quite obvious that considerable effort will have to be expended in this particular area, making sure that all affected technical and operational factors are considered in the design optimization process. The result will be fewer detail crew duties, better schedule-holding, less possible reaction time. Much work has been done on the nature of warning signals and their standardization for military aircraft, but a supersonic transport aircraft will introduce new criteria, particularly on the number and distribution of bisensory signals, e. g., those mediated through vision and sound, or vision and vibration, or other combinations."

CONCLUSIONS

Many of today's conventional cockpit concepts will soon be replaced by newer ones because of the requirements placed on the aircraft crew by the high performance characteristics of the SST. With the advances made in the areas of thin films, inertial guidance, etc., it appears logical for these systems to be incorporated into the SST. Studies will have to be made into the reliability of these systems, and how they will affect the performance of the flight crews. Many of the systems present sound theories, but each must be surveyed with respect to the overall system. The ultimate concept chosen will in all likelihood incorporate ideas from several systems.

It must always be remembered that the high performance aircraft will usually require experienced flight crews to man them. This means that radically new concepts will require some amount of retraining. Again studies will have to be made to see if flight crews will be able to function with the new stimuli. This is particularly true in the area of informational displays.

This report is the first Interim Report developed under Contract NAS 2-2209. In many respects it is a collation and presentation of background material pertinent to the project. It is also assumed that this material will be useful to others concerned with SST crew factors.

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