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A STUDY OF POTENTIAL ROLES OF SUPERSONIC TRANSPORT CREWS AND SOME IMPLICATIONS FOR THE FLIGHT DECK

VOLUME I:
WORKLOAD, CREW ROLES, FLIGHT DECK CONCEPTS, AND CONCLUSIONS

by Harold E. Price, William D. Honsberger,
and William J. Ereneta

Prepared by
SERENDIPITY ASSOCIATES
Chatsworth, Calif.
for Ames Research Center

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FOREWORD

This study would not have been possible without the cooperation and contribution of many organizations of the aviation community. The authors and the National Aeronautics and Space Administration hope that the results of this study will be useful to all the organizations who have contributed to this study. While it is not possible to list all the organizations who have cooperated or contributed to the problem, they may be identified by the reference material used during the study. We are gratified by their interest, time, effort, cooperation, and data released for this study effort.

SUMMARY

The study was conducted to investigate potential roles of supersonic transport crews and the implications of these roles on flight deck design. The results of the study should be useful as an objective data base for decisions concerning crew complement and qualifications, flight deck design, allocation of functions to the crew or automatic equipment, and distribution of duties among crew members. The study results should further be useful for the planning and conduct of empirical simulation research on crew requirements by providing the basis for realistic crew workloads, identification of simulator characteristics, and identification of crew research requirements for simulation investigation.

The study was conducted largely as a field research and literature survey program to synthesize requirements and constraints relative to potential crew roles and to review technical concepts for implementing SST operational functions with emphasis on potential crew participation. An analysis of the data so developed was conducted to investigate crew workload, distribution of this workload among different numbers of crew members to define potential crew roles, and implications of these potential roles for flight deck design.

The results obtained warrant the general conclusions concerning SST crew requirements that:

A realistic workload must be developed and utilized for SST crew simulation studies

The full-time capabilities of a three-man crew may be required for SST operations

There are some unexpected potential high workload areas such as preflight checkout and cruise

Monitoring tasks will contribute substantially to the crew workload and unique monitoring techniques may be necessary

Flight management operations are changing to a more cognitive performance rather than neuromuscular, and new man-machine interface concepts must be developed to support this role

Major malfunctions may require an additional crew member's capability if the flight plan is to be maintained, and cost effectiveness criteria must be developed

Crew incapacitation should be researched to determine potential effects on workload

Empirical research should be conducted to determine the effectiveness of 2, 3, and 4 man crew complements

Crew qualifications may change particularly for 3 or 4 man crew complements

Navigation and all-weather landing are unsettled with respect to the crew's role

Research directed towards new concepts of instrumentation and crew acceptance should be conducted

Flight deck layouts for simulator evaluations and/or SST operations should be designed to specifically accommodate the responsibility, authority, and qualifications of each crew member.

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INTRODUCTION

PROGRAM OBJECTIVES

This program was performed under contract NAS2-2209 between Serendipity Associates and the Biotechnology Division of the Ames Research Center of the National Aeronautics and Space Administration. The program consisted of both field research and analytical studies to provide:

1. A delineation of requirements and constraints on the potential roles of supersonic transport crews.
2. A delineation of SST activities and functions and the role of the crew in implementing these functions.
3. A delineation and analysis of typical emergency and non-routine incidents in commercial air carriers.
4. An estimate of crew workload and distribution of this workload among various crew sizes to develop potential crew roles.
5. Development of basic flight deck concepts implied by the potential crew roles.

The interim and end products of this research are considered to be of use to the NASA, other government agencies, and the aviation industry in general in the following ways:

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

2. As a basis for planning empirical research programs to investigate critical aspects of crew complement, instrumentation, and man-machine integration factors of SST.

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

4. Analysis of the emergency and non-routine incidents in air carrier operations indicates where emphasis should be placed in design, simulation, human engineering, and training.

5. The methods developed should be valuable in assessing the validity of the crew performance requirements derived for the SST as well as in providing a basis for systematically and consistently deriving crew performance requirements in other systems.

An initial report has been completed under this contract and published as NASA CR-146, Requirements and Constraints of Potential Roles of Supersonic Transport Crews, by Harold E. Price, Richard A. Behan, and William J. Ereneta (ref. 1). The present report is the final report under the original contract and is contained in two volumes.

ORIENTATION AND APPROACH

The Commercial Supersonic Transport Aircraft Report (ref. 2) issued jointly by the Department of Defense, the National Aeronautics and Space Administration, and the Federal Aviation Agency, defines the role and broad responsibility of the National Aeronautics and Space Administration as "basic research and technical support." The program described here is directed at the broad responsibility of the NASA and more specifically to crew requirements for supersonic transports. Serendipity Associates, contractor to the NASA for this program, exists for the purpose of conducting analytical and empirical research and is not engaged in the development or manufacture of hardware. This program then is an objective study of operational crew requirements for supersonic transports. In addition, the program is oriented toward developing and documenting methods in support of the program objectives.

A prime consideration underlying this program was the awareness that a great deal of simulator work may be necessary to support the SST, and that crew workloads during simulator evaluations should be as realistic as possible. Therefore, the program was concerned with operations of a commercial carrier and not just aircraft operations.

The program approach included field research, analytical studies, and synthetical studies. No empirical research was planned. The field research was directed towards individuals and organizations concerned with the development and/or operation of supersonic transports. Field work consisted of informal interviews and working sessions with 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.

The analytical aspect of the program involved obtaining requirements, constraints, and other technical data for those representative groups and individuals described above, and analyzing these data both qualitatively and quantitatively to derive subsequent requirements and constraints necessary for investigating operational crew tasks. This aspect of the program also included, 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 consisted 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 here 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, 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.

PURPOSE AND ORGANIZATION OF THIS REPORT

The present report, published in two volumes, covers work completed since the publication of the first interim report (ref. 1) and is the final technical report under the original contract. A broader discussion of requirements and constraints affecting crew task requirements in the SST is provided in the initial report and establishes the context for the material which follows. Frequent references are therefore made to that document and it should be available to the reader to complete the technical information developed under the program.

Volume I of this report is in three parts. Part I is concerned with the development of potential crew roles, and presents an identification of SST operational functions (Section 1), an SST crew workload analysis (Section 2), a brief examination of human factors considerations in monitoring since monitoring constitutes a large amount of the workload (Section 3), an analysis of emergency and non-routine activities based on current jet transport malfunction data (Section 4), a delineation of workload distribution for 2, 3, and 4 man crews (Section 5), and a synthesis of potential crew roles (Section 6). Part II is concerned with flight deck design concepts implied by the potential crew roles developed in

Part I. Part II presents an analysis of information required by the crew to operate an SST (Section 7), development of some basic instrumentation concepts (Section 8), and a synthesis of the information requirements and display concepts into basic flight deck concepts for two-, three-, and four-man crews (Section 9). Part III presents a final section containing conclusions and recommendations (Section 10).

Volume II of this report contains the results of the effort to derive SST operational functions. Its organization is based on a flow-logic diagram defining each function in terms of input and output states and depicting their relationships with SST flight phases. Detailed discussions of current and projected implementation concepts for each of the SST operational functions are also presented in Volume II. Operational requirements and constraints pertinent to current subsonic jet transport operations and those expected to apply to SST operations are discussed and feasible automated and manual techniques for accomplishing each function are described.

The principal objective of the present effort, as indicated above, was to synthesize information from many sources which is directly related to the problem of defining SST crew roles and flight deck design concepts and to organize and present this material as a data base for subsequent, more sharply focused research on specified crew requirement problems. For this reason, the content of the two volumes of this report cannot easily be reduced to a concise, summary statement of "results" or conclusions." In the sections which follow, however, general results have been expressed at the end of each section, representing distinguishable technical efforts, and conclusions and recommendations are synthesized in Part III. Corresponding sections of this volume and of Volume II must be consulted for a complete discussion of these problem areas and the many pertinent details considered in this study.

PART I

POTENTIAL ROLES OF SUPERSONIC TRANSPORT CREWS

1.0 SST ACTIVITIES AND FUNCTIONS

This chapter is divided into two sections. The first section review of the SST flight profile developed in the first report under this contract (NAS2-2209). The second section explains the derivation of the SST functions and the kind of information developed about each function. The actual technical information developed for each function is contained in Volume II of this report. (NASA CR-562).

1.1 FLIGHT PROFILE AND ACTIVITIES

The SST flight profile depends entirely on a specific aircraft configuration and payload, the particular route being flown, and atmospheric conditions which exist along the route. The profile information used in this report is general or typical flight profile information and thus represents generalized SST performance and provides a baseline for later analysis. 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. Meteorological and atmospheric data were developed on the basis of a standard day and a no wind condition using U.S. Standard Atmosphere Data (1962) as a basis for any calculation.

Generally, the optimum flight path for SST performance will be dictated by considerations of aerodynamic efficiency and fuel economy within the structural limitations of the aircraft. However, the optimum flight path can not be flown in commercial operations because of sonic boom and air traffic control problems. The annoyance and damage aspects of sonic boom and the obvious necessity to have the ircraft operate with other trafffic under air traffic control impose limitations in the ascent, cruise and descent portions of the flight.

Figures 1 and 2 are general flight profiles for the SST. Rather than giving a specific value or specific flight path, data are presented in the form of flight envelopes or ranges of values which can be expected in most cases. An average value is shown on the profiles, but it is merely the average of the range of values and does not represent any particular aircraft. The flight profile phases are arbitrary. Twelve particular phases were used principally because of their logical distinctions and their utility to the general objectives of the program rather than because of radically different performance aspects during each phase. The twelve flight phases used in this study are listed below.

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

A set of SST operational activities was developed to help identify specific functions within each flight phase. This list of SST activities is as follows:

1. Flight management
2. Phase oriented system checks
3. Communication
4. Power plant operation
5. Flight control
6. Inlet nozzle configuration
7. Navigation

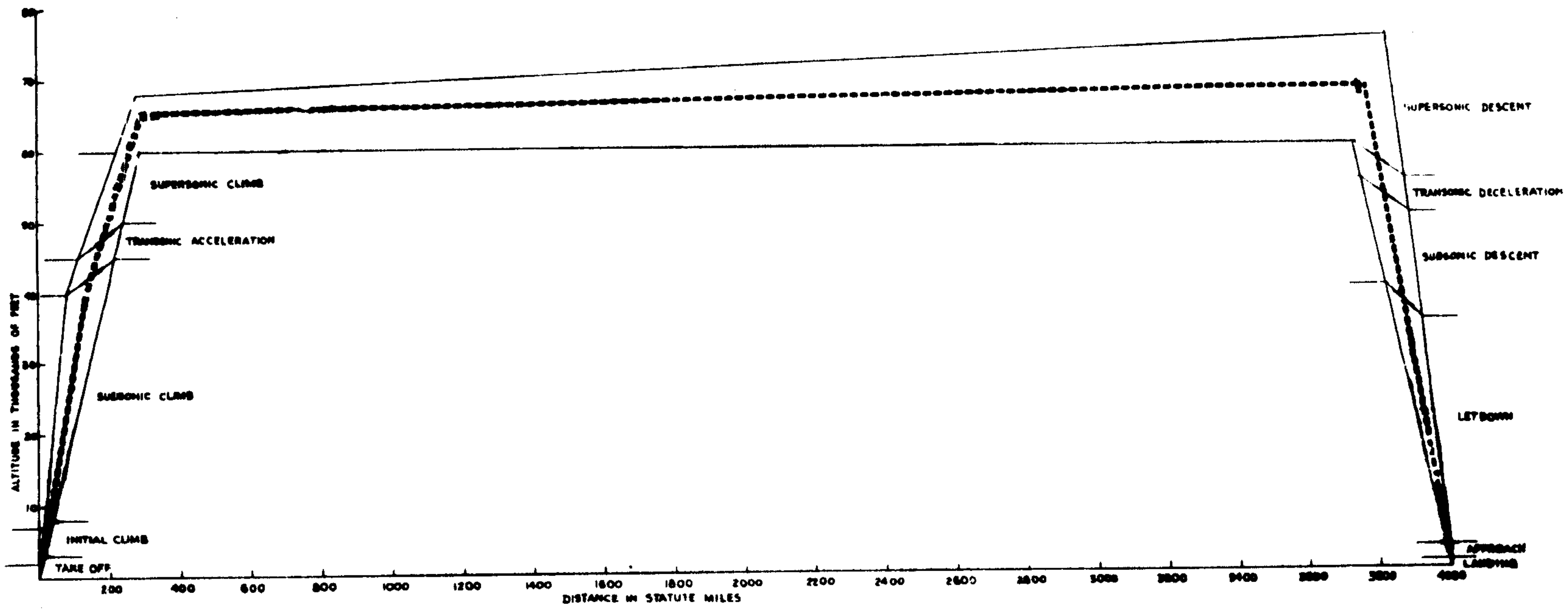


Figure 1. SST altitude-distance profile (taken from reference 1)

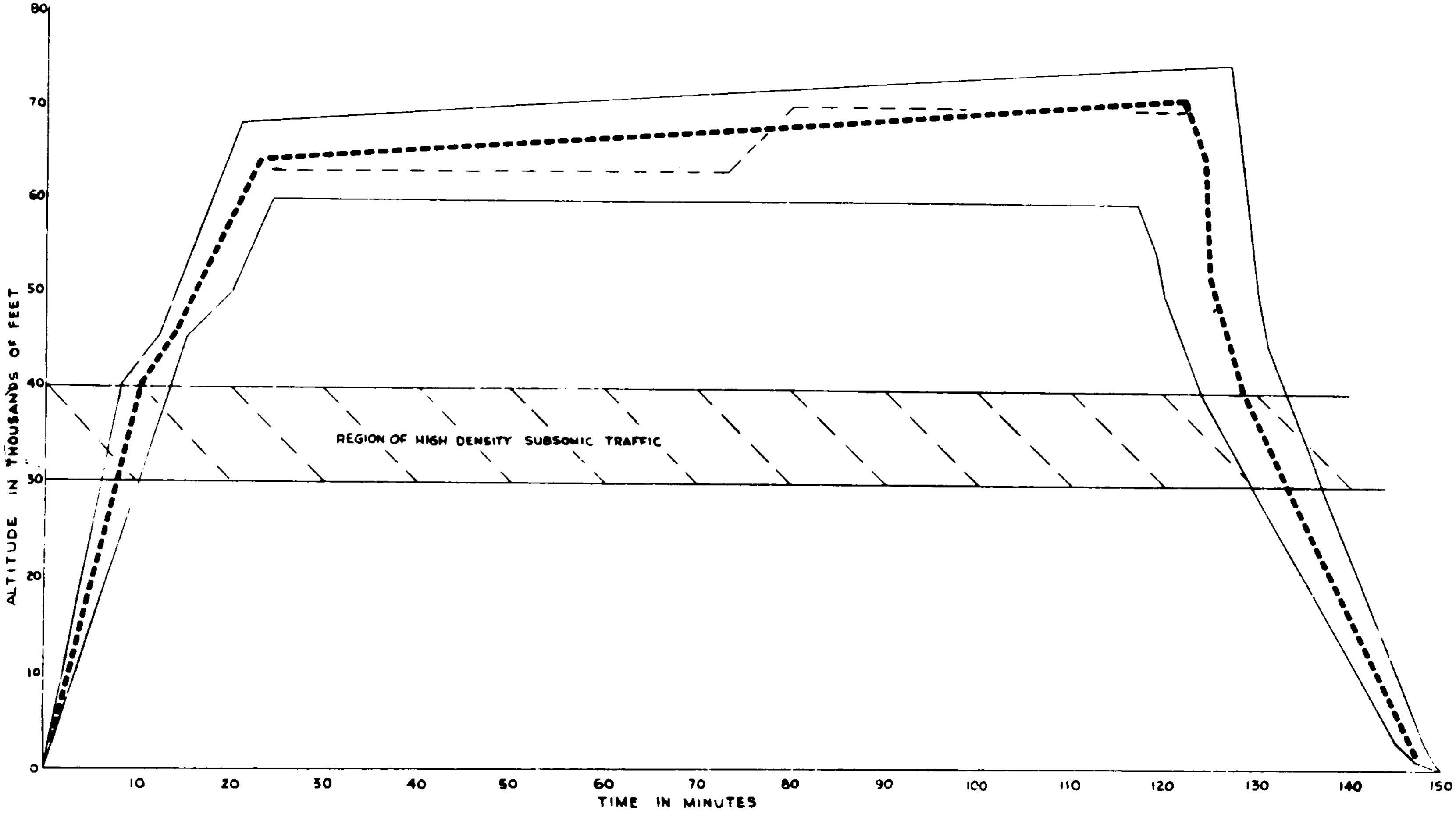


Figure 2. SST altitude-time profile (taken from reference 1)

All of the operational functions are associated with one of the activities.

1.2 SST OPERATIONAL FUNCTIONS

In order to analyze potential crew roles in the implementation of SST operations it was necessary to partition the SST operations into units of performance smaller than flight phases and activities. This unit of performance was designated a function. The functions were derived in a systematic, a priori analysis. Each activity was divided into smaller performance units until it was believed that the performance unit represented individual functions. These functional units could then be analyzed with respect to different concepts for their implementation as well as the potential role of the crew in each of these implementation concepts. Only the operational functions were derived (i. e., those functions necessary to take the aircraft from its departure airport to a destination airport within a supersonic cruise profile).

Volume II of this report contains the results of the derivation and analysis of the SST functions. The results of the derivation of SST functions are presented as a flow-logic diagram in Volume II. The input and output states of each function are identified as well as the interrelationships between functions. An identification of the functions derived within each activity is presented in Table 1 at the end of this chapter. A summary of the implementation concepts for each function is also presented in Table 1. The detailed results of the analysis of each activity and function are presented in Volume II. Each activity and function description has six sub-parts which make up that description. These sub-parts and the kinds of information contained in each part are described below:

Purpose. The basic requirements and constraints of the activity or function as well as the general rationale or need for the activity or function is presented in this sub-part.

Current Jet Operational Requirements and Constraints. This sub-part includes International and Federal Air Regulations or comments about these regulations which are pertinent to the activity or function. No attempt was made to be exhaustive and include all regulations which applied to a function, but rather those regulations which had some effect on the operation and thereby on the crew requirements of current jets were generally included. Specifically not included were regulations dealing with certification and air worthiness. Regulations were included for both international (flag) and domestic commercial air carriers. Regulations were from two principal sources: (1) The Federal Aviation Regulations (FAR's) which are issued by the Federal Aviation Agency of the United States and which all U. S. domestic air carriers and international carriers (whether U. S. or other) must comply with when operating within the Continental boundaries of the United States and (2) International Standards issued by the International Congress of Aviation Organization (ICAO) which apply to all international carriers which are members of the ICAO when operating outside of the boundaries of their country. As stated earlier there are many standards and regulations with which aircraft and commercial operators have to comply. However, for the purposes of this report the regulations used were taken from four sources: (1) Federal Aviation Regulations, Part 91, General Operating and Flight Rules, Federal Aviation Agency, (2) Federal Aviation Regulations, Part 121, Certification and Operations: Air Carriers and Commercial Operators of Large Aircraft, Federal Aviation Agency, (3) International Standards, Rules of the Air, Annex 2 to the Convention on International Civil Aviation, ICAO, and (4) International Standards and Recommended Practices, Operation of Aircraft, International Commercial Air Transport, Annex 6 to the Convention of International Civil Aviation, ICAO.

Current Jet Implementation Concepts. This sub-part is a description of the means whereby the activity or function is implemented in current jet aircraft. There is, of course, no standardization throughout current jet operations and in general we have presented or discussed several different concepts for implementing the activity or function and frequently integrated these into a typical concept for our purpose. This sub-part is included for two principal reasons, first, to enable useful comparison between SST concepts for this function and current jet concepts for the specific function and, second, because the manual implementation concepts for SST are frequently very similar or the same as current jet implementation concepts. The information in this sub-part was not broken up into smaller subdivisions, but in general focussed on the equipment involved, the crew responsibility, the crew equipment interface (displays and controls), any job aids used, and procedures where appropriate.

SST Potential Operational Requirements and Constraints. This is a discussion of the current jet requirements and constraints which may have to be changed in order to accommodate SST. Further, some discussion of new requirements and constraints necessary for SST operation is presented. The discussion here sometimes refers to a specific regulation and sometimes to an area of operation which affects the crew.

Feasible Automated Implementation Concepts for SST. This is a description of automated means or techniques for implementing a specific function of concern for the SST. Automation, as used here, implies that the function may be initiated, terminated, data inserted, and the process monitored by the crew, but in general the crew did not participate in the actual processing *per se*. Feasibility as used here is primarily a qualification based on concepts which were available in the technical literature. Thus, if the technical literature contained a discussion of a concept for implementing the function of concern for the SST, it was deemed a feasible concept. No attempt was made by the authors to invent new concepts, although some existing concepts were extended or integrated to develop what may be considered new concepts. While no rigid format was followed, the same general factors which were discussed under current jet implementation concepts were also discussed here. These were equipment, crew responsibility, crew interface (controls and displays, job aids) and appropriate procedures. Frequently several alternative automatic concepts were presented. These automated concepts and the feasible manual concepts in the next sub-part were the basis for determining the crew workload and the implementation of each function.

Feasible Manual Implementation Concepts for SST. This sub-part is very similar to the previous one with the exception that it included feasible manual implementation concepts rather than automated concepts. The term, feasible manual concepts, was used to imply mechanized means or some level of aid to implement the functions in an operational situation. Thus, the concepts described do not imply the maximum or limit of human capability, but rather concepts which may be considered realistic in the operation of supersonic transport and not emergency situations. In general, the concepts are no more manual than those in current jet operations and in many cases they are the same. It was stated occasionally that no feasible manual implementation concepts exist for a particular function. This statement means that there are no manual concepts deemed feasible if the aircraft is to remain within the intended flight plan and accomplish the cruise phase supersonically. While most planned flights for the SST could be completed subsonically within the planned fuel reserve criteria, this obviously would have a severe economic impact because of the failure to utilize supersonic flight. Thus, throughout this report the phrase, SST operational functions, refers to those functions necessary for a flight profile involving supersonic cruise and not subsonic cruise operations.

1.3 RESULTS

As previously stated, Volume II contains the detailed results of the derivation and analysis of SST functions. Table 1 which follows identifies the functions which were derived and summarizes the results of the analysis of implementation concepts. A total of seven (7) activities and 89 functions were derived for operation of the SST in normal air carrier operations. Insofar as possible the functions were derived as performance requirements and not design means. A synthesis of feasible implementation concepts (design means) was performed using available technical literature as the criterion for feasibility. Emphasis was placed on defining the crew role in the implementation of each function. Detailed discussions of these implementation concepts are reported in Volume II.

Table 1. Summary of Implementation Concepts

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
1.0 Flight Management Activity	The nature of this activity in current aircraft is such that the entire crew operates as the manager, even though the Captain is fully responsible for the aircraft and the flight. However, the management task, per se is not as distinctly defined in current operations as it will be in SST operations.	With the SST the concept of flight management will take on a new connotation, and a manager's position will need to exist. In most cases the senior pilot will receive the responsibility of the position, and as a result will no longer concern himself with the actual control of the aircraft. His task will be to make appropriate evaluations, judgments, and decisions in the available time. To assist in this the flight manager will be able to utilize the capabilities of a high speed, general purpose computer.	Because of the time compression brought about by high speed flight, it would appear that the task of the flight manager could not be accomplished within the necessary tolerances without the assistance of some sort of high speed computer. Without doubt the flight manager could continue to make decisions, but the amount of information utilized to base such judgments would make the results quite gross. To realize the problems which will be encountered in such an environment, refer to Vol. II, Activity 1.0.
2.1 Pre-Start System Checkout	Lengthy and complex checklists are utilized by the crews of today's aircraft to insure that the aircraft system is ready for engine start. For the most part the instructions of these checklists are manually followed by the crew.	Ground testing equipment, the general purpose computer, and some checklists will be utilized in the SST to conduct the pre-start system checks. The economics of the SST dictate that the ground time be kept to a minimum, which means faster system checkouts.	If equipment were not available, and if the computer were to malfunction, the crew would have to rely on checklists to complete the pre-start system check. Although this would tend to increase the ground time, and hence decrease the availability of the aircraft during any day, the concept is quite feasible.
2.2 Post-Start System Checkout	The crew following lengthy checklists is the means currently employed to accomplish this function.	Once the engines have been started on the SST any extensive ground lingering will result in sizeable fuel penalties. For this reason every effort will be made to automate the system check and to reduce the necessary ground time to a minimum.	The use of a checklist as in current operations is feasible, but will result in larger fuel consumption due to the inefficiency of the SST power plants on the ground.
2.3 System Preparation For Take-off	Same as for 2.2.	There are very few items to check during this particular function, so in all likelihood the performance could be accomplished by utilizing a checklist.	Same as for 2.2.
2.4 Post Take-off Check	Same as for 2.2.	A combination of computer check and the crew using a checklist will be utilized in this phase to accomplish the objectives of the function.	Same as for 2.2.
2.5 Pre-Transition Phase System Checkout	Not applicable.	Prior to commencing the acceleration to supersonic speeds, the crew will need to ascertain that the aircraft's systems are set-up properly, and that their outputs are consistent with the required performance. In all likelihood the checks will be a combination of computer and checklist.	Merely utilizing a checklist, the crew would be required to initiate checks at an earlier time in the climb, and would in all likelihood check the more critical parameters first.
2.6 Pre-Deceleration/ Descent Phase System Checkout	Prior to descending from cruise altitude, the crew will utilize a checklist to insure that the aircraft's systems are prepared for the descent.	Computer and checklist as described in the preceding functions.	Checklist as described in the previous functions.
2.7 Pre-Landing System Checkout	Same as for 2.2.	Same as 2.4.	Same as 2.2.

Table 1. Summary of Implementation Concepts (Continued)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
2.8 Accomplish System Deactivation Procedures	Same as for 2.2.	Computer/checklist will be used where feasible to keep the "turn around time" to a minimum.	Same as for 2.1.
3.1 Ground Handling Phase Communications	Interphone, VHF/UHF/HF communication equipment.	Interphone, VHF/UHF/HF communication equipment.	Interphone, VHF/UHF/HF communication equipment.
3.2 Cockpit Communications for Take-off	Coordination information is passed via the intercom system or by direct voice during the take-off function.	Intercom and direct voice.	Intercom and direct voice.
3.3 Departure Control Communications	The UHF or VHF communication equipment is utilized during the initial ATC control procedures.	UHF or VHF communication equipment.	UHF or VHF communication equipment.
3.4 Activate/Deactivate "No Smoking" Signs	Manually actuated switch.	Manually actuated switch.	Manually actuated switch.
3.5 Activate/Deactivate "Fasten Seat Belt" Signs	Manually actuated console switch.	Manually actuated console switch.	Manually actuated console switch.
3.6 Initial Position Report	Same as for 3.3.	Data link/standard communication equipment.	VHF/UHF (SELCAL) equipment.
3.7 ATC Communications Handoff	Same as for 3.3.	Same as for 3.6.	Same as for 3.6.
3.8 Enroute ATC Communications	Same as for 3.3.	Same as for 3.6.	Same as for 3.6.
3.9 Intercom Announcements	Intercom system.	Intercom system.	Intercom system.
3.10 Enroute Company Communications	HF communication equipment.	Data link.	HF communication equipment.
3.11 ATC Communications for Deceleration/ Initial Descent	Same as for 3.3.	Same as for 3.6.	Same as for 3.6 and LF/HF communication equipment.
3.12 ATC Approach Control Communications	Same as for 3.3.	Same as for 3.3.	Same as for 3.3.
3.13 Final Approach Communications	Same as for 3.3.	Same as for 3.3.	Same as for 3.3.

Table 1. Summary of Implementation Concepts (Continued)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
3.14 Destination Ground Handling Communications	Same as for 3.1.	Same as for 3.1.	Same as for 3.1.
3.15 Visual Traffic Vigilance	All crew members not otherwise occupied scan the area within the proximity of the aircraft in an effort to avoid any conflicting traffic.	It is assumed that the standard procedure of maintaining visual traffic vigilance by all crew members not occupied with other performance tasks which would preclude their participation will be continued in the cockpit of the SST.	Same as for the automatic implementation concept.
4.1 Engine Start and Checkout	Using a checklist as a guide, the crew manually performs the engine start and the subsequent checkout.	The crew would manually start the engines, but would utilize a computer to assist in the checkout.	Same as for the current implementation concept.
4.2 Thrust Application = F (Surface Speed) - Taxi	Manual throttling.	Manual throttling.	Manual throttling.
4.3 Thrust Application = F (Maximum Power) - Take-off Thrust	Same as for 4.2.	Same as for 4.2	Same as for 4.2.
4.4 Thrust Application = F (Surface Speed) - Thrust Reversal	Manual throttling (thrust reverser levers activated).	Manual throttling (thrust reverser levers activated).	Manual throttling (thrust reverser levers activated).
4.5 Thrust Application = F (Noise Abatement) (V_2, PNdb)	Same as for 4.2.	Same as for 4.2.	Same as for 4.2.
4.6 Thrust Application = F (Optimum Maneuver Speed) - Initial Climb	Same as for 4.2.	Auto-throttle.	Same as for 4.2.
4.7 Thrust Application = F (Optimum Maneuver Speed) - Subsonic Climb	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.
4.8 Thrust Application = F (Sonic Barrier Penetration) - Transonic Acceleration	Not applicable.	Same as for 4.6.	Same as for 4.2.
4.9 Thrust Application = F (Optimum Air Speed) Supersonic Climb	Not applicable.	Same as for 4.6.	Manual fuel control.

Table 1. Summary of Implementation Concepts (Continued)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
4.10 Thrust Application = F (Transition to Cruise)	Same as for 4.2.	Same as for 4.6.	Same as for 4.9.
4.11 Thrust Application = F (Constant Mach 3.0) - Cruise	Same as for 4.2.	Same as for 4.6.	Same as for 4.9.
4.12 Thrust Application = F (Optimum Air Speed) - Deceleration/Descent	Same as for 4.2.	Same as for 4.6.	Same as for 4.9.
4.13 Thrust Application = F (Sound Barrier Penetration) - Decelerating	Not applicable	Same as for 4.6.	Same as for 4.2.
4.14 Thrust Application = F (Optimum Maneuver Speed) - Subsonic Maneuvering	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.
4.15 Thrust Application = F (Optimum Maneuver Speed) - Let Down	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.
4.16 Thrust Application = F (Optimum Maneuver Speed) - Level Off	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.
4.17 Thrust Application = F (Optimum Maneuver Speed) - Initial Approach	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.
4.18 Thrust Application = F (Optimum Maneuver Speed) - Final Approach	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.
4.19 Thrust Application = F (Maximum Power) - Missed Approach	Same as for 4.2.	Same as for 4.2.	Same as for 4.2.
4.20 Thrust Application = F (Flare Execution)	Same as for 4.2.	Same as for 4.6.	Same as for 4.2.

Table 1. Summary of Implementation Concepts (Continued)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
4.21 Thrust Application = F (Surface Speed) - Thrust Reversal for Braking	Manual throttling (thrust reverser levers activated).	Manual throttling (thrust reverser levers activated).	Manual throttling (thrust reverser levers activated).
4.22 Thrust Application = F (Surface Speed) - Taxi to Line	Manual throttling.	Manual throttling.	Manual throttling.
4.23 Accomplish Power Plant System Deactivation	Using a checklist as a guide, the crew manually performs the power plant deactivation and the subsequent checkout.	The crew would manually deactivate the power plant system, but would utilize a computer to assist in the checkout.	Same as for the current implementation concept.
5.1 Taxi from Line	The portion of the flight control system which is utilized by the crew is the nose-wheel steering and/or differential braking.	The implementation will be the same as is currently employed.	Same as for the current implementation concept.
5.2 Initial Roll Control - Take-off	The crew utilizes the nose-wheel steering system and the rudder/aileron system to control the aircraft during the take-off roll. It can also utilize differential braking to assist in the directional control.	Same as for the current implementation concept.	Same as for the current implementation concept.
5.3 Take-off Abort Control	Same as for 5.2.	Same as for 5.2.	Same as for 5.2.
5.4 Take-off Control - Rotation, Configuration Change	Elevator/rudder/aileron system.	Elevator/rudder/aileron system.	Elevator/rudder/aileron system.
5.5 Initial Climb Control - Initial Portion of Standard Instrument Departure	Elevator/rudder/aileron system.	Same as for 5.4.	Same as for 5.4.
5.6 Subsonic Climb Maneuvering	Same as for 5.4, and the linkage of the autopilot may be utilized to maintain a specific attitude.	Autopilot (computer coupled).	Same as for the current implementation concept.
5.7 Transonic Acceleration Control	Not applicable.	Same as for 5.6.	Same as for 5.6.
5.8 Supersonic Climb Control	Not applicable.	Same as for 5.6.	Same as for 5.6.
5.9 Transition to Cruise	Same as for 5.6.	Same as for 5.6.	Same as for 5.6.

Table 1. Summary of Implementation Concepts (Continued)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
5.10 Cruise Control	Autopilot or the basic control system.	Autopilot (computer coupled).	Same as for the current implementation concept.
5.11 Supersonic Descent Control	Not applicable.	Same as for 5.10.	Same as for 5.10.
5.12 Transonic Descent Control	Not applicable.	Same as for 5.10.	Same as for 5.10.
5.13 Subsonic Descent Control	Same as for 5.10.	Same as for 5.10.	Same as for 5.10.
5.14 Let Down Control	Basic control system, speed brakes/spoilers and autopilot (linkage only).	Same as for 5.10.	Same as for the current implementation concept.
5.15 Level Off Maneuver	Same as for 5.10.	Same as for 5.10.	Same as for 5.10.
5.16 Initial Approach Control	Same as for 5.10.	Basic control system or the autopilot system (manual mode).	Same as for 5.10.
5.17 Final Approach Control	Basic control system.	Autopilot/coupler (landing system).	Same as for the current implementation concept.
5.18 Missed Approach Execution Control Operations	Same as for 5.17.	Same as for the current implementation concept.	Same as for 5.17.
5.19 Flare Maneuver Execution	Same as for 5.17.	Same as for 5.17.	Same as for 5.17.
5.20 Rollout Control	Nose-wheel steering, rudder/aileron system, or differential braking.	Same as for 5.17.	Same as for the current implementation concept.
5.21 Taxi to Line	Nose-wheel steering/differential braking.	Same as for the current implementation concept.	Same as for the current implementation concept
6.1 Duct System Configuration for Supersonic Climb	Not applicable.	Automatic control system.	Automatic control system.
6.2 Duct System Configuration for Transition to Cruise	Not applicable.	Same as for 6.1.	Same as for 6.1.

Table 1. Summary of Implementation Concepts (Continued)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
6.3 Duct System Reconfigured as Required	Not applicable.	Automatic control system.	Same as for automatic implementation concept.
6.4 Duct System Configuration for Supersonic Descent Operations	Not applicable.	Same as for 6.3.	Same as for 6.3.
6.5 Duct System Configuration for Transonic Deceleration/Descent	Not applicable.	Same as for 6.3.	Same as for 6.3.
6.6 Duct System Reconfiguration for Subsonic Operations	Not applicable.	Same as for 6.3.	Same as for 6.3.
7.1 Maintain Take-off Flight Path	Basic navigation sensors/displays.	Basic navigation sensors/displays.	Basic navigation sensors/displays.
7.2 Maintain Flight Path for Standard Instrument Departure (SID)	Basic navigation sensors/displays, and published placards.	Automated, integrated navigation system.	Same as for current implementation concept.
7.3 Monitor Enroute Weather Conditions	Basic weather sensors and communication system.	Automated, integrated navigation system.	Same as for current implementation concept.
7.4 Monitor Destination and Alternate Weather	Communication system to receive updated forecasts.	Automated navigation system/and data link.	Same as the current implementation concept.
7.5 Provide Differential in Forecast/Actual Weather Conditions	Manually compare forecasted weather phenomena with that actually encountered and assess the effects on the flight.	Computerized solutions.	Comparison of actual to forecast conditions by manual means (lowered standard).
7.6 Calculation of Overpressure being Generated	Not applicable.	Computerized solutions.	Computerized solutions (manual monitoring).
7.7 Internal System Position Generation	Currently doppler radar systems and some inertial systems are being utilized.	Duplex/triplex inertial navigation systems; Duplex/triplex doppler; or Hybrids.	Same as for the automated system but with manual monitoring.
7.8 External System Position Generation	Ground-equipment-generated fix, hyperbolic systems such as LORAN; celestial navigation techniques.	Automated Hyperbolic system; automated bearing/triangulation system; ground-equipment-generated fix.	Same as the automated system, but with manual monitoring.

Table 1. Summary of Implementation Concepts (Concluded)

FUNCTION	CURRENT IMPLEMENTATION	SST AUTOMATIC IMPLEMENTATION	SST MANUAL IMPLEMENTATION
7.9 Present Position Updating	Internally generated position fixes are updated periodically by manually deriving an external fix.	Computerized updating.	Temporary storage and interrogation devices.
7.10 ETA Prediction	Airspeed/distance calculations provide a rough estimate.	Computerized solutions.	Manually generated ETA's.
7.11 Optimum Profile Generation	Not applicable.	Computerized solutions.	Crew-controlled profile optimization.
7.12 Maintain Flight Path for Standard Instrument Approach (SIA)	Basic navigation sensors/displays, and published placards.	Automated navigation system.	Conventional (current jet) techniques.
7.13 Maintain Flight Path for All Weather Landing	Instrument landing system coupled approaches are providing a lower minima landing approach.	Automated "all weather" landing system.	Same as for the current implementation concept, or visual inputs (contact flying conditions).

2.0 CREW WORKLOAD ANALYSIS

Once concepts for functions implementation were delineated in terms of automatic and manual feasibility, the next step was the application of an analytical technique designed to define the specific human performance requirements in terms of workload. The objectives of this analysis were as follows:

1. Specification of the maximum human performance required at any instant during an SST flight profile, assuming a design incorporating the most feasible automation scheme as specified in each function description, and assuming no malfunctions;
2. Specification of the maximum human performance required at any instant during an SST flight profile, assuming a design incorporating the most feasible manual implementation scheme as specified in each function description, and assuming no malfunctions;
3. Specification of the maximum human performance required as would be occasioned by a reasonable and logical distribution of system failures in a typical SST operation;

To satisfy the objectives of this portion of the work effort, the following steps were taken:

1. The SST functions were ordered along a time-base line indicative of a normal SST flight profile.

2. A scheme for rating the restrictiveness of each required element of human performance was derived and implemented. Section 2.1 describes this scheme and shows the results of the implementation in terms of the product which was used to indicate the relative restrictiveness values in each SST function.

3. The most feasible automation scheme, as defined by the functions analysis, was examined in terms of human performance restrictiveness for each function as it occurred along the SST profile time-base. Section 2.2 shows how this application was made, indicates the results in graphic form, and contains a rationale for the ratings.

4. Item 3 above was duplicated for the most feasible manual implementation scheme as defined by the functions analysis. Section 2.3 contains the results of this effort.

2.1 CREW WORKLOAD MEASUREMENT

The development of a cumulative workload profile, which would indicate total human performance requirements at any instant in a given SST flight operation, first required that each SST function be ordered along a time base commensurate with an appropriate flight profile. The purpose of this ordering is to indicate finite points in time representative of function initiation time, duration, and completion time. This permits the analysts to consider any weighting or value, for example, associated with the human performance required by that function, over the appropriate time interval.

The flight profile developed in the first report of this study (ref. 1), and included in the introductory section of this report, was utilized in preparing the time based analysis. This analysis assumes that time begins with the crew "at stations" in the cockpit, and further assumes that pre-engine start system checkout activities will be required. The profile concludes with checkout activity associated with system deactivation. It is emphasized that this profile is a representation of what might be typical, and it is recognized that both total time, and time in given flight phases, may vary considerably due to different SST configurations, variations in standard-day atmospheric conditions, and so forth. However, the net effect will simply be a shortening or lengthening of the time base associated with a given phase, and as a result, a like increase or decrease in the period over which a given function occurs. Since the phases do not overlap, there will be little appreciable effect on the instantaneous workload values. The function time base was developed to show initiation time, duration, and completion time. A graphic representation of this time base, per se, is not included herein. However, one may be easily inferred from Figure 3 and/or 4.

The next step in the development of the cumulative workload profile was to derive a scheme which would permit reasonable and logical assignment of numerical values to each function. These values would be indicative of an appropriate measure of the human performance inherent in the function performance. Consistent with time constraints and scope of the contractual effort, it was decided that a single measure would be employed, i. e., "restrictiveness." Restrictiveness was defined as the degree or extent of preoccupation with a given performance element, to the exclusion of concurrent concerted effort on any other given performance element. The rationale, in simple context, is based on the argument that the human performance inherent in the accomplishment of any function can be characterized by a relative measure of the degree or extent of concentration required by the humans involved. Degree or extent of concentration included consideration of man's capabilities and limitations in terms of his cognitive, motor, and perceptual processes.

In order to obtain more objective ratings and to provide for consistency and applicability of the performance-weighting task, the restrictiveness scale was developed to the extent possible on the basis of questionnaire data. Questionnaires were developed and distributed among airline personnel from both domestic and international carriers (including foreign carriers). These questionnaires consisted of statements describing tasks performed in the cockpit on current subsonic jets. Pilot, copilot, and navigator personnel were requested to rate each task on a five-point scale of restrictiveness, i. e., (1) non-restrictive, (2) lightly restrictive, (3) moderately restrictive, (4) severely restrictive, and (5) completely restrictive. Other questions deemed pertinent were also included in the questionnaire, e. g., the nominal time associated with individual task performance under normal conditions. The outgrowth of this data collection is shown in Table 2. Details on the data collection process are discussed in Appendix III. An explanation of each column shown in Table 2 follows:

Column 1:	A statement of the task the airline personnel were requested to rate on the five-point restrictiveness scale. Tasks P1 through P27 appeared on one version of the questionnaire and were distributed among pilot/ copilot personnel of several commercial jet operators. Tasks N1 through N17 appeared on another version of the questionnaire which was distributed among pilot/ navigator and specialist navigator personnel of several commercial jet operators.
Column 2: $\overline{R}$	The average restrictiveness value obtained by a straight averaging process.
Column 3: No. D. P.	The number of questionnaires returned which reflected a valid, or usable, answer, and hence the number of data points included in the average value.

Table 2. Current Jet Tasks and Restrictiveness Values for Workload Scaling.

Task No.		$\bar{R}$	No. D. P.	R Range Min.	Max.	$\bar{T}$	No. D. P.	T Range Min.	Max.
P1.	Predict fuel over destination.	2.29	31	1	5	1'15"	30	0.16	3
P2.	Verify ETA validity.	2.18	31	1	4	1'04"	29	0.05	3
P3.	Receive, copy and verify ATC clearances or revisions.	3.17	30	1	5	1'04"	28	0.25	3
P4.	Intercom announcement.	2.72	32	1	5	1'15"	26	0.033	3
P5.	Claculate wind velocity and relative bearing.	2.82	30	1	5	1'12"	27	0.25	4
P6.	Calculate drift and ground speed.	2.03	30	1	5	1'11"	28	0.033	4
P7.	Evaluate aircraft speed vs. runway remaining on take-off for take-off/abort decision.	2.45	29	1	5	0'14"	19	0.016	1
P8.	Fly one minute holding pattern without use of autopilot.	2.81	32	1	5	3'40"	13	1	4.5
P9.	Fly one minute holding pattern using autopilot COURSE-HOLD.	2.25	32	1	3	3'38"	12	1	4.5
P10.	Fly a standard instrument departure manually.	2.84	32	1	4	5'22"	11	3	10
P11.	Fly a standard instrument departure using autopilot COURSE-HOLD.	2.52	31	1	4	5'24"	10	3	10
P12.	Fly standard instrument approach manually.	3.44	32	1	5	5'05"	18	2	10
P13.	Fly standard instrument approach using autopilot COURSE-HOLD.	3.06	32	1	5	5'05"	13	2	10
P14.	Fly ILS final approach manually.	3.59	32	1	5	3'32"	13	2	5
P15.	Fly ILS final approach using autopilot coupler.	3.19	32	1	5	3'45"	12	2	5
P16.	Maintain runway centerline and wings level attitude during take-off roll.	3.19	32	1	5	0'50"	12	0.5	1.5
P17.	Perform pre-descent check.	2.27	30	1	5	0'35"	19	0.16	1.5
P18.	Reconfigure aircraft for landing (flaps, spoilers, gear, etc.)	2.23	31	1	4	1'01"	13	0.05	4
P19.	Maintain constant MACH cruise speed.	1.70	30	1	4	0'24"	*5	0.08	1
P20.	Monitor engine performance instruments during take-off.	2.55	29	1	5	0'38"	11	0.05	1
P21.	Verify VOR station identification.	2.13	31	1	5	0'16"	18	0.05	0.5
P22.	Maintain cognizance of enroute weather conditions via all cockpit instrumentation (radar, temperature guages, etc.)	2.19	31	1	4	0'49"	*6	0.05	2
P23.	Vectoring aircraft through storm, using airborne weather radar.	3.30	30	1	5	4'28"	*6	0.25	10
P24.	Monitor communications to other aircraft in terminal area.	2.63	32	1	4	2'47"	*4	0.16	10
P25.	Monitor autopilot operation at cruise.	1.47	32	1	2	2'08"	*5	0.033	10
P26.	Maintain altitude control in moderate to severe turbulence.	3.87	31	2	5	4'08"	*4	0.5	10
P27.	Maintain obstruction and other traffic clearance from parking area to operational runway.	2.91	32	1	5	3'53"	*8	1	5
N1.	Obtain position fix by means of standard hyperbolic system.	3.94	33	2	5	2'36"	30	0.5	5
N2.	Obtain position fix by means of celestial techniques.	4.45	38	2	5	11'01"	35	5	18
N3.	Perform airborne compass alignment check via celestial techniques.	3.95	38	2	5	2'43"	35	0.5	10
N4.	Unslave gyro compass and align for "free gyro mode" operation.	3.67	31	1	5	2'26"	26	0.12	8
N5.	Obtain position fix by means of short range point-source system.	2.75	32	1	5	1'47"	32	0.25	12
N6.	Verify the validity of the destination ETA.	3.16	32	1	5	1'44"	32	0.33	11
N7.	Calculate wind velocity and relative bearing.	3.24	37	1	5	2'34"	33	0.33	30
N8.	Calculate drift and ground speed.	2.76	37	1	5	1'46"	27	0.33	11
N9.	Pre-set and reset destination coordinates in self-contained navigation system.	3.60	*5	2	5	0'58"	*5	0.33	2
N10.	Determine course to steer.	3.22	37	1	5	1'30"	32	0.25	10
N11.	Maintain geographic plot of navigational situation.	3.24	37	1	5	1'30"	32	0.16	11
N12.	Calculate initial point of turn to minimize cross track error following turn.	3.30	26	1	5	1'20"	22	0.25	3
N13.	Derive navigational data to modify flight plan for storm avoidance.	3.30	26	1	5	2'36"	18	0.16	6
N14.	Predict fuel over destination.	3.00	22	1	5	1'57"	21	0.5	8
N15.	Derive doppler bias error.	3.00	10	1	5	2'02"	10	0.5	4
N16.	Maintain cognizance of enroute weather conditions via all cockpit instrumentation.	2.13	23	1	3	1'52"	15	0.5	5
N17.	Determine self-combined navigation system accuracy following a maneuver requiring memory operation.	3.57	*7	1	5	2'26"	*7	0.25	6.25

*Minimal Data

Columns 4 and 5: R Range min/max	The minimum and maximum restrictiveness value range, respectively, assigned to that task on any on of the questionnaires utilized to obtain the average value.
Column 6: $\overline{T}$	A straight average of the nominal time-to-perform values assigned on each questionnaire.
Column 7: No. D. P.	The number of questionnaires returned which reflecte a valid, or usable, time estimate, and hence the num ber of data points included in the average time value.
Columns 8 and 9: T Range min/max	The minimum and maximum time value range, respe tively, shown as nominal time-to-perform under norn operating conditions, and assigned to that task on any one of the questionnaires utilized to obtain the average value. Units are tens of minutes, minutes, tenths of minutes, hundredths of minutes.

These data were utilized to assess each SST function in terms of restrictiveness. It was the job of the participating analysts to consider the human performance requirements inherent in the accomplishment of each SST function and to identify a reasonable and logical correlation among those tasks listed in Table 2.

As the restrictiveness assessment proceeded, it was found necessary to develop some additional restrictiveness values in the form of "procedure rules." Brief statements of these rules follow:

Rule 1: All checkouts performed manually, rate 5.0 restrictiveness. The burden of determining the rightness/wrongness of system operation rests entirely upon the crew's perception of the appropriate cues. Automatic checkout assumes some machine assistance in this area.

Rule 2: Any function occurring during the "take-off-climbout" phase, and the "descent-landing" phase of SST operations, which involves a combination of tracking with any one or more of the higher order cognitive processes, e. g., problem solving, concept formations, etc., rates 5.0 restrictiveness, if the function is performed manually.

Rule 3: Button-pushing and switch flicking, not serially as in a checkout procedure, rate 1.0.

Rule 4: For any automated function during cruise where no crew member is directly involved except in monitoring, "not applicable" should be entered. Where computer-monitoring with alarm excitation is assumed, scale task P25 ($\bar{R} = 1.47$) should be the standard entry to denote "sampling monitoring." Where computer-monitoring is not assumed, critical parameter monitoring (single parameter) is rated by scale task P19 ($\bar{R} = 1.70$), and multiparameter monitoring is rated by scale task P20 ($\bar{R} = 2.55$).

Rule 5: Any discrete, automated function occurring during enroute operations, for which an error of commission and/or omission in the monitoring performance required, could result in a potential safety hazard, is rated 5.0 in restrictiveness.

Rule 6: Direct inclusion of man as a component part of any servo-loop, either null-seeking or error-bounding is rated as 5.0 for the duration of the function.

2.2 SST WORKLOAD (AUTOMATIC FEASIBILITY)

This section contains the results of the SST function restrictiveness assessment for the most feasible degree of automation. Each function was examined to determine the human performance inherent in function accomplishment via the most feasible automatic implementation concepts (where applicable, alternatives were considered). This performance was (a) likened to an appropriate current jet task from Table 2 and judged as to its similarity in terms of relevant cognitive, motor, and sensory components, and assigned the restrictiveness value for that task, or (b) judged to be of such a nature that one or more of the procedure rules was applicable and a restrictiveness value assigned accordingly

Table A1 in Appendix I contains the intermediate results of the restrictiveness assessment for each function. Initiation time, duration, and completion time for function performance are also contained in Table A1. Figure 3 shows the cumulative effects on instantaneous values at any point in time during a typical SST flight profile. The cumulative workload profile was actually prepared by plotting out all of the data in Table A1 and summing it up geometrically. The left-hand scale is the "Total Restrictiveness" value. Restrictiveness was summed every 30 seconds to develop the profile. Where alternative means were rated, the worst-case rating was included in the cumulative totals.

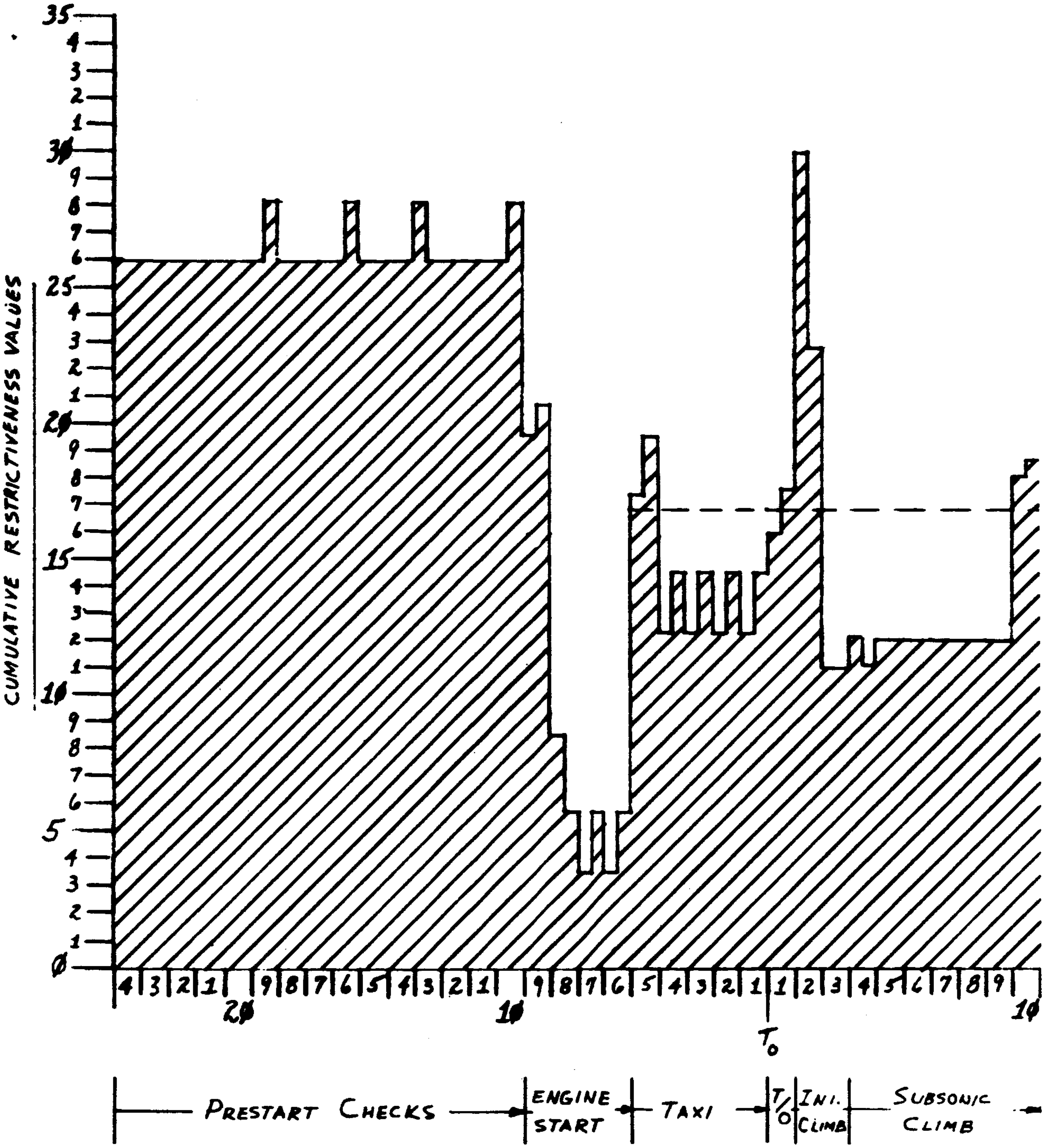


Figure 3. SST Crew Maximum Workload with Automated Implementation Concept

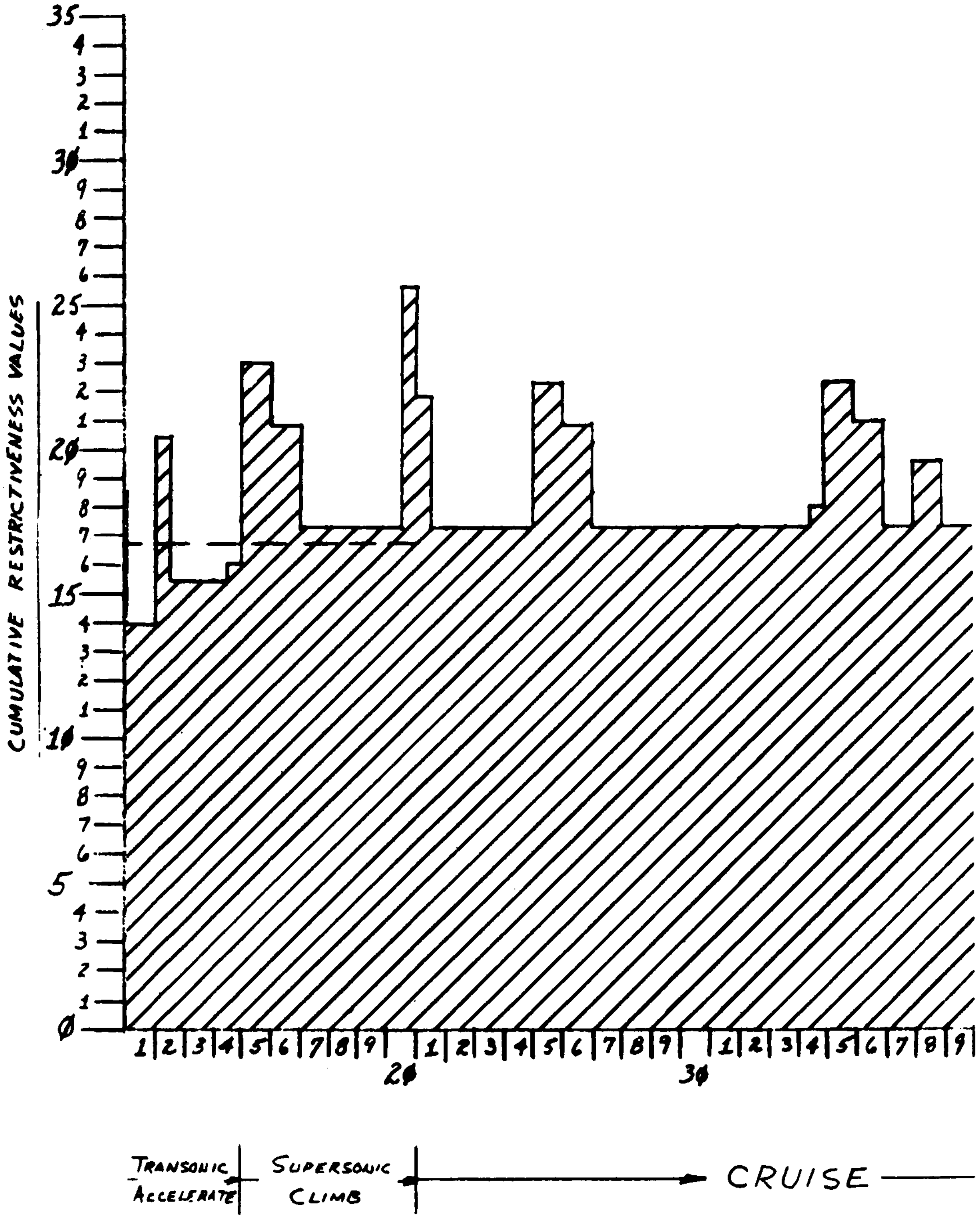
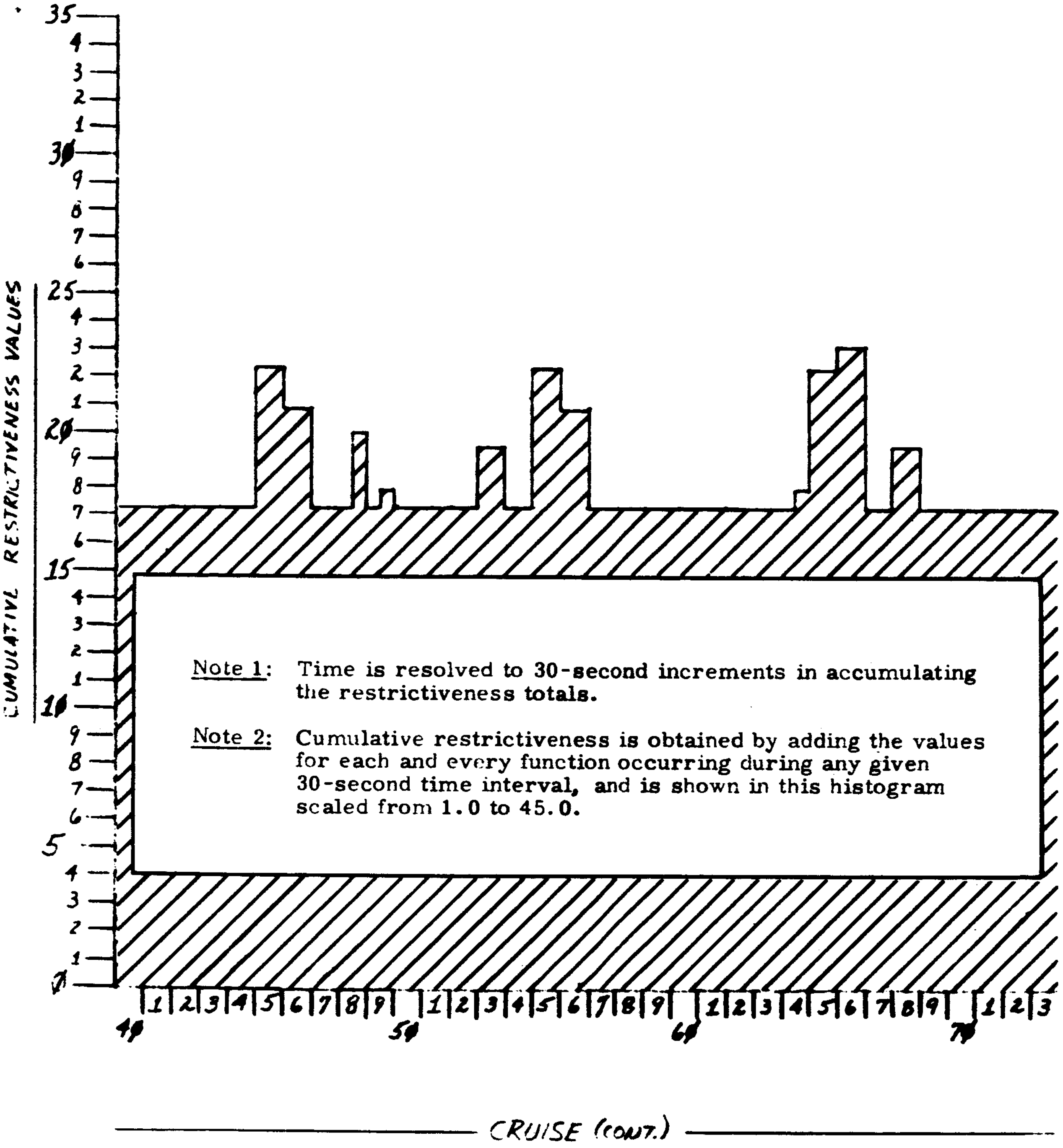


Figure 3 (Continued)



Note 1: Time is resolved to 30-second increments in accumulating the restrictiveness totals.

Note 2: Cumulative restrictiveness is obtained by adding the values for each and every function occurring during any given 30-second time interval, and is shown in this histogram scaled from 1.0 to 45.0.

Figure 3 (Continued)

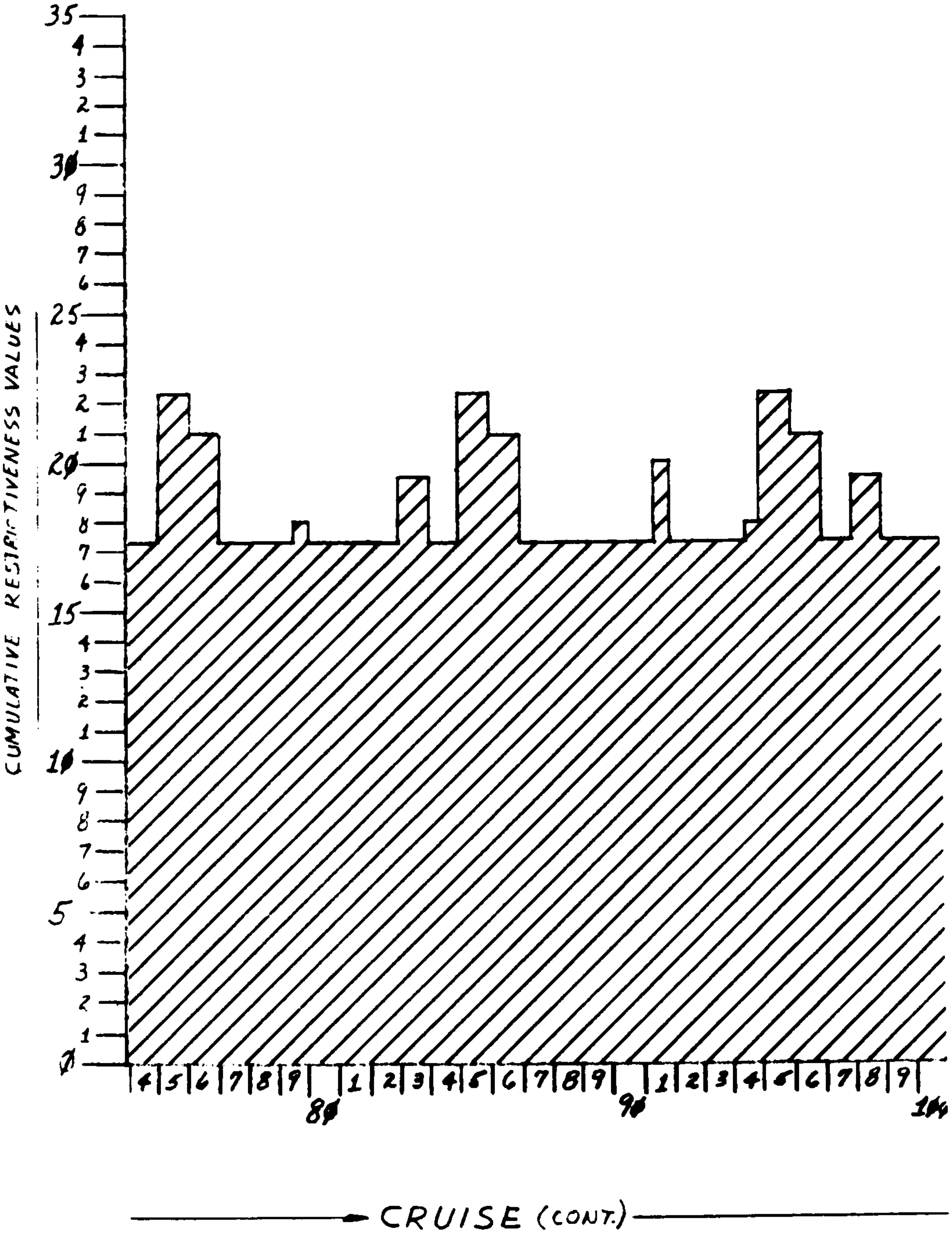


Figure 3 (Continued)

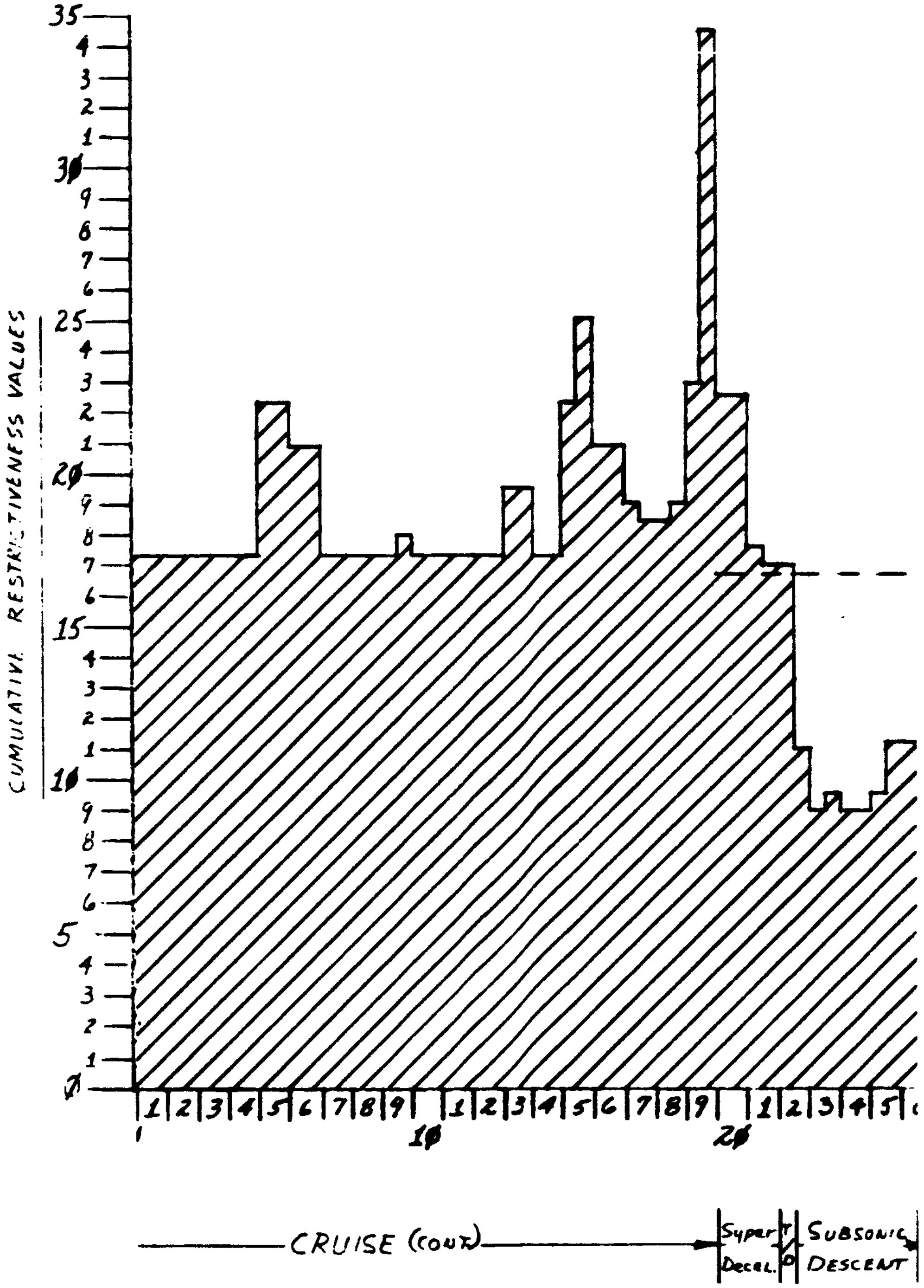


Figure 3 (Continued)

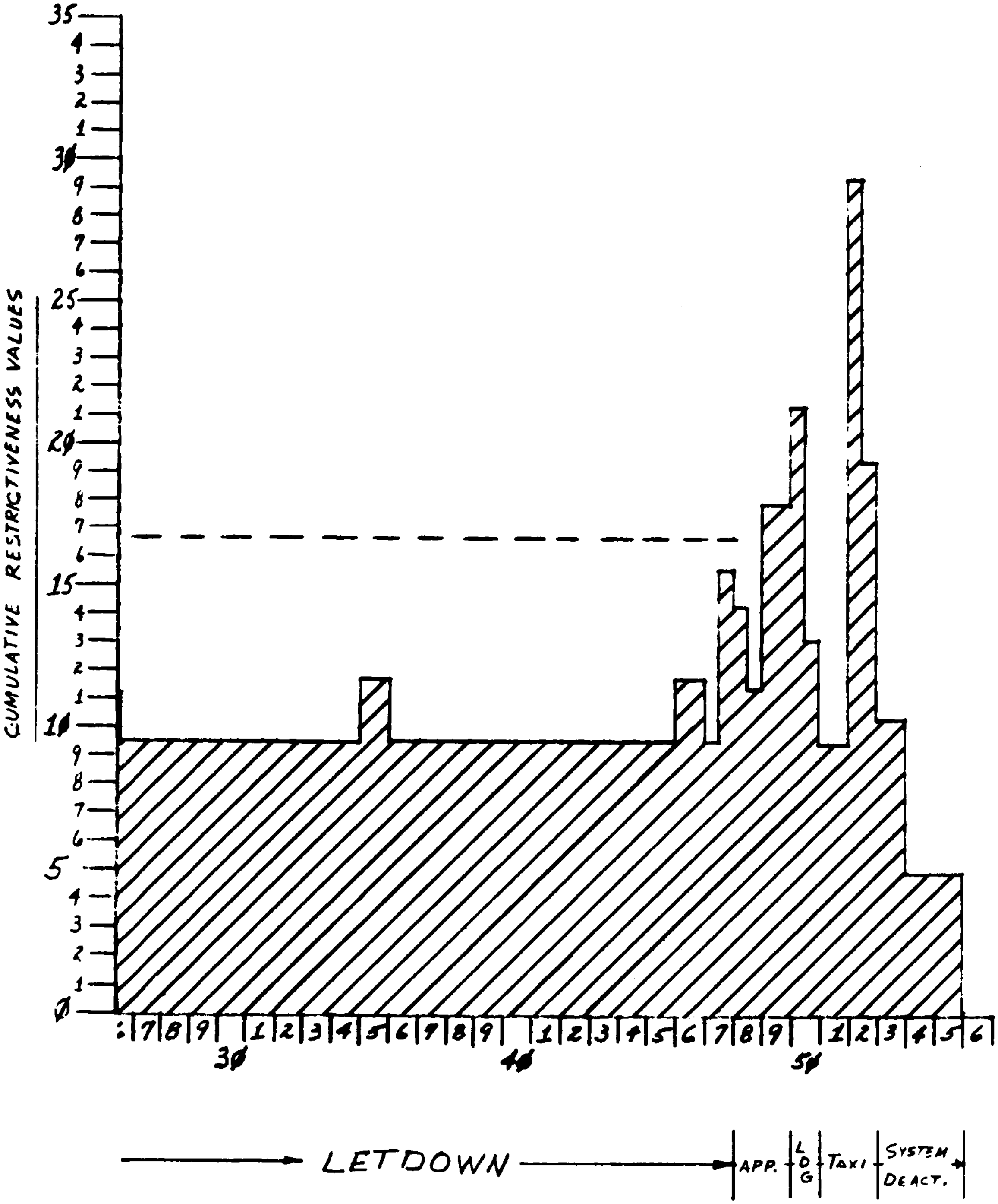


Figure 3 (Continued)

It will be noted that Function 3.15, "Visual Traffic Vigilance," does not reflect a specific weighting factor. This is due to our assumption that all "eyes" not preoccupied with accomplishment of any other specific function will be participating in the performance of this function. A dotted line has been shown at the bottom of Figure 3, in the cumulative workload profile. This dotted line is plotted at the average workload value, over the duration times of Function 3.15. The conclusion is drawn that at any time the workload over those periods indicated is less than the average value, the difference will be employed in accomplishing Function 3.15 performance requirements.

2.3 SST WORKLOAD (MANUAL FEASIBILITY)

This section contains the results of the SST function restrictiveness assessment for the most feasible degree of manual implementation visualized under each specific function. However, this must be qualified by defining "feasible manual implementation" as the extent of function accomplishment by manual methods which provides adequate system performance such that the SST can complete its flight in the supersonic speed regime. In the event the SST should abort the flight, or continue the flight after returning to the subsonic speed regime, this workload analysis would not be applicable.

The same analytical procedure discussed in section 2.2 was utilized in this effort. Table A2 of Appendix I contains all the data used in preparing the cumulative workload for SST feasible manual implementation concepts. The same rules of procedure and columnar entry definitions used in preparing Table A1 are applicable to Table A2. The same rules apply in this case as in the automated feasibility case. And, where manual implementation is not considered an alternative, the table entry will reflect the automated means envisioned and the appropriate weighting factors. Where alternative means were rated, the worst-case rating was included in the cumulative totals. The discussion of Function 3.15 included in section 2.2 is also applicable in this analysis.

Figure 4 shows the results of this analysis in the same manner as the automated feasibility profile.

2.4 RESULTS

A crew workload index, reflecting the degree of restrictiveness or attention required of the crew member in task performance, was developed and applied to the derivation of workload profiles for both automated and manual implementation concepts for SST operational functions.

When the most automatic implementation concepts were used, assuming that peak restrictiveness values could be smoothed by appropriate distribution of workload among crew members or design of operational procedures, the estimated workload distribution requires the full time and attention of a three-man crew, i.e., no allowance is included for crew relief, non-routine task requirements, or growth potential.

When the most manual function implementation concepts were assumed the results indicated an average load factor exceeding the capabilities of a six-man crew.

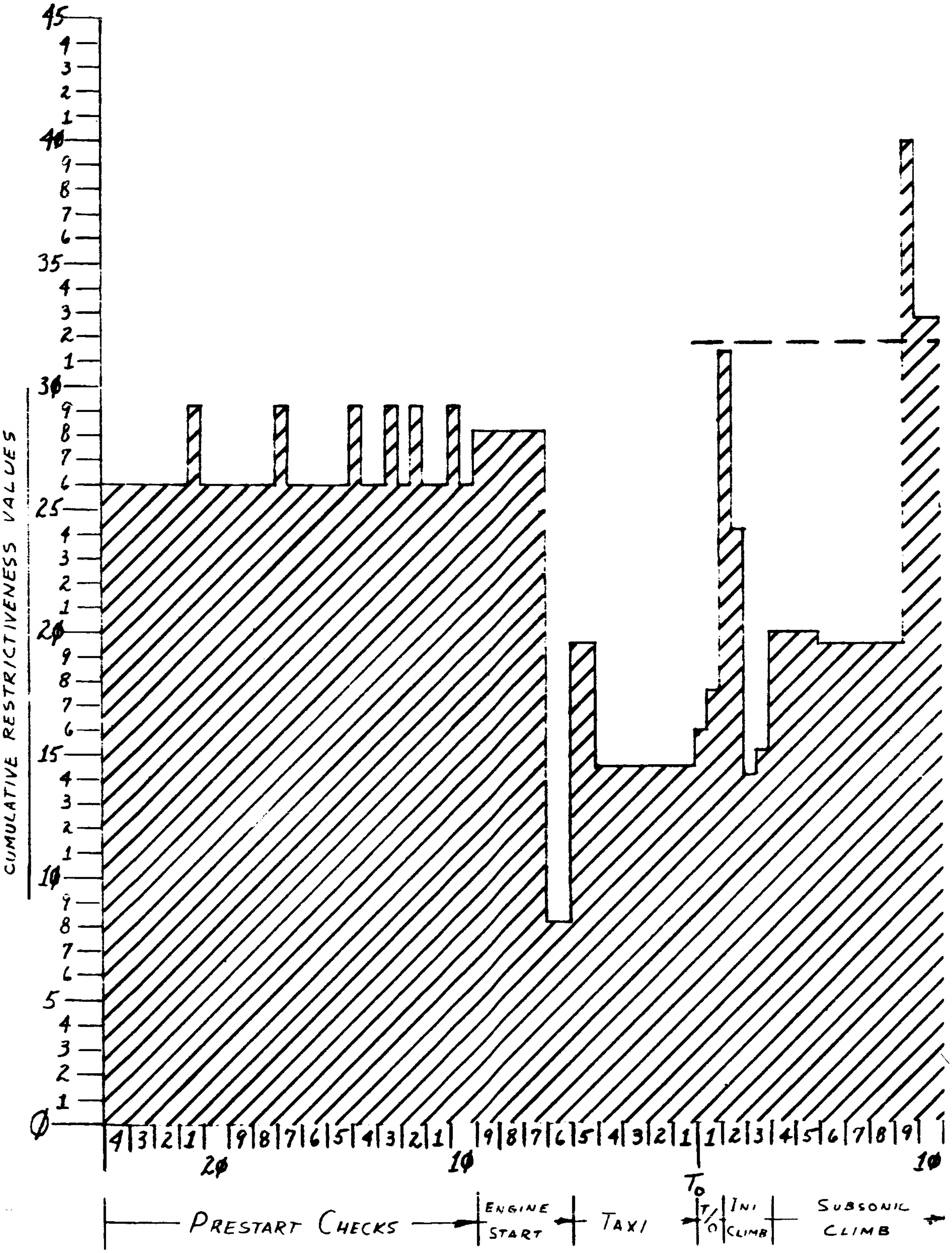


Figure 4. SST Crew Maximum Workload with Manual Implementation Concept

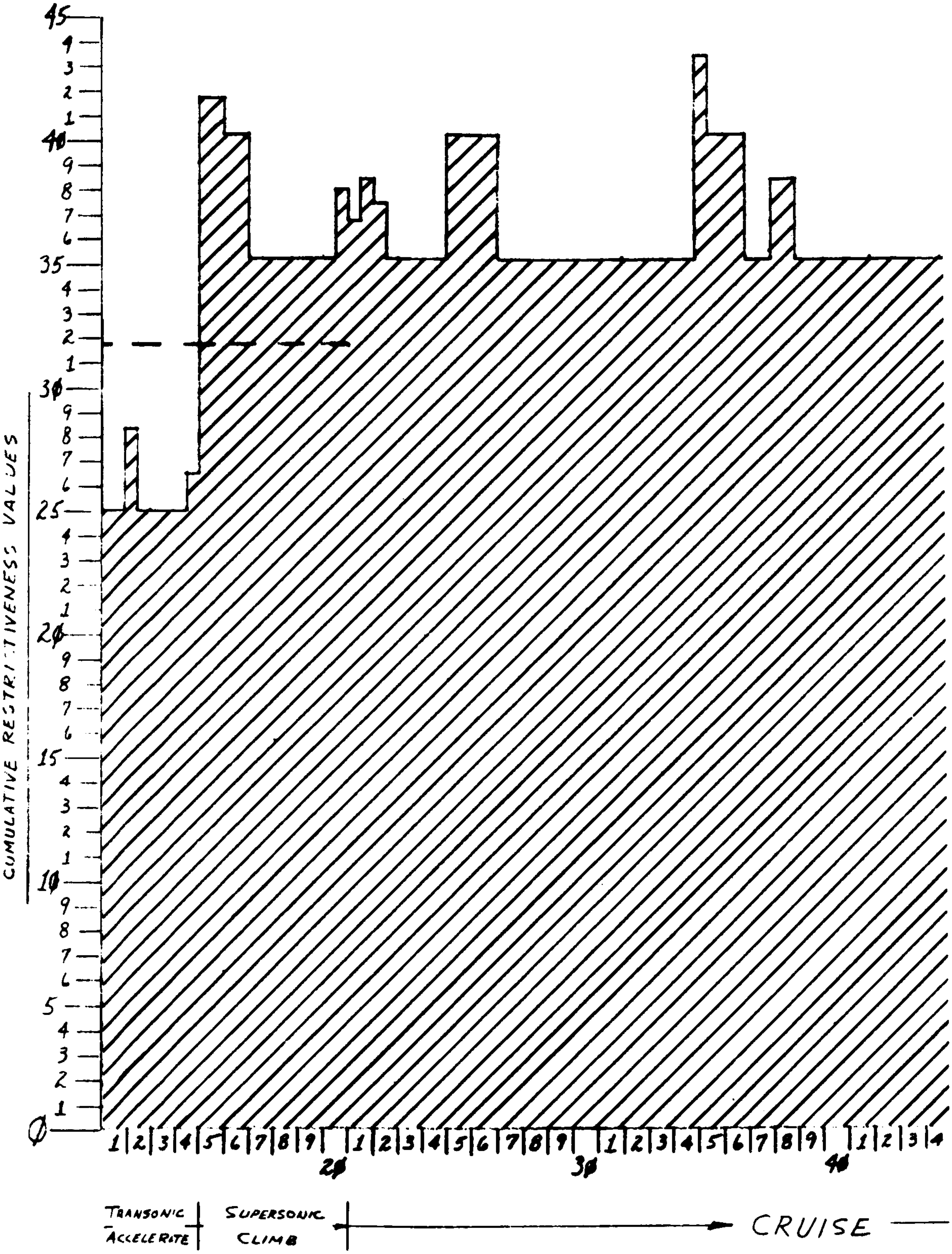
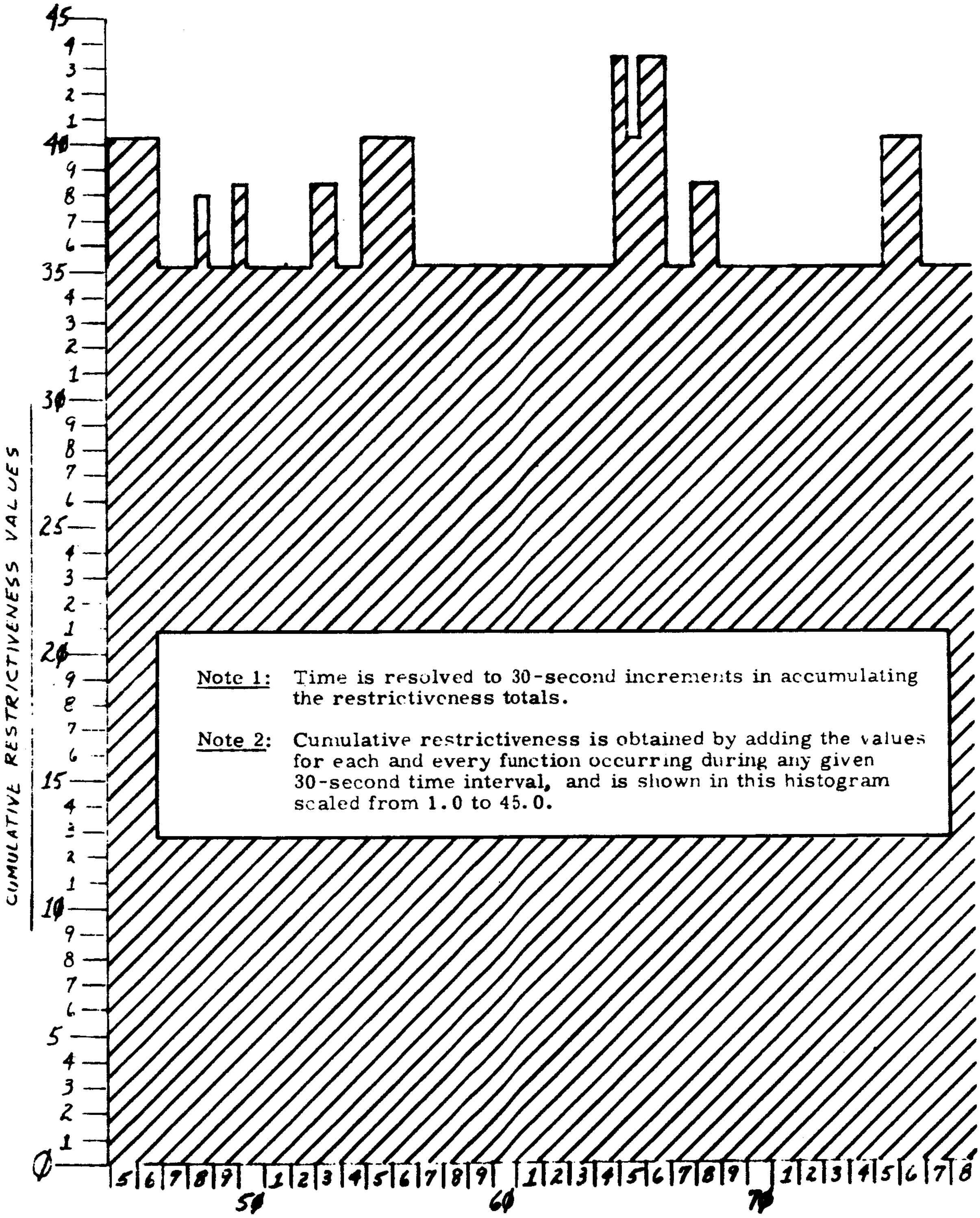


Figure 4 (Continued)



Note 1: Time is resolved to 30-second increments in accumulating the restrictiveness totals.

Note 2: Cumulative restrictiveness is obtained by adding the values for each and every function occurring during any given 30-second time interval, and is shown in this histogram scaled from 1.0 to 45.0.

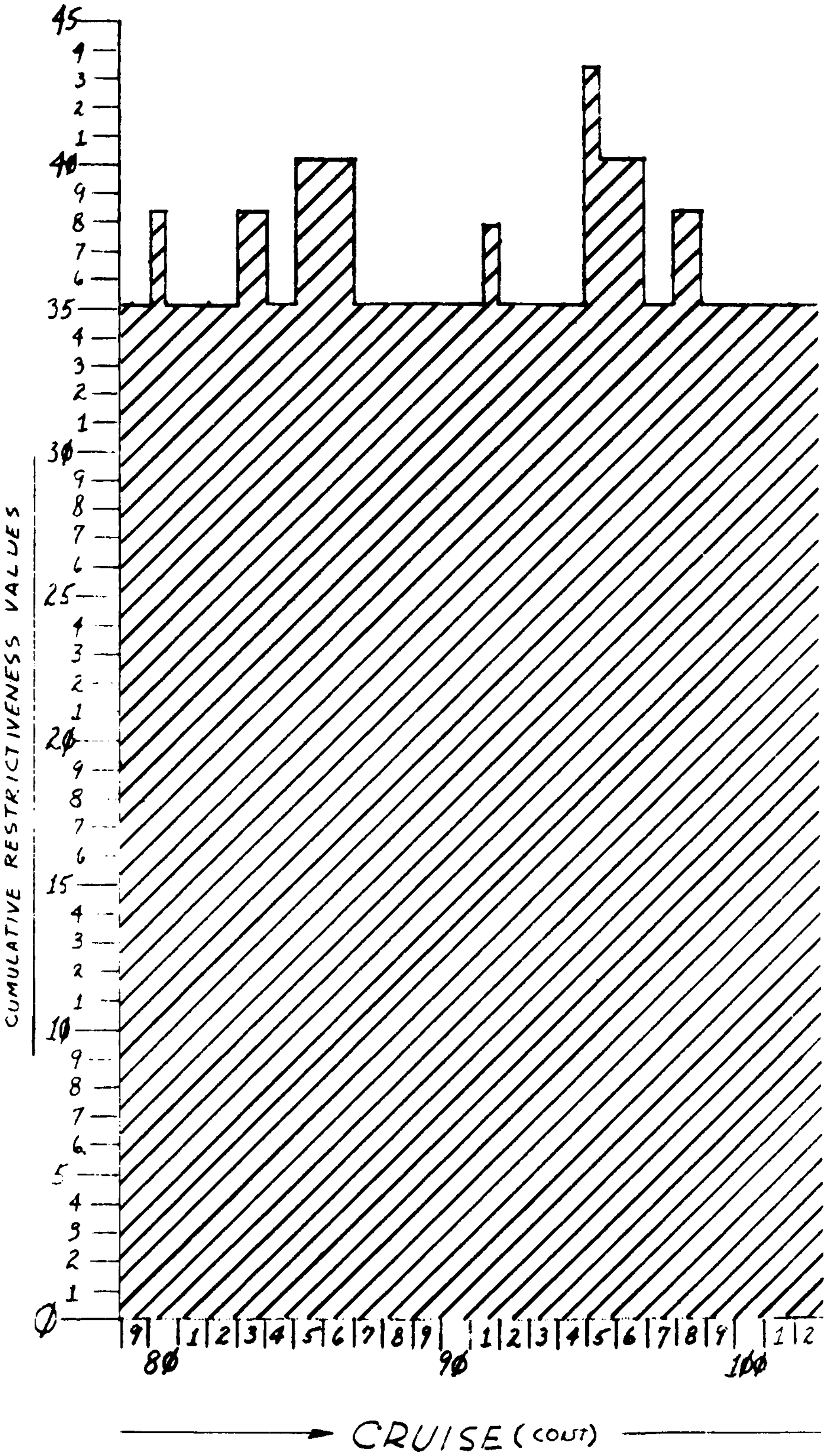


Figure 4 (Continued)

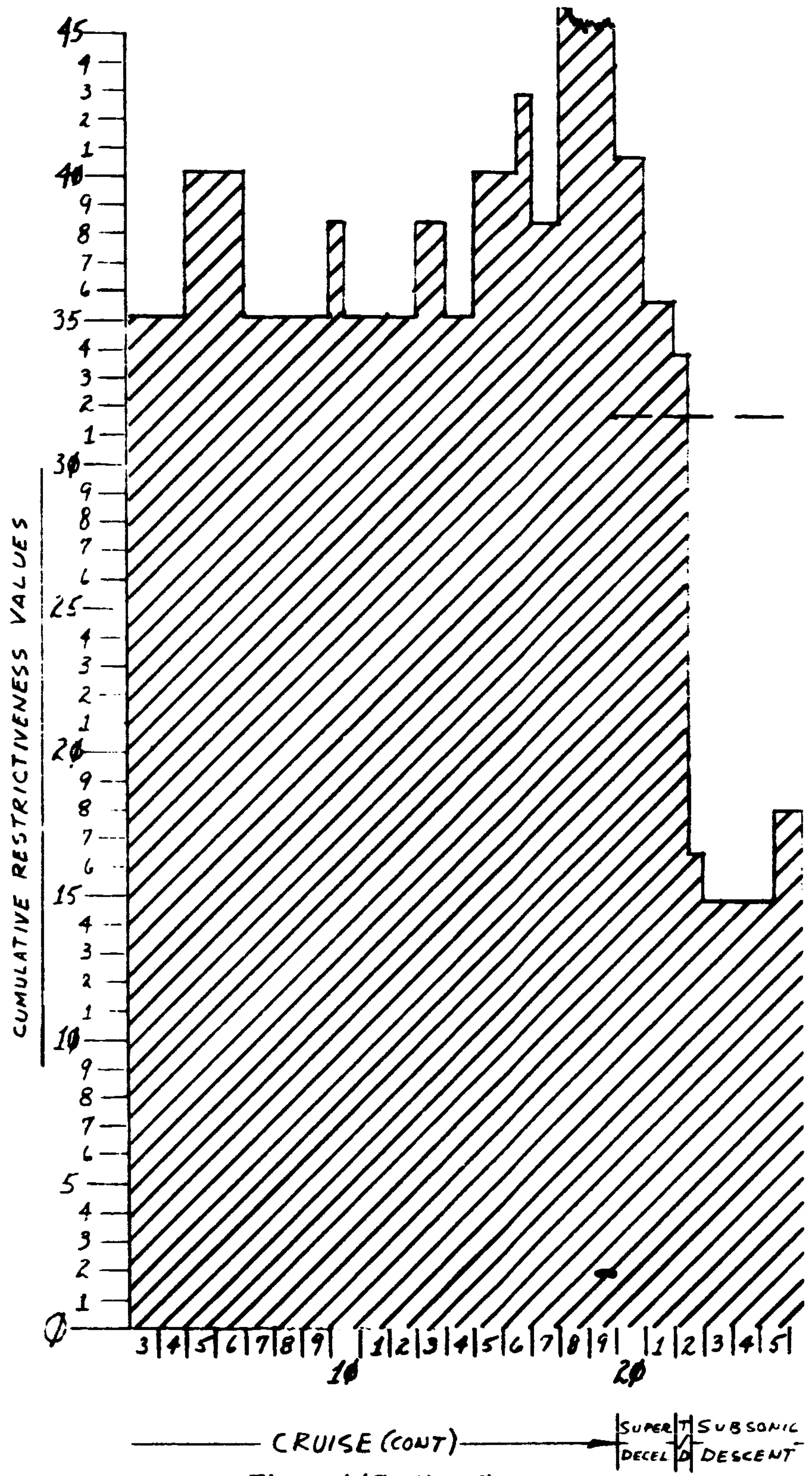


Figure 4 (Continued)

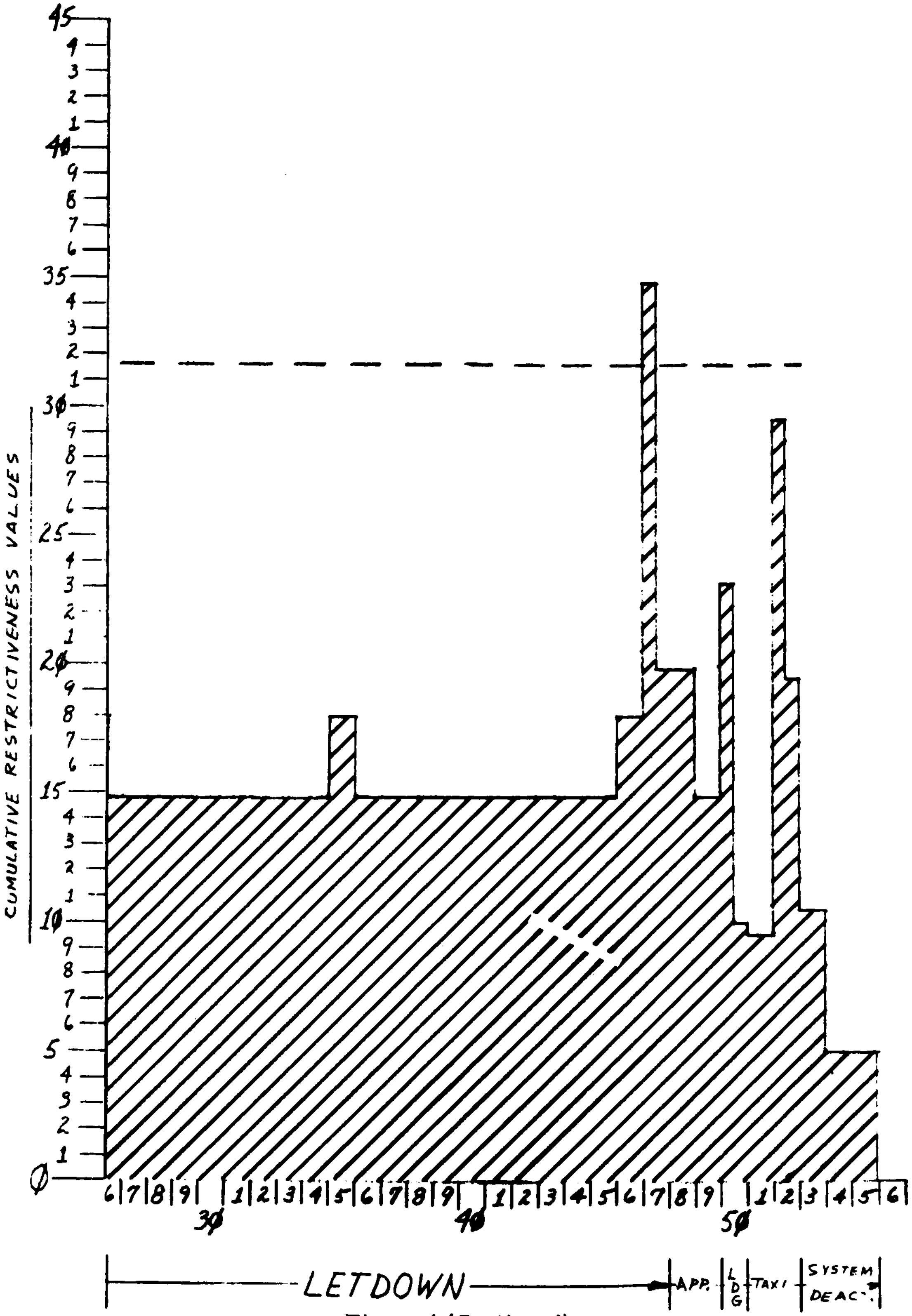


Figure 4 (Continued)

In general, the results indicated a higher workload during cruise than expected. Examination of this revealed that this was due to the large number of monitoring tasks and the cumulative restrictiveness values that were assigned to these tasks. Thus some speculation is justified that the values may be too high or that design of the monitoring systems may have considerable impact on crew workload during cruise. Because of this a fundamental review of the monitoring problem was undertaken in section 3 which follows.

3.0 MONITORING AND FLIGHT MANAGEMENT IN THE SST

3.1 INTRODUCTION

The crew workload analysis (Section 2) indicated a consistently high workload during the cruise phase of flight which was contrary to the general expectation. Examination of this reveals that the apparent workload is due to the extensive amount of monitoring required and the restrictiveness values assigned to the monitoring tasks. Because of the potential effect on crew workload a specific examination of the monitoring problem was undertaken and is reported in this section.

3.2 STATEMENT OF THE PROBLEM

In the operation of semi-automatic and automatic systems man is used as a monitor of the state of the system. In the past, this task has consisted primarily of monitoring various dials and devices which indicated whether this or that part of the system was operating properly. In the case of failure, or trend toward failure, the operator could shut down the system or subsystem in question. In some cases, alternative subsystems could be utilized to continue system operation. Examples of such systems include the Air Defense Command's Semi-automatic Ground Environment (SAGE) system, oil refineries and cracking plants, automatic switchboards and dialing systems, computerized accounting and billing systems, the programming of commercials and other advertisements at a radio station, operations at large digital or analog computing centers, and finally, supersonic aircraft are likely to become, at least, semi-automatic systems.

There is, however, one very important difference between the operation of the SST and the operation of ground based semi-automatic and automatic systems. When a malfunction, or failure occurs in a ground based system that system may be shut down. It is true that queues may develop, as far as the handling of the input is concerned, but the system can be shut down. For the SST this will not be true. Thus, the decision possibilities for the SST crew become greater and the consequences of an action taken are much more profound. This profundity arises primarily from economic considerations. It is true that the safety and comfort of passengers is, and will continue to be, of greatest importance. However, it has always been recognized that the safety and comfort of the passengers is a product of a variety of other factors.

With the advent of the SST, the aircraft itself is more costly by an order of magnitude. Therefore, any factor which influences the probability of the loss of an aircraft has greater influence by an order of magnitude. Further, the SST offers the alernative of the subsonic mode of operation which is more expensive by far. The decision to go to an alternate airport also has more effect on economics for the SST than for the conventional subsonic jet. Finally, the environment in which the supersonic transport will operate is such that decisions made by the crew are more resolute than otherwise.

Because of the trend toward semi-automatic operations of the SST and the importance of crew decisions, two problems which always arise in the development of such systems become critical for the SST. One of these is the problem of monitoring the status of the various subsystems of the SST, and the other is the allocation of functions between men and machines. The present section is devoted primarily to the first problem. However, it should be realized that the monitoring function assumes some allocation of functions between men and machines resulting in essentially automated implementation concepts.

In the SST, the concept of flight management must include more than the monitoring of subsystem status. The concept of monitoring must be extended to include:

1. The anticipation of malfunctions before they occur;
2. The anticipation of the effects of a malfunction in one subsystem or related subsystems;
3. The anticipation of the effects of a malfunction in the context of the operational environment of the aircraft.

Given the above; then a series of decisions must be made, related to the continued operation of the aircraft:

1. Can the flight be continued supersonic:
    a. In a degraded mode with primary equipment;
    b. Utilizing back-up equipment;
    c. Utilizing a manual back-up mode?
2. Can the flight be continued subsonic:
    a. In a degraded mode with primary equipment;
    b. Utilizing back-up equipment;
    c. Utilizing a manual back-up mode?
3. Must the flight be aborted?

The above questions are based on the following assumptions:

1. It is best to remain supersonic as long as possible;
2. If the flight cannot remain supersonic, then it is best to continue at subsonic speeds;

3. If the flight must be terminated, it should be terminated in the most cost effective manner.

From the above, it may be seen that the problem for flight management revolves around the necessity to evaluate the performance of the aircraft to allow decisions concerning the most cost-effective manner of continuing the flight. The Captain must have information to allow him to:

1. Anticipate malfunctions;
2. Anticipate the effects of such malfunctions;
3. Make appropriate decisions concerning flight continuation;
4. Take appropriate action in light of the decisions reached.

3.3 ASPECTS OF THE PROBLEM

Given the above statement of the problem, we may turn to various aspects of man's ability to perform the flight management function.

Readiness to Respond

Poulton has presented evidence that human reaction time is increased on the order of 40 percent by having to be ready to respond (ref. 81). Thus,

> The mental load on the pilot is not simply what he is doing at the moment, but includes what he has to hold himself in readiness to do at very short notice.

These findings suggest that monitoring information should be presented in such a way that the crew will know when action is <u>not</u> required and to allow them to anticipate a requirement for action, rather than having the requirement for action thrust upon them without warning.

Performance Decrement in Vigilance Tasks

One of the most ubiquitous findings associated with the monitoring of infrequent events is that the accuracy of performance decreases over time and that the reaction time increases over time. These findings imply that the monitoring situation should be so designed that a continuous watch was not required. This same conclusion is also required by the fact that there will be precious little time available to the crew for continuous watch of a few selected parameters.

Monitoring and Manual Back-up

Most monitoring tasks may be accomplished by visual or auditory watching. The reason for this is that the actions taken by the monitor require no more information than knowledge of the occurrence or the need for action. This fact is frequently overlooked in the design of a monitoring task. In fact, the information required by a monitor is of two kinds:

1. Event detection information;
2. Action to be taken information.

In those situations where the action required is simple, the information requirement reverts essentially to event detections information. In those situations where the action to be taken is complex, then it may be necessary to supplement event detection information with additional data which allow adequate performance.

The example which comes immediately to mind is the pilot monitoring the automatic landing of an aircraft. The visual display is adequate to allow the pilot to detect a need for action. However, should the pilot have to take over, he needs to know also what corrective action to take and how and when to take it. Further, if the pilot is to take over successfully, he must have available to him motion and kinesthetic cues which will allow him to anticipate the situation of the aircraft with respect to the landing operation. In summary, for the pilot to successfully monitor an automatic landing he needs the same information he would have if he were landing the aircraft himself.

Acceptance Factors in Monitoring Automated Systems

In an earlier study concerned with pilot acceptance factors (ref. 8) it was suggested that pilot acceptance should be a criterion of system design because if the system design is unacceptable to the pilot the system may be under-used and/or used improperly, either covertly or overtly. Thus the design of a system for monitoring automatic or semi-automatic operation should be acceptable to the crew. The same study further states about this problem:

> Frequently non-acceptance of automation could be greatly reduced, if not eliminated, through the use of additional hardware, which hardware would not be necessary on grounds other than the acceptance problem. The feasibility of this type of solution was apparent in earlier research on this contract on the resistance of pilots to automating certain landing functions. Pilots frequently would state that they would not accept automation of some landing function, but when asked if they would accept such automation if they had a display for monitoring the function they stated that this would make the automation completely acceptable. Additional displays for monitoring and thus providing understanding of what is occurring while automatic functions are being performed is obviously the most likely additional hardware technique for reducing non-acceptance of automation.

Information Presentation

Most of the information about system performance is today presented via the visual sense (although recently investigations have been looking into other senses, e. g., smell, for monitoring). The auditory sense is reserved for communications. In the SST, it is quite possible that communications may be handled, for the most part, by automatic means. If this is the case, then considerable thought should be devoted to the use of the auditory sense to present warning information about impending or actual malfunction. There are two aspects of audition which make this an attractive possibility. In the first place, unusual sounds have a certain insistent quality which intrudes onto the consciousness of the human. Thus, a crew member may be engaged in another task and still monitor via the auditory mode. The second quality of sound is that it can be modulated and changed so that the sound is descriptive of the impending malfunction. Thus, the use of auditory cues would tend to shorten the time required to recognize which system was malfunctioning or approaching an out of tolerance condition. As examples, a hissing sound might warn of the loss of cabin air pressure. A dripping sound might warn of a liquid leak. A sound like relays clicking might warn of an impending failure of the electrical system. A sound like tape slapping at the end of a reel might warn of computer failure, etc.

Whatever is done along this line, system designers must be careful not to usurp some legitimate uses of the auditory channel for terminal communication. When the pilot is communicating with the tower, information presentation principles (ref. 79) dictate that such communications should be via the auditory channel.

Available data suggest the following principles for information presentation:

1. Easy material, in the sense of short declarative sentences, familiar words, and concrete subject matter, are best presented auditorily;
2. Familiar, meaningful and related materials are best presented auditorially;
3. Difficult materials are best presented visually;
4. Unfamiliar or unrelated (discrete) materials are best presented visually.

It is unlikely that difficult materials, in the sense of involved sentences, unusual words or tense usage will be presented in the cockpit. On the other hand, a great deal of discrete factual information--numerical values--will be presented. These should be presented visually. Terminal area communications are easy, familiar, meaningfully related materials, and should be presented auditorially.

The point has been made many times, and need not be elaborated here, that there is too much information presented in the cockpit of the commerical aircraft. The automation of many of the flight control activities will not reduce the amount of information to be presented. For those activities for which man is the back-up system, the same displays will be needed. When he is the monitor, additional display will be needed. For those activities for which man is not the back-up system, additional information displays will be needed. Further, with a semi-automatic system, the flight manager will need a sophisticated fault isolation system. This will require additional information presentation.

With the addition of information displays to the cockpit, it would be well worthwhile to consider the possibility of multiple use instruments. Since it is undesirable and perhaps dangerous to have more than a single kind of information displayed on a particular instrument at one time, instrument sharing must be based on other means. Three possibilities suggest themselves. For flight control information, instruments may be categorized in terms of whether the information is used in a given flight phase (see Section 8 on General Purpose Displays).

The second possibility is with respect to instruments used to monitor system status. Routine checks of subsystem status may be performed by using one set of instruments and switching from one subsystem to another. Routine schedules for frequency of check could be established.

A third possibility is automatic monitoring until a particular subsystem goes out of tolerance to a given degree. Then the human monitor would be notified. He would then switch to the defective subsystem and assess the magnitude of the difficulty by noting the trend involved.

Decision Alternatives and Computer Simulation

One approach to part of the monitoring and flight management problem is the use of computer simulation models which would permit the flight crew to test the effect of decision alternatives. Computers have generally been thought of as high speed data processors or calculators, or as problem solvers providing an optimum solution to a given problem. Another more recent use of computers is as a synthesis tool wherein the operations of real systems can be simulated on a computer. The computer simulation model can then be "run" on a computer. System operations which will actually occur over an extended period of time can be simulated in a few seconds or minutes. Thus, a simulation model allows one to see what will happen to system operations in the future based on a given set of operating conditions. Such models have been used for some time to guide decisions in relation to the development of maintenance concepts, functions and practices (ref. 80), and these models have proved themselves to be cost effective. It has been established that there is low pilot acceptance toward automation of decision functions per se (ref. 8), but it is suggested that a simulation model of SST flight operations which would let the crew test the effects of decisions in advance might prove much more acceptable. This concept would allow the crew to essentially ask the computer "what effect on performance (e.g., ETA, fuel remaining, G-loads, etc.) will occur if I do this (e.g., change course, change altitude, change speed, etc.)."

3.4 RESULTS

The design of monitoring systems for SST can have a significant effect on crew workload and performance efficiency. Because of the large number of continual real time monitoring tasks and known decrement in performance in vigilance tasks, consideration must be given to use of human senses other than vision for monitoring.

Consideration should be given to "advance monitoring" capability which would permit the crew to investigate in advance the effects of decision alternatives.

4.0 EMERGENCY AND NONROUTINE ACTIVITIES

In deriving the flow-logic diagram and the descriptions of potential activities and functional performances of the crew in the SST, it was assumed that all performances were achieved under routine conditions and further that no failures occurred in any system which caused the crew to deviate from the originally proposed flight. However, these are unrealistic assumptions. One problem then was to determine a basis for predicting failures in aircraft systems so that the effect of such failures on crew performance could be analyzed.

One of the few bases for predicting failure rate in a conceptual system is the historical reliability of current systems. It can be assumed that the distribution of malfunctions due to system failures in current flight operations should be similar to that expected with the SST. Projected malfunction data can also be utilized to increase emphasis on certain areas of design, to initiate human engineering studies, and to develop new training procedures in those areas which show high rates of failure. Such a data base can also be used in crew simulation work to enable the distribution of malfunctions introduced in the experiments to approximate a "real world" probability of failure rate.

In this study, we chose to use current jet malfunction data to provide the base for the three areas of concern discussed above, namely

1. As a basis for estimating the effect on crew workload due to malfunction.
2. As a basis for indicating where problems exist in current jets and where emphasis might be put on SST design.
3. As a basis for programming malfunctions in SST simulation.

This chapter deals with the background of malfunction data available, how it is presented, and what the projected implications will have on the performance of the SST.

4.1 CURRENT JET MALFUNCTION DATA

In attempting to gather data concerning emergency and non-routine incidents in commercial jet operations, the sources below were considered:

1. Commercial air carrier records
2. The Airline Pilot's Association (ALPA) and its international organization, IFALPA, records
3. Federal Aviation Agency records
4. Individual pilots
5. Other organizations or manufacturers concerned with flight operations and safety.

The Flight Safety Foundation representative suggested two sources of malfunction data: (1) Civil Aeronautics Board Accident Reports, (2) Mechanical Reliability Reports (MRR).

Examination of the CAB reports indicated they were unsuitable for our purposes because they are concerned primarily with causes of accidents. The Federal Aviation Agency was contacted with regard to the MRR. It was found that air carriers are required to file two types of reports when any non-routine occurrence takes place. These reports, the MRR and the Mechanical Interruption Summaries (MIS) are filed in accordance with Federal Air Regulations 121.703 and 121.705. Appendix II explains both the MRR and MIS reporting requirements and process in some detail. Briefly, the MRR data are prepared quarterly as statistical summaries in the form of rates (reported failures/1000 aircraft flight hours) of failures of aircraft major systems, accumulated for each different type of aircraft. The MIS is similar to the MRR in that they are also published as quarterly statistical summaries (recently they have been tabulated monthly) which present a breakdown of failures with regard to specific aircraft type and specific subsystem within the major aircraft system category.

ANALYSIS OF CURRENT JET MALFUNCTION DATA

Data for a continuous six-month period, June through December 1964, were obtained from the Western Region Office of the FAA. This period had the advantage of taking into account fluctuations due to seasonal climatic conditions. Only MIS and MRR data on jet aircraft were used.

The first task was to tabulate the average number of reported incidents per 1000 hours of flight from the MIS and MRR reports for the six month period. The basic ATA Spec. 100 "Systems" were used and the resultant graph indicated that distributions for both MIS and MRR reports were similar. Because these reports are exclusive of each other, it was assumed that the values should be summed to ascertain the total incidents occurring in each major system per 1000 hours of flight. The resultant graph, Figure 5, presents the distribution of system failures in jet aircraft per 1000 hours of flight, and also the corresponding mean time between failure (MTBF) values.

This form of data presentation points out vividly those systems in which the greatest number of malfunctions will probably occur and permits many broad conclusions concerning the effects of such malfunctions on the SST flight profile. However, these data are presented for major systems, and greater specificity is desirable in drawing conclusions.

To obtain increased specificity, the computerized breakdown by subsystem of the MIS reports was analyzed for the same period mentioned previously. Each major system in jet aircraft was analyzed to find the specific cause of a reported malfunction. These data, presented in Figure 6, illustrate the percentage of failures caused within a system by a particular portion of that system (e.g., the VHF subsystem in the communications system).

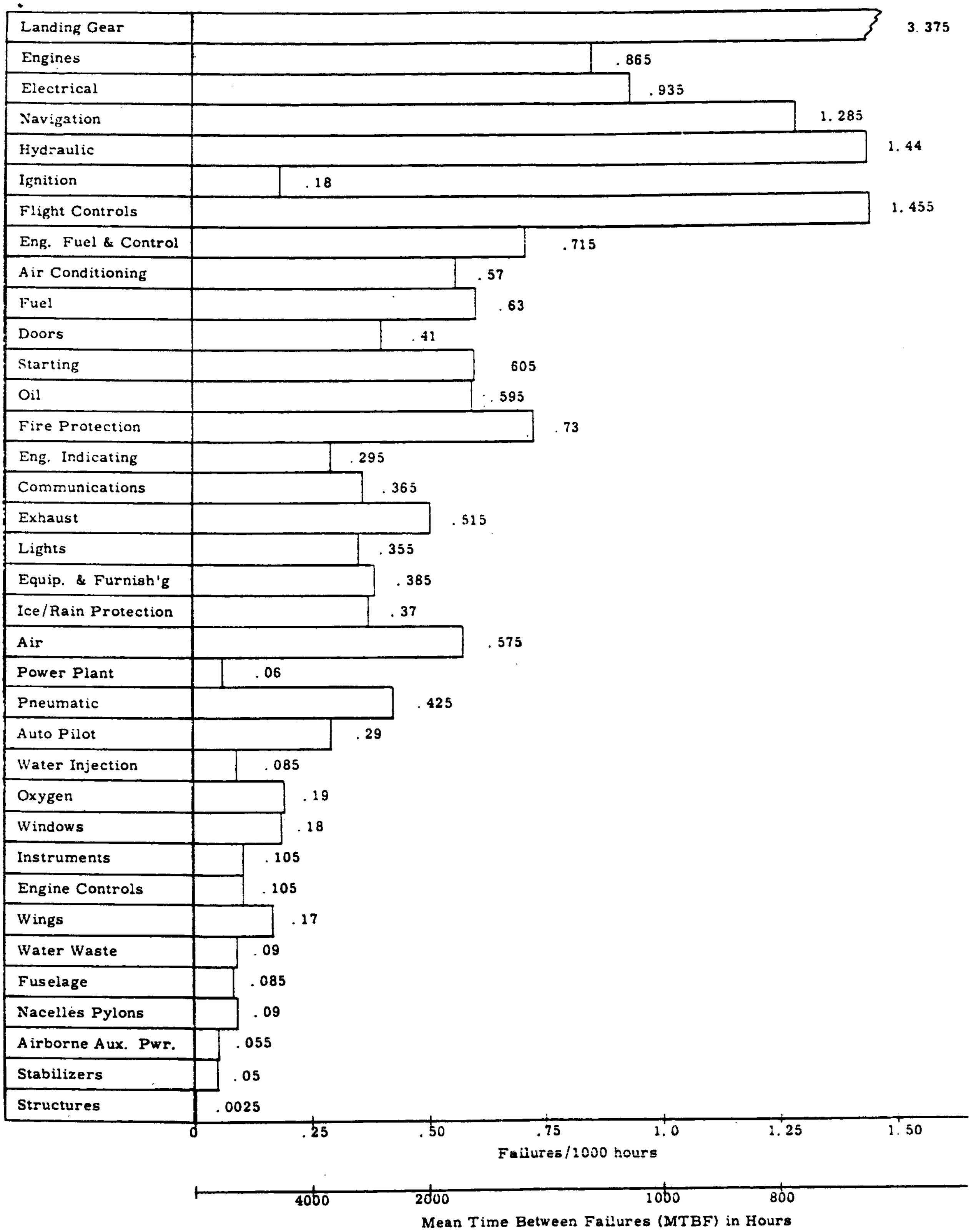
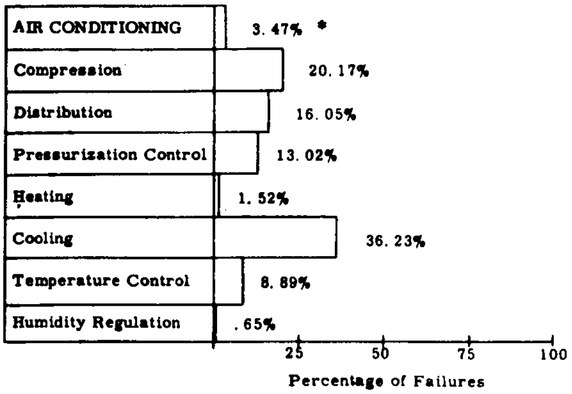
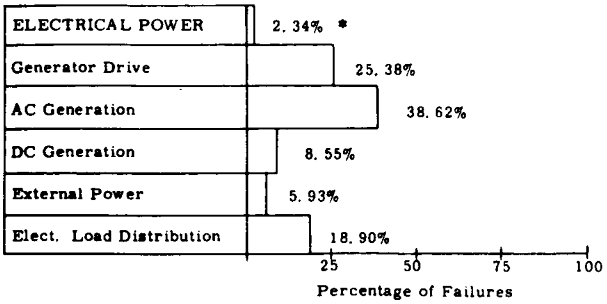


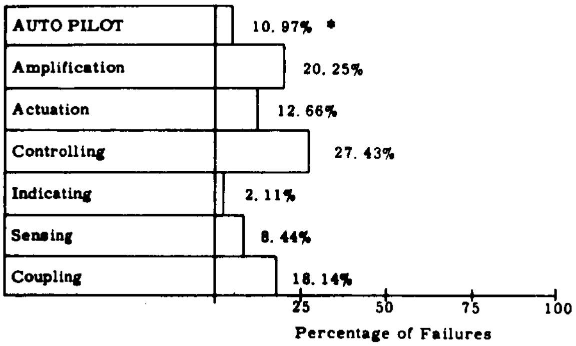
Figure 5. System failures per 1000 hours of flight.



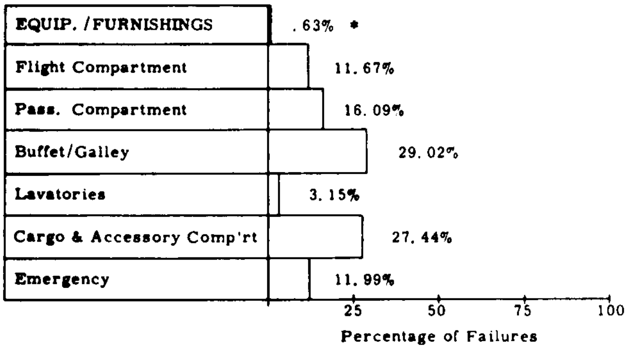
Air conditioning subsystem failures.



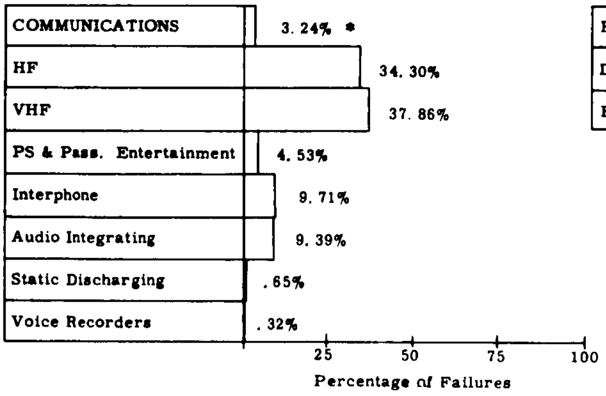
Electrical power subsystem failures.



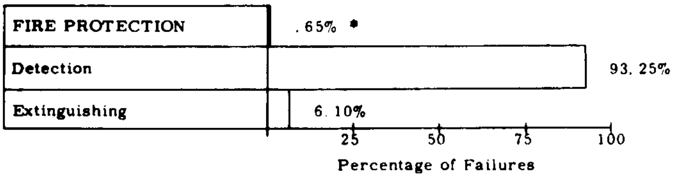
Auto pilot subsystem failures.



Equip. / furnishings subsystem failures.



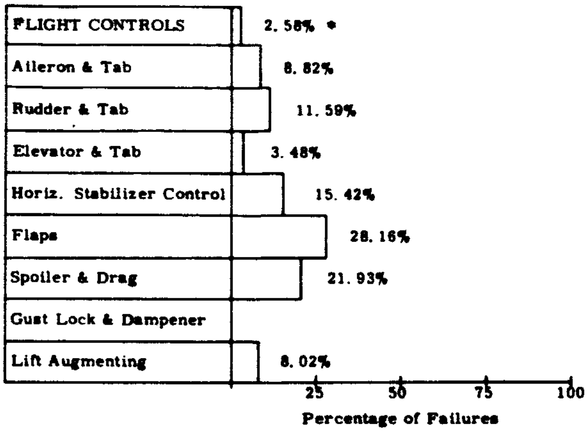
Communications subsystem failures.



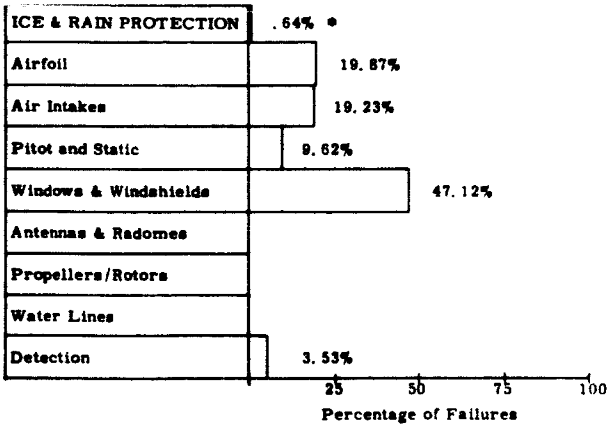
Fire protection subsystem failures.

* These figures indicate percentages of those failures not attributable to any particular subsystem within the system.

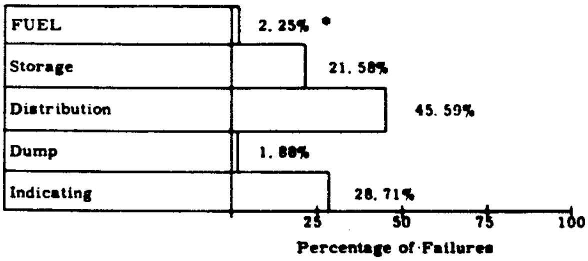
Figure 6. Distribution of system failures among subsystems.



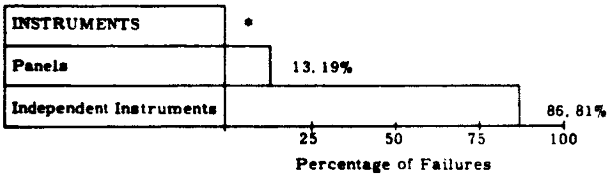
Flight controls subsystem failures.



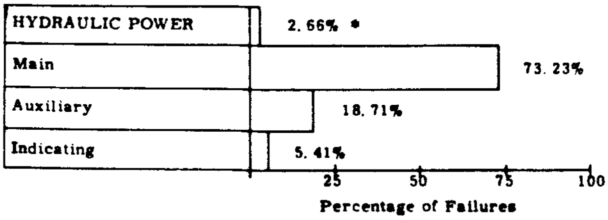
Ice & rain protection subsystem failures.



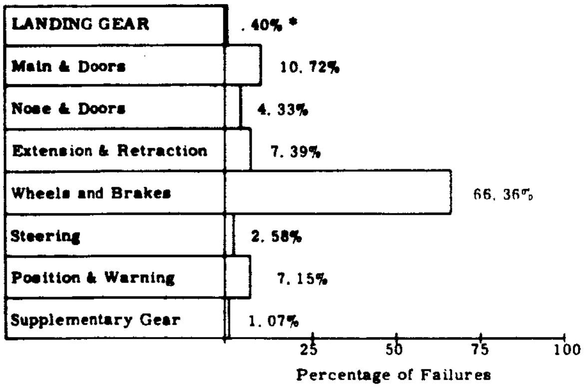
Fuel subsystem failures.



Instruments subsystem failures.



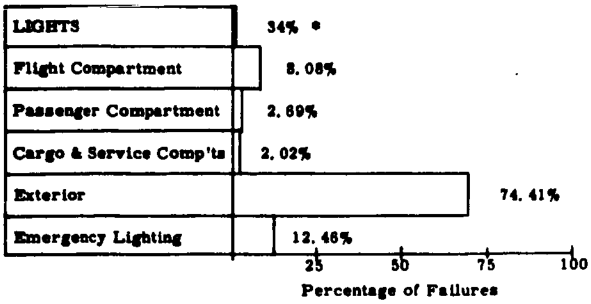
Hydraulic power subsystem failures.



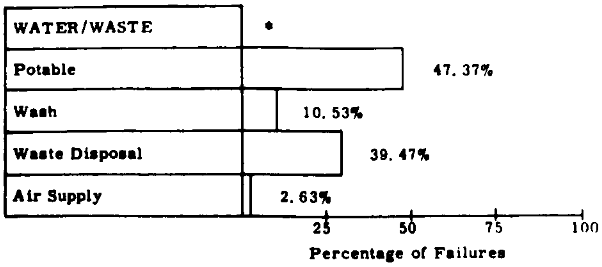
Landing gear subsystem failures.

* These figures indicate percentages of those failures not attributable to any particular subsystem within the system.

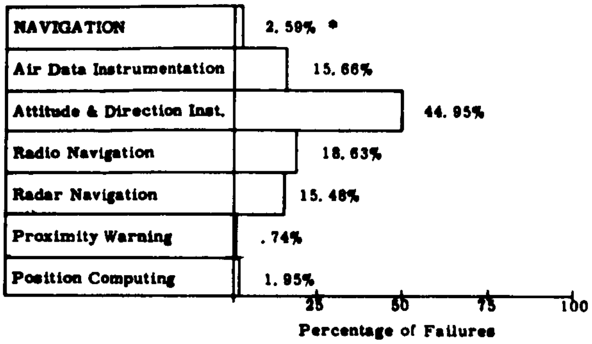
Figure 6. Distribution of system failures among subsystems (Continued).



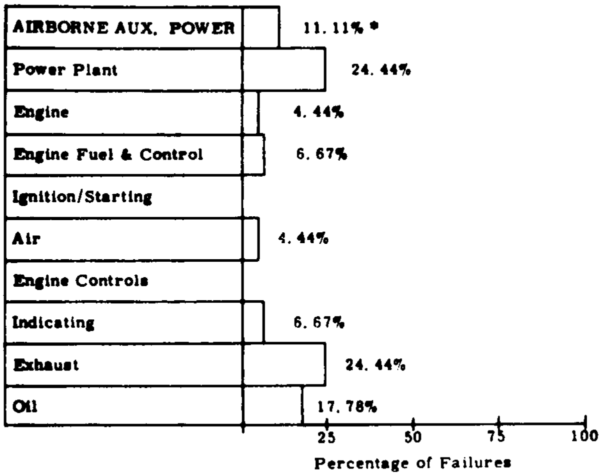
Lights subsystem failures.



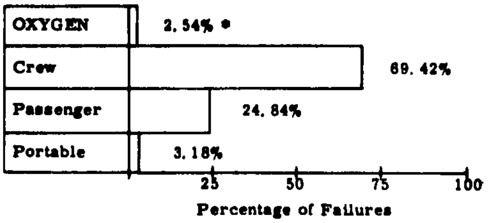
Water/waste subsystem failures.



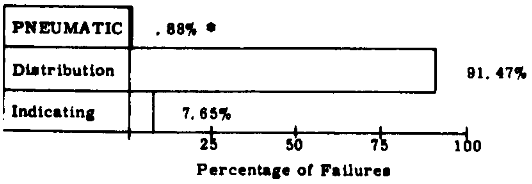
Navigation subsystem failures.



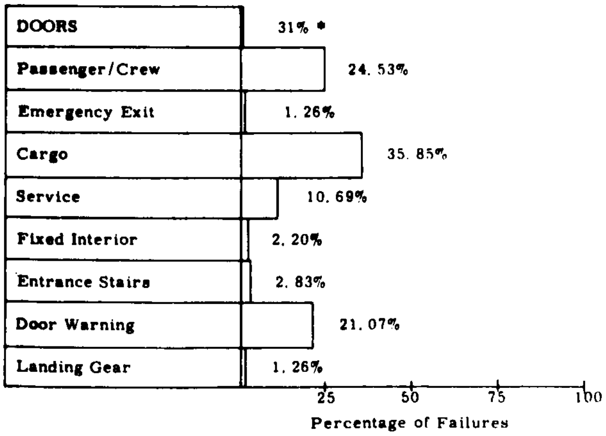
Airborne aux. power subsystem failures.



Oxygen subsystem failures.



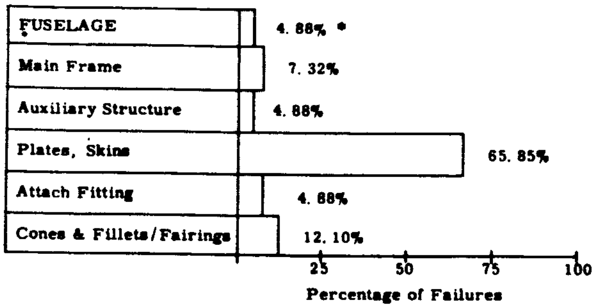
Pneumatic subsystem failures.



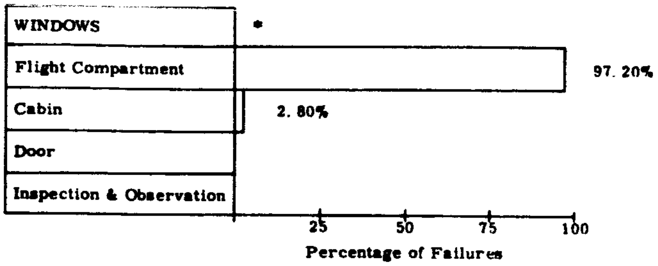
Doors subsystem failures.

* These figures indicate percentages of those failures not attributable to any particular subsystem within the system.

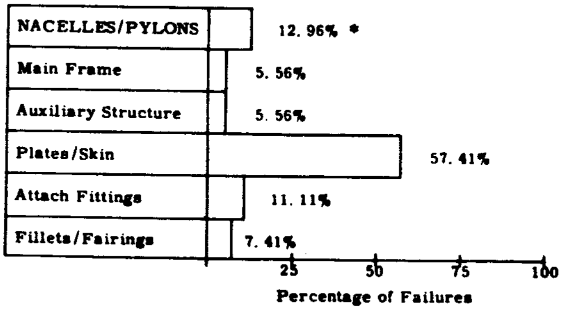
Figure 6. Distribution of system failures among subsystems (Continued).



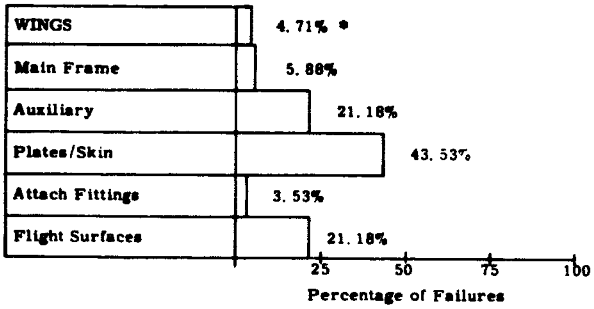
Fuselage subsystem failures.



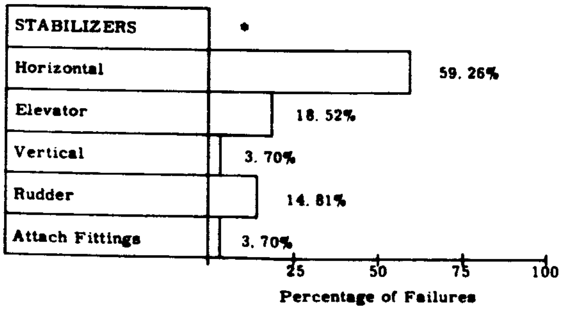
Windows subsystem failures.



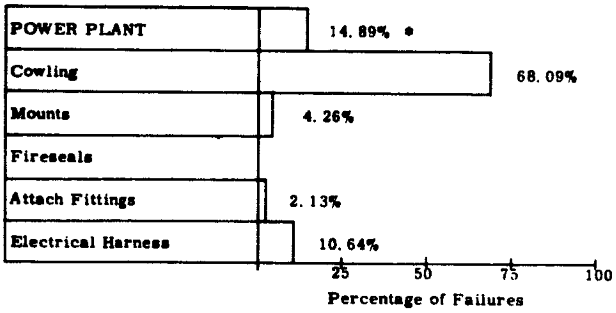
Nacelles/pylons subsystem failures.



Wings subsystem failures.



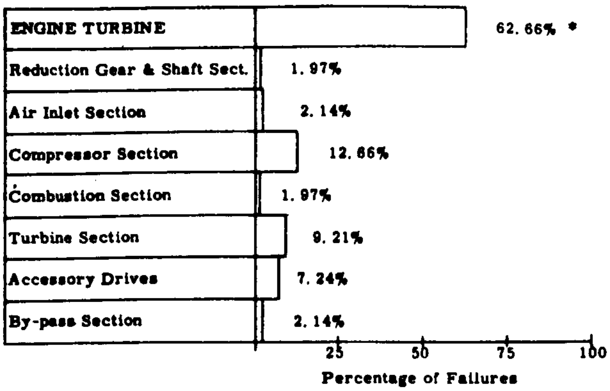
Stabilizers subsystem failures.



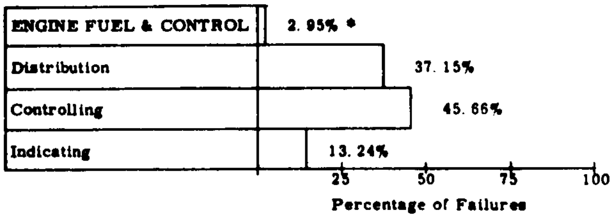
Power plant subsystem failures.

* These figures indicate percentages of those failures not attributable to any particular subsystem within the system.

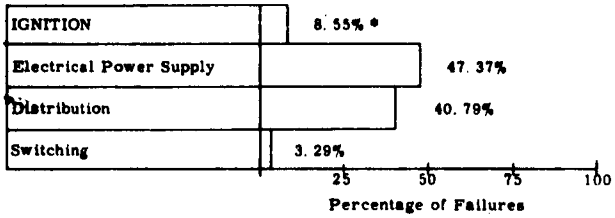
Figure 6. Distribution of system failures among subsystems (Continued).



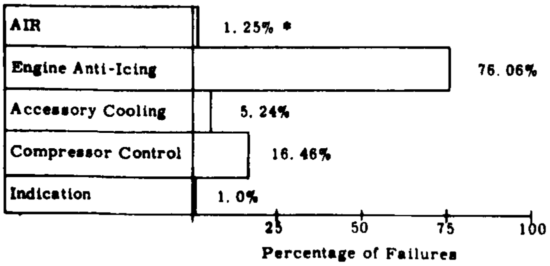
Engine turbine subsystem failures.



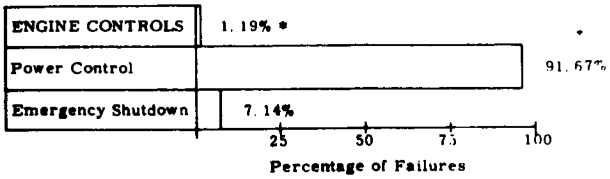
Engine fuel & control subsystem failures.



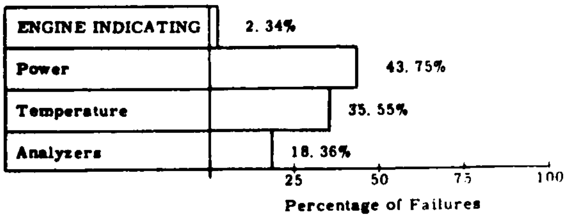
Ignition subsystem failures.



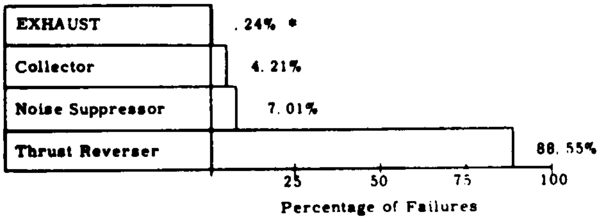
Air subsystem failures.



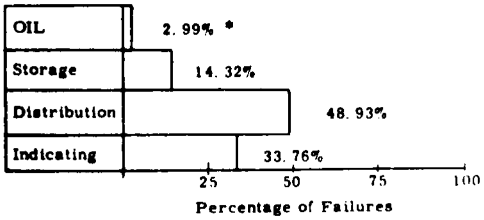
Engine controls subsystem failures.



Engine indicating subsystem failures.



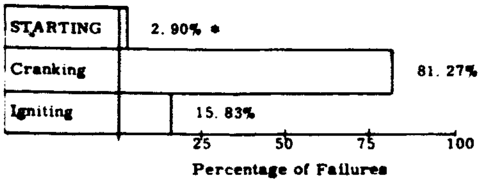
Exhaust subsystem failures.



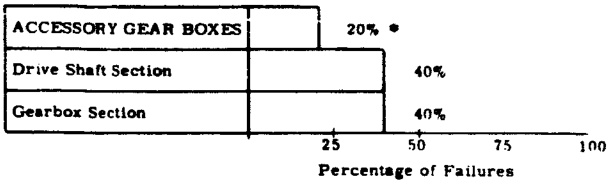
Oil subsystem failures.

* These figures indicate percentages of failures not attributable to any particular subsystem within the system.

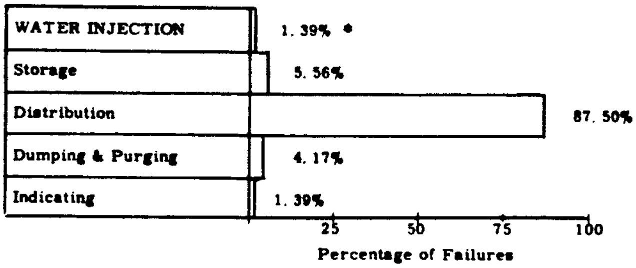
Figure 6. Distribution of system failures among subsystems (Continued).



Starting subsystem failures.



Accessory gear boxes subsystem failures.



Water injection subsystem failures.

* These figures indicate percentages of those failures not attributable to any particular subsystem within the system.

Figure 6. Distribution of system failures among subsystems (Concluded).

Figure 6 can be used with Figure 5 to determine probability factors with regard to specific equipment. For example, Figure 5 shows that there are 3.375 landing gear system failures per 1000 hours of flight. Then, from the landing gear subsystem failure chart, Figure 6, it can be seen that 66.36% of the time such failures are attributable to wheels and brakes. These figures permit many conclusions to be made readily. For instance, since the landing gear is used primarily during the initial and terminal phases of the flight, the potential crew role and implementation concepts can be inspected with these numbers in mind and implications concerning crew workload and back-up equipment are easily apparent.

An important point should be made here: using assumptions based on historical data, such as that from FAA reports, it is still impossible to pinpoint the causes of the malfunction (i.e., know why it failed). The cause might have been a system failure, while on the other hand it might have been the effect of poor design or poor human engineering studies. The reduced data in the FAA reports is in terms of numbers only and these factors are not shown.

It would appear that the data available in the FAA reports could be utilized in many ways to assist in both design and safety programs. However, this application of the data is beyond the scope of the present study.

Our investigations will be utilized primarily to furnish a basis for showing possible malfunction effects on the SST profile with regard to the potential crew role. It is anticipated that some basis for determining crew composition (i.e., both number and ability) will evolve.

The next section will deal with SST malfunctions and their implications.

4.2 SST MALFUNCTION ASSUMPTIONS

Before discussing the function assumptions for the SST it is necessary to define malfunction and the impact of failure in equipment or functions. Generally speaking, the SST may be considered to have three alternative operational modes as follows:

1. The first mode (and certainly the preferable one) is to follow the original flight plan and complete the flight to the destination terminal, remaining within the flight path and ETA tolerances established prior to the flight. This alternative in itself has two modes of operation:
    a. The flight can be completed with no malfunctions, in which case the implementation concept for each function would be the primary system design.
    b. The flight can be completed according to the original flight plan, with a malfunction which caused a reconfiguration of one or more functions but without compromising safety.
2. Alternative two is to return to a subsonic flight regime, but still complete the flight to the destination. This alternative obviously has economic penalties associated with it because of failure to fully utilize the aircraft, but at least passengers and aircraft do arrive at the originally planned destination.
3. Alternative three is to abort the flight. In this case abort means to descend and land at the nearest feasible airport regardless of where the aircraft may be in its flight profile. This alternative is, of course, the most serious of all from both an economic and safety standpoint.

The use of the term malfunction in this study has been restricted to those failures associated with alternative one (1) above. Thus, a malfunction is indeed a failure, but one in which reconfiguration is possible, and flight may continue within the originally filed flight plan. Reconfiguration may imply increased crew workload since the crew may have to resort to the manual implementation concept, but every attempt was made to permit reconfiguration rather than choose alternative two (2) or three (3) with the consequent drastic economic impact. Further, we have not considered the system and subsystem redundancy effects. In all likelihood, many, if not all, of the major systems and subsystems will have redundant or parallel mechanization. Therefore, a single failure may simply mean that the secondary system is put into operation and crew workload is essentially not affected. In this study, the term, malfunction, is restricted to failure of all the primary systems under the automatic implementation concepts, by definition causing the particular function to be performed within the manual implementation concept.

At this time very little is known about SST systems and subsystems and their predicted reliability. Therefore, rather than utilize unfounded estimates of system reliability and distributions of failures, we have used the empirical data available from current jets as a basis for making a cursory examination of possible malfunction effects on SST. While there may be some who disagree with this premise, we have also attempted to indicate clearly what we have done with these data so that as more specific SST malfunction data are available, new analyses can be made of the same problems. We believe that for our purposes, historical data which is well founded empirically is much better than unsophisticated estimates and will yield reasonable results. The specific assumptions we have made for our calculations then are as follows:

1. The distribution of failures among systems and among subsystems within the systems is the same for SST as it is for current jets.
2. Failure rate for SST will be no worse than it is for current jets per 1000 hours aircraft flight time.

Using the current jet malfunction data and making the assumptions stated above, we first attempted to develop a matrix which related all the functions we had identified for SST to all of the system and subsystem failure data for current jets. This proved to be impractical (see Chapter 6 methodology) and consequently we decided to use a very simple method for calculating the effects of malfunction on crew loading. We thus constrain this portion of the analysis with the following rules:

1. Only those functions were included which would result in a significant increase in crew workload if the malfunctions were considered. (It must be remembered that malfunction here refers to reconfiguration to allow continuation of the flight according to the originally filed flight plan. This in essence meant failure of the automatic implementation concept and resort to the manual implementation concept for the function.) It was decided to include the following functions:
   a. Enroute ATC communications.
   b. Thrust Application = F (Constant Mach 3.0).
   c. Cruise control.
   d. Monitor enroute weather conditions.
   e. Monitor destination and alternate weather.
   f. Provide differential in forecast/actual weather conditions.
   g. Calculation of overpressure being generated.
   h. ETA prediction.
   i. Optimum profile generation.
2. The principal systems associated with those functions (here systems means the ATA 100 Series Systems) were used to establish the probable failure rates of those functions. In other words it was assumed that the function failure rate was the same as its associated system failure rate.

3. It was assumed that the average flight time for a single SST flight was 2. 5 hours.
4. It was assumed that the probability of any system (and consequently its associated function) failing was equal throughout the flight and therefore the average workload associated with the failure was one-half (1/2) the maximum possible workload over the entire flight.

The data in Table 3 were calculated using these assumptions. For each of the functions in the analysis the MTBF and the failure workload increase in terms of restrictiveness were calculated (the restrictiveness value is explained in Chapter 2 which deals with crew workload analysis; essentially the restrictiveness value of five (5) requires the total abilities of one man). The failure workload value is the difference between the loading required for automatic performance of the function and manual performance of the function. The other values calculated include the average additional man-minutes of work because of the failure, expected failures per SST flight, and the expected increase per flight in man-minutes due to each failure. As can be seen in Table 3 two important values were derived. The first is the average expected increase in manning per flight because of malfunction of the functions being considered. This value turns out to be 2. 5 man-minutes per flight or 0. 25 men to handle malfunctions per flight. Flight time of 100 minutes was used instead of 150 minutes because all the functions considered were enroute functions and the enroute flight time is approximately 100 minutes.

4. 3 EFFECT OF MALFUNCTIONS ON CREW WORKLOAD

The value, 0. 025 men per flight, is obviously a difficult value upon which to base conclusions. It was decided that a more useful value could be obtained by calculating the average increase in manning per malfunction. This value was obtained by calculating that 104 man-minutes is the workload increase per malfunction and using a flight time of 100 minutes (the enroute portion of the flight). For all practical purposes this turned out to be one man per malfunction.

Table 3. Expected Increase in Manning Due to Key Malfunctions During the Enroute Phase of Flight

Function	Related Equipment System	Failures/ 1000 Hrs.	MTBF	Failure Workload Increase	Average Additional Man-Minutes	Expected Failure Per Flight	Expected Increase Per Flight (Man-Minutes)
3. 8: Enroute ATC Communications	Communications	0. 365	2740	1. 04	52. 0	. 0009	. 0468
4. 11: Thrust Application = F (Constant Mach 3. 0)	Engine Fuel and Control - Engine Controls	0. 715 +0. 105 0. 820	1220	3. 53	176. 5	. 00205	. 3618
5. 10: Cruise Control	Auto Pilot	0. 29	3449	1. 34	67. 0	. 0072	. 0482
7. 3: Monitor Enroute Weather Conditions	Navigation	1. 285	778	1. 08	54. 0	. 0032	. 1728
7. 4: Monitor Destination and Alternate Weather	Navigation	1. 285	778	0. 98	49. 0	. 0032	. 1568
7. 5: Provide Differential in Forecast/Actual Weather Conditions	Navigation	1. 285	778	1. 77	88. 5	. 0032	. 2832
7. 6: Calculation of Over-pressure Being Generated	Navigation	1. 285	778	. 23	11. 5	. 0032	. 0368
7. 10: ETA Prediction	Navigation	1. 285	778	1. 46	73. 0	. 0032	. 2336
7. 11: Optimum Profile Generation	Navigation	1. 285	778	7. 45	372. 5	. 0032	1. 1920
				Total	940. 0		2. 532

Note: Average Expected Increase in Manning/Flight $\frac{2.532 \text{ man-minutes/flight}}{100 \text{ minutes/flight}} = .025$ man

Average Increase in Manning/Malfunction $\frac{104 \text{ man-minutes/malfunction}}{100 \text{ minutes}} \approx 1$ man/malfunction

That is, whenever a malfunction occurred, the average additional manning required to compensate for the malfunction was one crew member.

The consideration for manning then is in part based on the trade-off for carrying the "extra" men to handle a malfunction when it occurs. Table 3 indicates that the expected failure rate per flight is 0.029 or approximately 0.03 failures per flight. This, of course, can be converted to an average of one failure every 33 flights. Considering that the typical flight time used in this analysis is two and one-half hours a failure could be expected every 82-1/2 hours. The cost of the additional crew member may be viewed somewhat more realistically with these figures. While there is no actual data as far as costs are concerned, the expected utilization of the SST is on the order of 50 to 60 hours per week. Therefore, a malfunction might be expected every 10 days or so. Without the extra crew member this might necessitate either the flight having to return to the subsonic speed regime or being aborted. Considering the functions (or malfunctions) used in this study, the likelihood is that the flight could continue subsonically rather than abort. Although the economics of the situation are beyond the scope of this effort they can presumably be calculated.

One additional factor which must be considered with respect to the cost of the extra crew member is the possibility of "human malfunction." So far only equipment malfunctions have been considered, but it is possible that a crew member would be unable, at some time, to perform his assigned tasks. The additional crew member would be available to at least maximize the probability that the flight could continue according to the original flight plan if one of the other crew members were incapacitated. At the time of preparation of this report we did not have sufficient data concerning the probability of crew member incapacitation to draw definite conclusions. However, a cursory examination of some available data may be illuminating.

In 1958, the ALPA circulated a questionnaire concerned with pilot incapacitation. While there are certainly some differences in current airline equipment and aircrew standards, we believe the information to be representative. The first question asked was as follows:

1. Have you ever been temporarily incapacitated in flight because of any of the following reasons, so that it became necessary or desirable for another crew member or members to take over your duties?

a. ( ) Severe Nosebleed
b. ( ) Headache
c. ( ) Stomach Cramps
d. ( ) Leg or Foot Cramps
e. ( ) Nausea
f. ( ) Diarrhea
g. ( ) Earache
h. ( ) Toothache
i. ( ) Abdominal Pain
j. ( ) Weakness or Faintness
k. ( ) Severe Coughing Spell
l. ( ) Severe Sneezing Spell
m. ( ) Severe Back Pain
n. ( ) Severe Chest Pain
o. ( ) Rapid Onset of Any Other Severe Pain
(Specify) ____________________
____
____
p. ( ) Other ____________________

A total of 2,562 Captains with a median experience of 12,500 hours reported 983 incidents of incapacitation. Multiplying the median flying hours by the number of respondents, there were approximately 32,000,000 flying hours over which 983 incapacitating incidents occurred, or approximately one incident every 32,500 flying hours. Since this figure is for Captains only the incidence rate will be higher when considering entire flight crews. We shall not try to draw further interpretations from this data as it could be misleading. One further matter for consideration however, is the fact that 28% of these same Captains felt the actual or potential safety of the flight was endangered as a result of their incapacitation incident--and they were flying propeller driven transports.

Finally, although we do feel that our workload calculations are on the high side, we have not included periods of rest or relaxation for the crew members. The workload values are for performance of the flight functions only. Although rest or relaxation may not be necessary in a two and one-half hour flight presumably it may be of some value. Moreover personal hygiene problems may reduce the availability of a crew member from the flight deck for short periods of time.

4.4 RESULTS

Available data on the incidence of malfunctions in current commercial jet transport operations was examined as a basis for projecting failure rates for the SST and for determining their effect on crew workload and manning requirements. Information reflecting a six month commerical aviation operational period was studied to obtain probability of failure rates per 1000 hours of flight for each major aircraft system. Then, assuming (1) that the distribution of failures among systems and among subsystems within systems is the same for the SST as it is for current jet, and (2) that failure rates per 1000 hours aircraft flight time for the SST will be no worse than for current jets, it was determined that the average expected increase in manning per flight required to handle malfunctions was 0.025 men/flight. This value translated into a more useful figure indicates that the average increase in manning per malfunction turns out to be one man. In general, this means that if the increased workload occasioned by the requirement to assume manual or back-up control when primary equipment malfunctions are incorporated into the workload distribution based on automatic implementation concepts, an extra man would be required to handle the malfunction. However, the failure rate data also indicates that, assuming an SST utilization schedule of 50 to 60 hours per week, malfunctions might be expected to occur only about once every ten days. Thus, a trade-off analysis of the economics of an increased crew complement versus the possibility of having to fly subsonic or to abort when malfunctions occur is indicated.

5.0 IMPLICATIONS OF WORKLOAD DISTRIBUTION FOR CREW COMPOSITION

In order to arrive at some reasonable conclusions regarding SST workload and potential crew roles, a preliminary assignment of functions to crew positions was performed. Statements regarding the number and type of possible crew positions should not be construed as recommendations for crew composition and/or individual qualifications. Rather, the conclusions offered should be regarded as suggested workload distributions among two, three, and four man crew complements.

5.1 PROCEDURE AND ASSUMPTIONS

The initial step in arriving at these position definitions was to group the operational functions identified in Section 1 on the basis of logical considerations affecting their assignment to a position. The objectives of this grouping were to distinguish groups of functions possessing some commonality with respect to the human performance required and to further partition these groups into sub-groups which should not be separated when functions are assigned to crew positions. The five considerations outlined below were used:

1. Sequential and Temporal Considerations. The sequential nature of events during operation may be a requirement for clustering functions into a single position. Similarly, considerations should be given to avoiding assignment of functions to a given position when the functions occur simultaneously.

2. Equipment Considerations. Functions relating to a particular equipment configuration should be grouped so as to involve the smallest number of positions.

3. Homogeneity of Qualifications. The skill, knowledge, and personnel characteristic requirements for any one position should be as homogeneous as possible. This refers to both homogeneity of content area and homogeneity of training level. Clustering in terms of homogeneity of qualification also conforms with a logical training and selection program.

4. Constraints Imposed by the System Design. A number of constraints upon the grouping of functions into positions may be imposed by (a) the required location of a certain position, (b) the assignment of responsibility to certain positions, and (c) the interaction of certain functions even though they may not be sequential. In the case of the SST the system design constraints are principally those of piloting the aircraft which must be done from the two positions located in the front of the flight deck (normally the pilot and copilot position).

5. Compatibility with Personnel Classification and Career Structure Policies. It is desirable that each position have a bona fide job and task responsibility related to an existing or potential career field.

These considerations were first applied at the activity or function class level (e. g., Flight Management, Navigation, etc.) in order to determine whether or not the entire activity should be performed at the same position. The results of this evaluation are outlined below in terms of a brief statement of the rationale for distributing component functions or of keeping the activity intact.

Flight Management - Component functions of this activity could be distributed among crew members. A considerable amount of the flight management workload is attributable to system monitoring. In the SST, monitoring requirement can be separated into two general sorts: (1) monitoring which requires some degree of historical reference and/or integration with other concurrent data readouts to determine system status, and (2) monitoring which requires no history to obtain system status. Since the latter type of monitoring can be exchanged among positions with no degradation in performance, the activity is judged to be amenable for workload distribution.

Phase-Oriented System Checks - Component functions can be distributed although their assignment to positions will be somewhat constrained by the actual equipment configuration chosen. The component functions are not visualized as being appreciably different from those performed in current jet operations where these functions are distributed among all crew members.

Communications - Component functions can be distributed. At the activity level, none of the five considerations appear applicable to any appreciable extent.

Power Plant Operations - Component functions can be distributed. At the activity level, two types of performance may be involved, i.e., thrust variation by throttle adjustment, and thrust variation by fuel flow control. This could result in different controls located at different stations. Moreover, there appears to be no reason why any position could not provide, at least to some degree, some of the required performance if adequate instrumentation is provided. This assumption is based on the fact that desired thrust during certain portions of the flight profile can be expressed in terms of "percentage RPM," or other such parameters, and may be obtained by straightforward performance given the desired setting as a command/request for initiating the action.

Flight Control - Component functions can not be distributed; this activity should be assigned as an entity to one position. Considerations one, three, four, and five are generally applicable to the required performance throughout this activity. To some extent, the second consideration is also applicable.

Inlet Nozzle Configuration - Component functions of this activity can be distributed, but the second consideration may restrict it to one position. The performance visualized in this activity is primarily monitoring, and no historical reference is required to obtain and maintain status evaluation of control system effectiveness.

Navigation - Functions comprising this activity can also be distributed. Although all five considerations are applicable to some extent to the performance required in this activity, none of them are applicable to the total performance of the activity.

As the preceding paragraphs indicate, only the Flight Control activity was considered unsuitable for distribution among crew positions. Component functions of all other activities could be assigned to different positions. The next step in the analysis was to examine these distributable functions in order to identify any sub-groups or sub-sets of functions which, based on the five considerations cited above, should be kept together at a given position. The results of this effort are outlined below.

Flight Management - No interrelated sub-groups were identified; all functions may be distributed.

Phase-Oriented System Checks - No sub-groups; all functions may be distributed.

Communications - Two sub-groups were identified. These are comprised principally of: (1) functions involving communications between the crew and a remote station; and (2) functions involving communications between the crew and the ground handling crew immediately adjacent to the aircraft, and also between crew members within the aircraft. Although not absolutely necessary, it appears reasonable to restrict the performance of those functions involving crew communication to a remote station to one position. The basis for this is that, to some extent, special skills and knowledge are required, as indicated by the fact that a special license must be obtained. The sub-groups below reflect a breakdown made on this basis. Sub-group 1 functions all involve use of radio communications of a nature requiring performance by a licensee and sub-group 2 functions may be performed by any crew member.

Sub-group 1 includes Functions:

3.1 Ground Handling Phase Communications
3.3 Departure Control Communications
3.6 Initial Position Report
3.7 ATC Communications for Hand-off
3.8 Enroute ATC Communications
3.10 Enroute Company Communications
3.11 ATC Communications for Deceleration/Initial Descent
3.12 ATC Approach Control Communications
3.13 Final Approach Communications
3.14 Destination Ground Handling Communications.

Sub-group 2 includes Functions:

3.1 Ground Handling Phase Communications
3.2 Cockpit Communications for Takeoff
3.4 Activate/Deactivate No Smoking Signs
3.5 Activate/Deactivate Fasten Seat Belt
3.9 Intercom Announcements
3.14 Destination Ground Handling Communications
3.15 Visual Traffic Vigilance.

Power Plant Operation - Two sub-groups of this activity were identified: Sub-group 1, throttling performance, and sub-group 2, fuel flow control performance. Sub-group 1 is comprised of functions which are all accomplished primarily by manipulation of the engine throttles. Sub-group 2 contains functions which are all accomplished by controlling the fuel flow to the engines. It seems reasonable to assign these sub-groups to different positions, since it can be assumed that different controls and instrumentation will be required for the two sets of functions. However, once assigned neither sub-group should be broken down to any greater degree, since this would require unnecessary duplication of controls and instrumentation.

Inlet Nozzle Configuration - No sub-groups are identified. All functions could be distributed as long as instrumentation does not become a constraint.

Navigation - Three separate sub-groups and two independent functions can be identified. They are as follows:

Sub-group 1 includes Functions:

7.3 Monitor Enroute Weather Conditions
7.4 Monitor Destination/Alternate Weather Conditions
7.5 Provide Differentials in Forecast to Actual Weather Condition
7.6 Calculation of Overpressure Being Generated.

These functions all involve, to a large extent, a capability to assess the impact of observed and forecasted weather phenomena on the operation of the SST. This implies a requirement for special skills and knowledge. And, to some extent, all five grouping considerations (pg. 77) are applicable.

Sub-group 2 includes Functions:

7.7 Internal System Position Generation
7.8 External System Position Generation
7.9 Present Position Updating.

These functions all involve the capability to provide the best possible estimate of the current position of the aircraft. To some extent, all five grouping considerations (pg. 77) are also applicable to this sub-group.

Sub-group 3 involves Functions:

7.1 Maintain Takeoff Flight Path
7.2 Maintain Flight Path for SID
7.12 Maintain Flight Path for SIA
7.13 Maintain Flight Path for All-weather Landing.

These functions are all concerned with navigation of the aircraft within the terminal control zone. Considerations 1 and 4 (pg. 77) are also applicable to these functions.

Independent Functions:

7.10 ETA Prediction
7.11 Optimum Profile Generation

ETA prediction can be assigned to any crew position at which the necessary data is available. Optimum profile generation should be assigned to a senior crew member who can bring the most experience to bear on any problem area involved, and has the responsibility and authority to make the appropriate judgments and implement the appropriate actions. (These functions are referred to as sub-group 4 in subsequent discussions.)

The next step in defining crew positions was to prepare a cumulative workload profile for each activity assigned as an entity, and for each sub-group of functions identified, such that these profiles, together with the remaining function/activity workload profiles, could be used to establish a workload-balancing distribution of functions among positions for different crew complements.

A few constraints were also considered relative to distribution of work among various number of crew members as follows:

Two-Man Operation - The assumptions utilized regarding the two-man operation may be generally summarized as follows: In view of present redundancy requirements, which undoubtedly will be retained for SST operations, two-man operation of the SST will dictate a crew composed of two pilots (e.g., a Captain and a First Officer).

Three-Man Operation - The same general assumption utilized in looking at the two-man operation is employed here, i.e., two of the three positions would be manned by pilot personnel. No other assumptions regarding crew composition were made.

Four-Man Operation - The same general assumption regarding the pilot/copilot concept was the only one made regarding composition.

5.2 RESULTS

The results of grouping activities and function sub-groups on the basis of homgeneity and level of workload, for two-man, three-man, and four-man operation of the SST, are shown in figure 7. A summary of the maximum (R max) and average ($\bar{R}$) workload for each position is shown in Table 4a below:

	Z Man Crew		3 Man Crew		4 Man Crew	
	R Max	$\bar{R}$	R Max	$\bar{R}$	R Max	$\bar{R}$
Position 1	16.71	8.48	13.11	5.23	10.00	3.78
Position 2	18.83	7.98	11.02	5.53	8.17	3.59
Position 3	---	---	9.41	5.66	9.91	3.98
Position 4	---	---	---	---	7.67	4.99

Table 4b shows the distributions of activity and function sub-groups to the various positions. To the extent possible, the five considerations used to break the activities down into sub-groups were applied in the position grouping The actual functions performed by each position are spelled out in the next Section (6).

It should be pointed out that no attempt was made to stipulate a firm crew size and complement, principally for two reasons: (1) any such conclusion of this stage of system development would be obviously

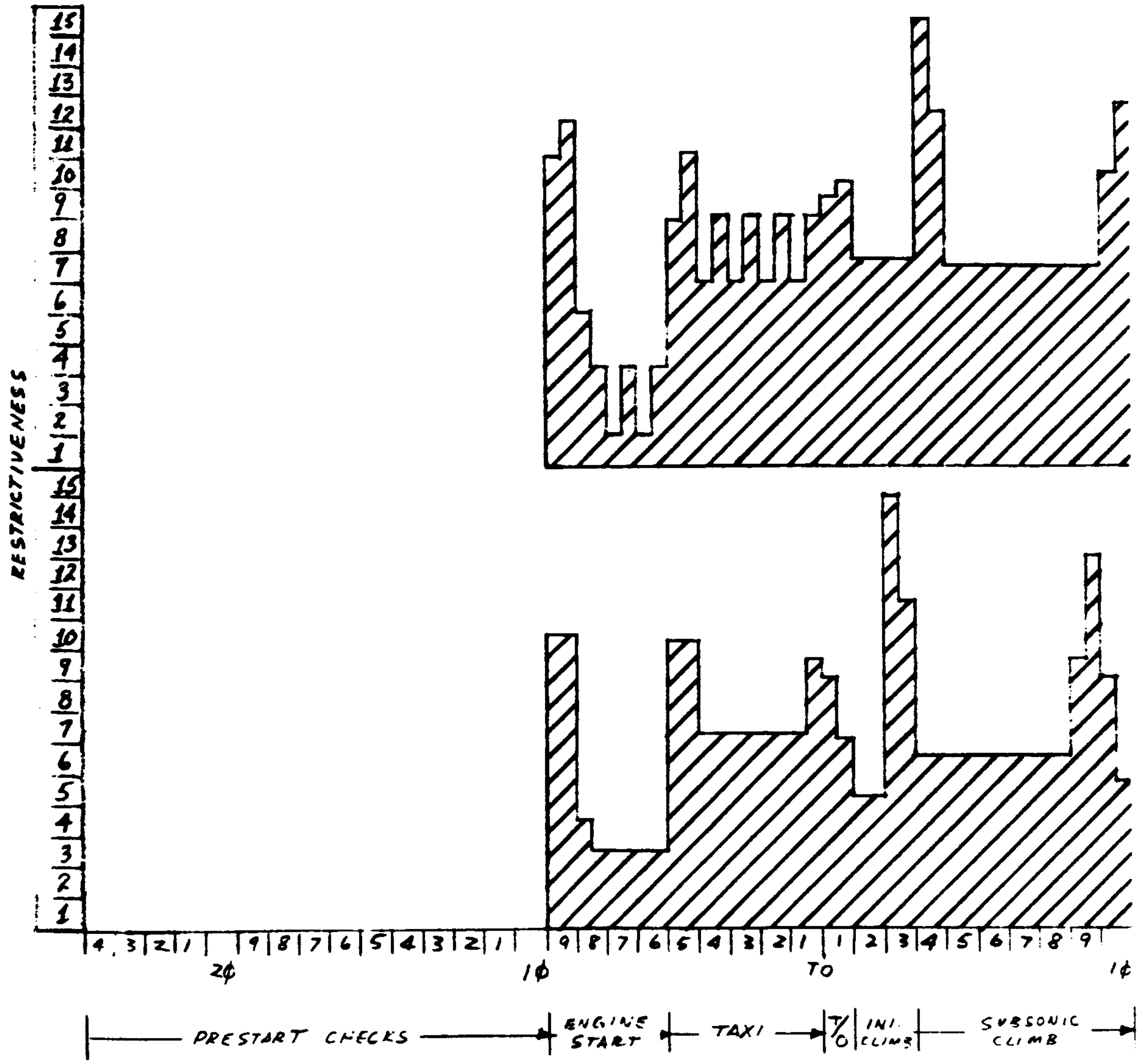


Figure 7a. Distribution and Workload for 2-Position Operation

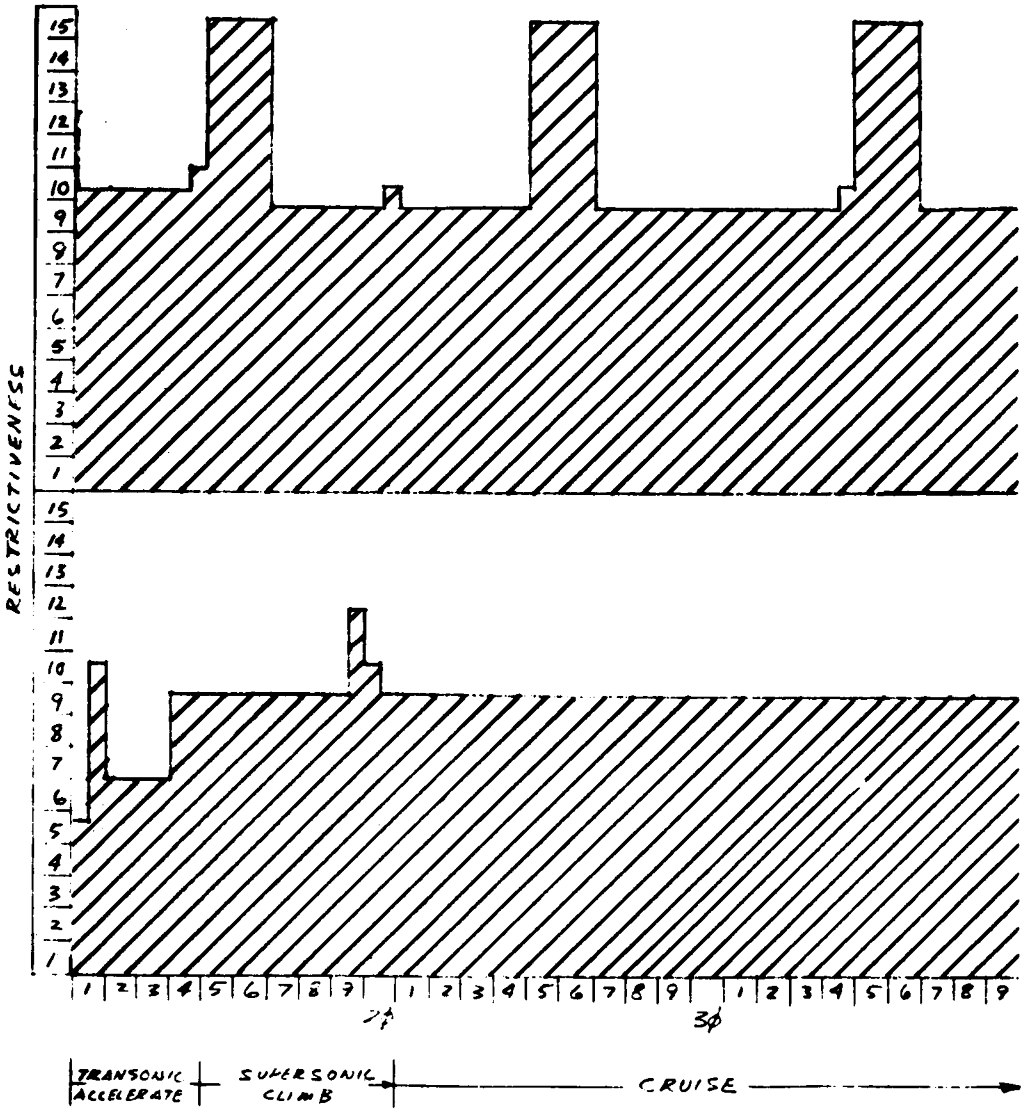


Figure 7a (Continued)

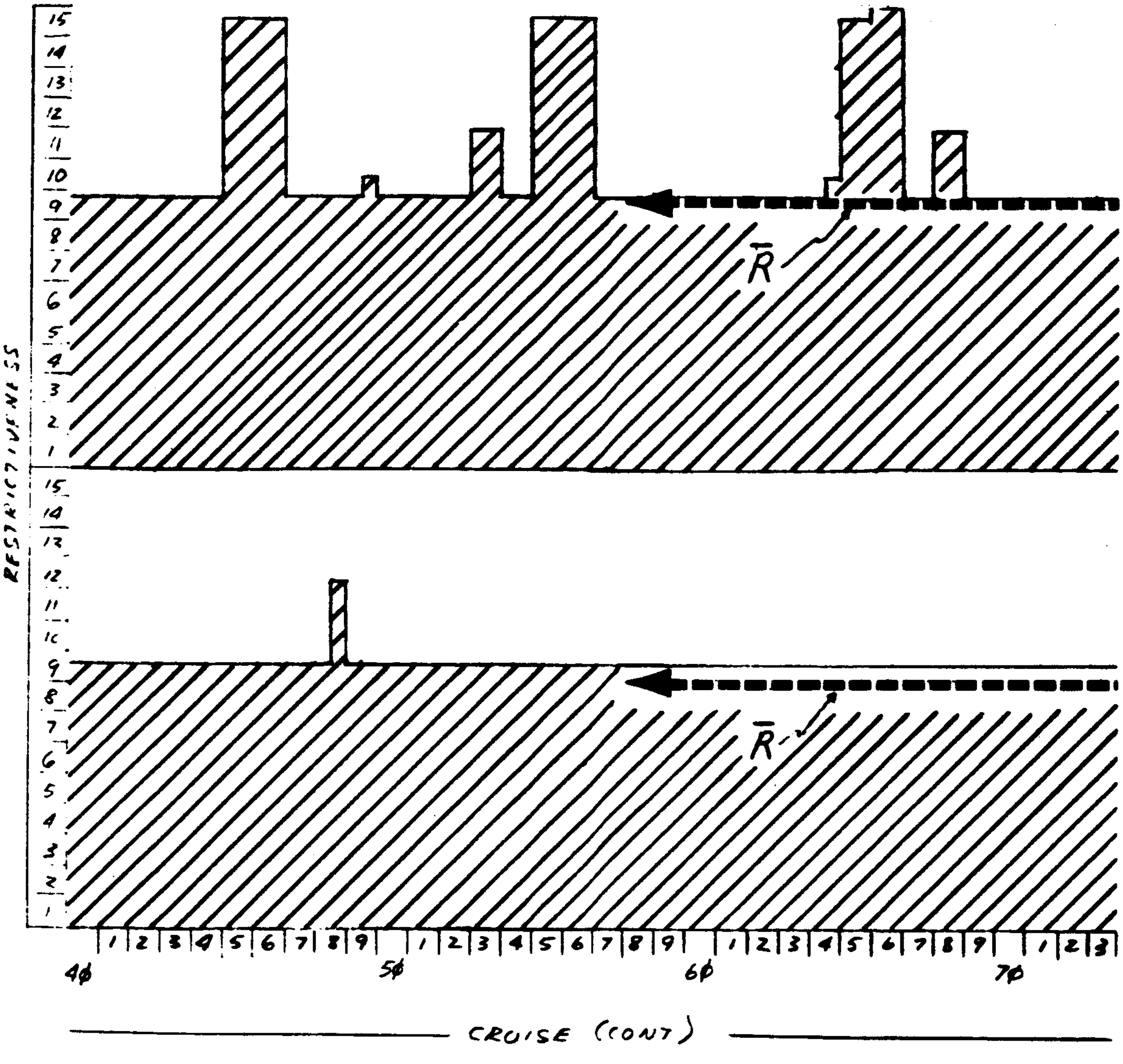


Figure 7a (Continued)

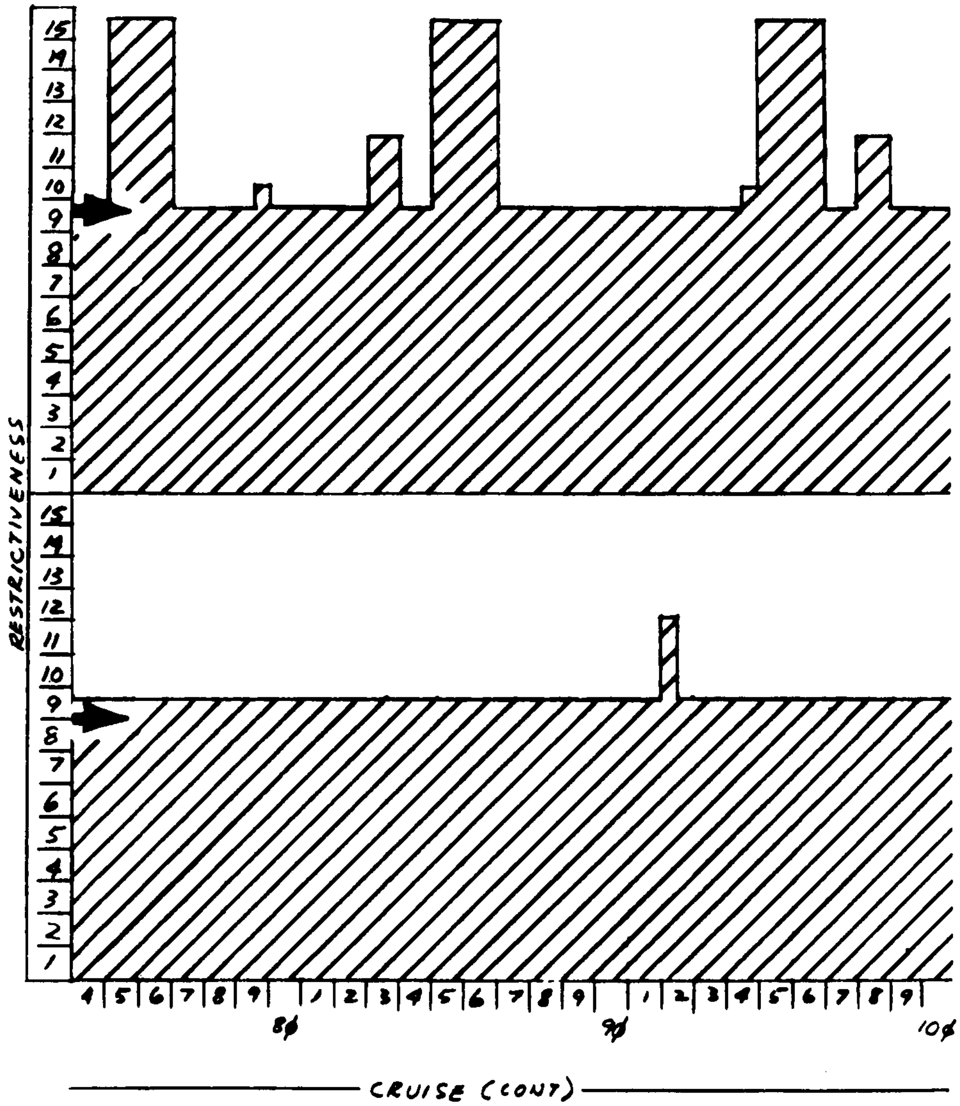


Figure 7a (Continued)

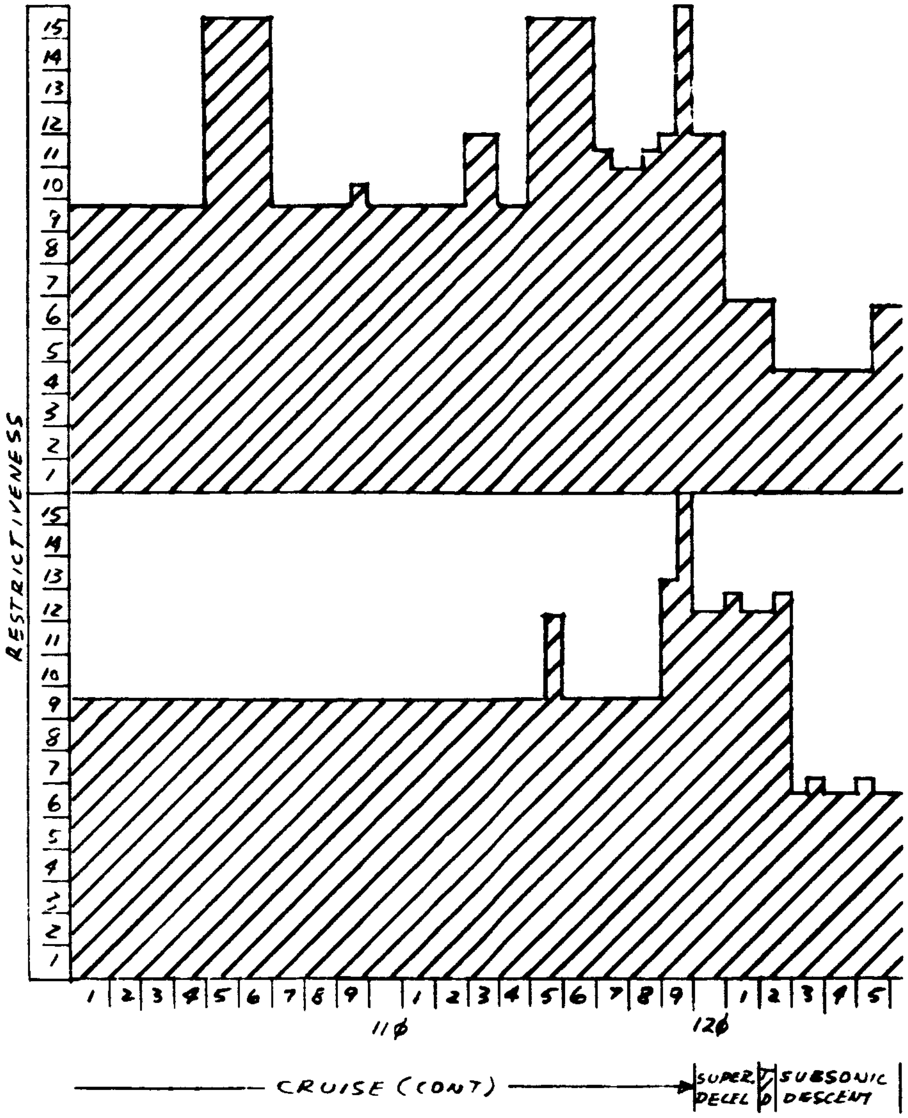


Figure 7a (Continued)

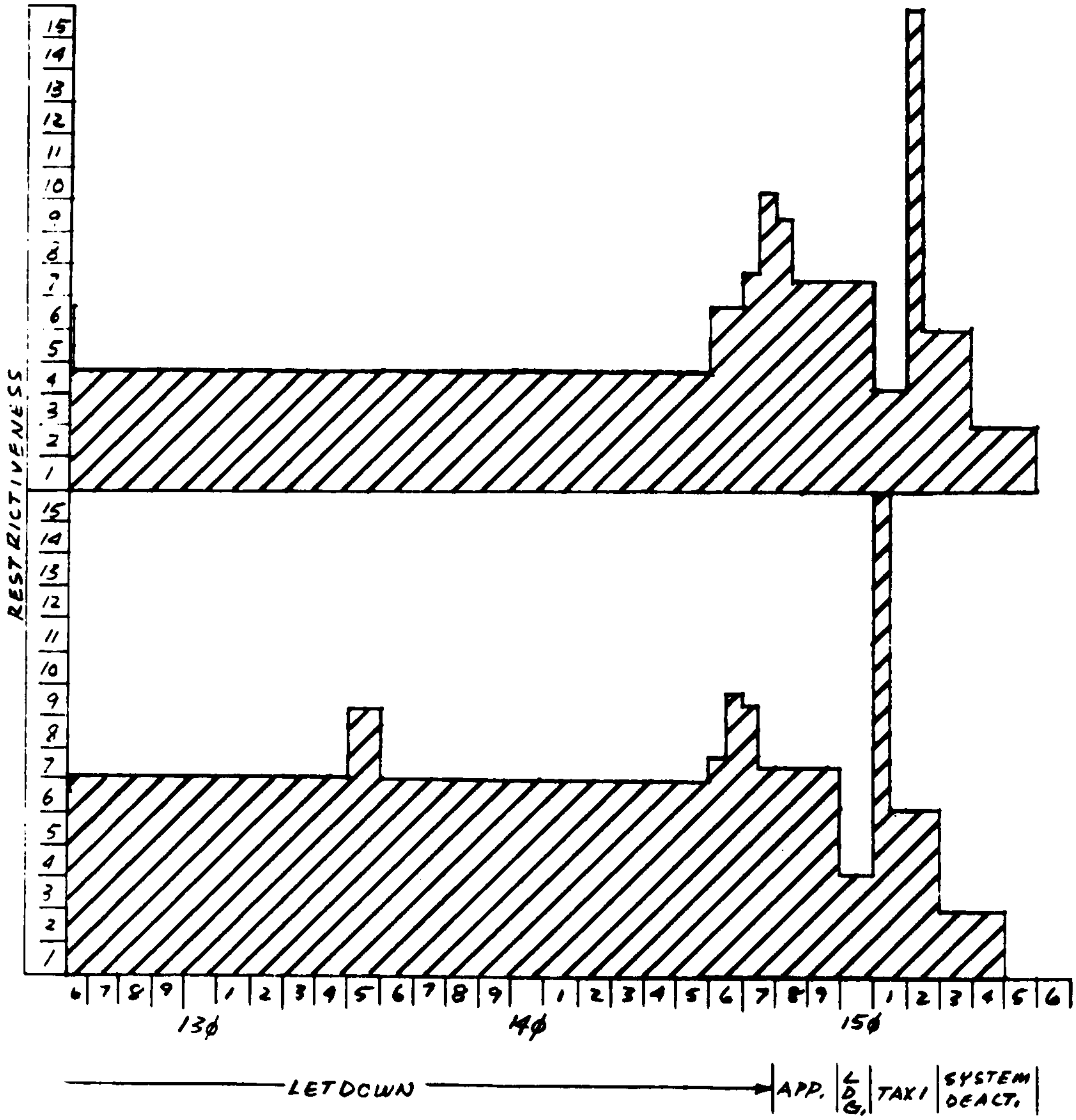


Figure 7a (Continued)

Figure 7b. Distribution and Workload for 3-Position Operation

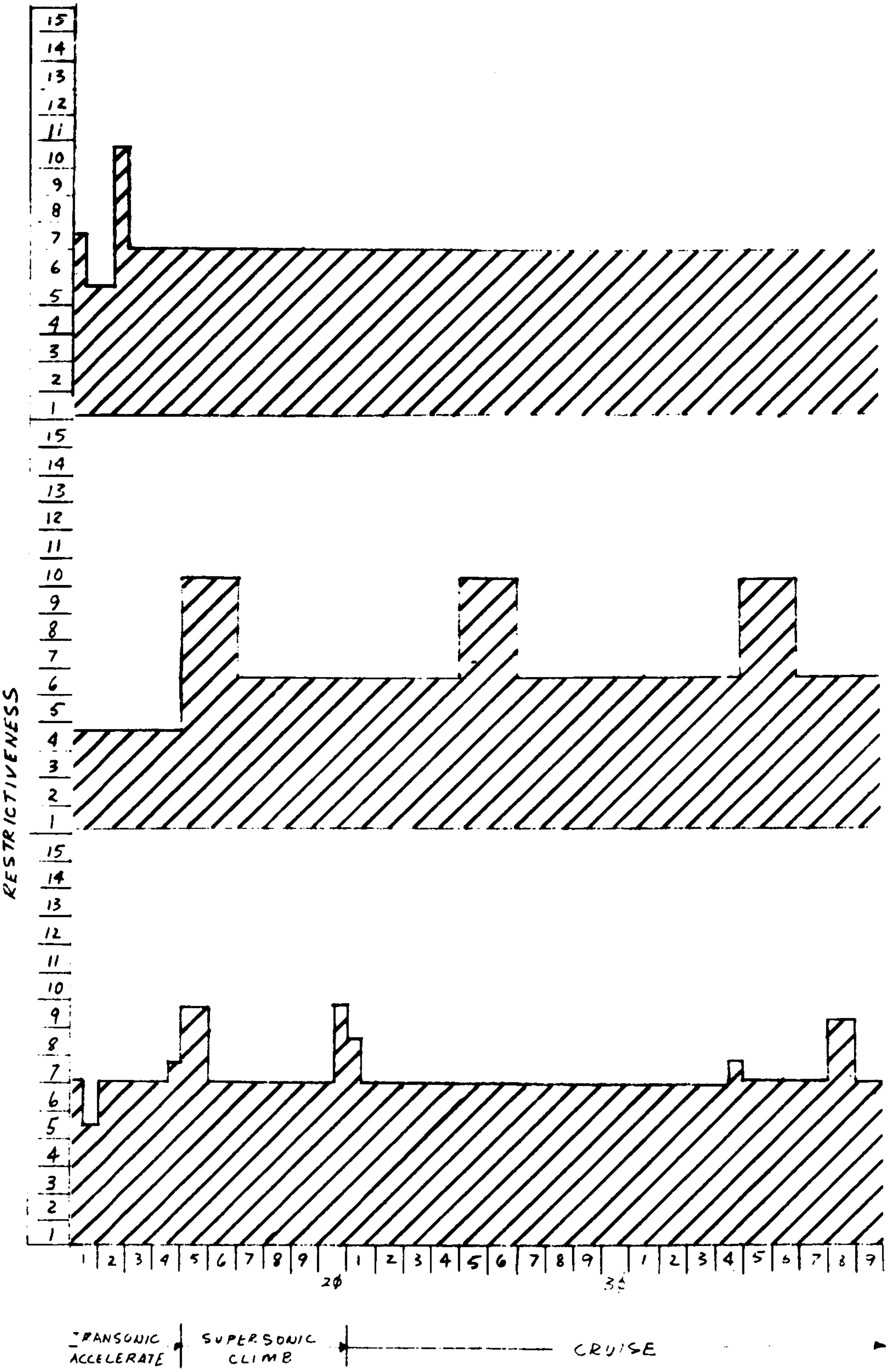


Figure 7b (Continued)

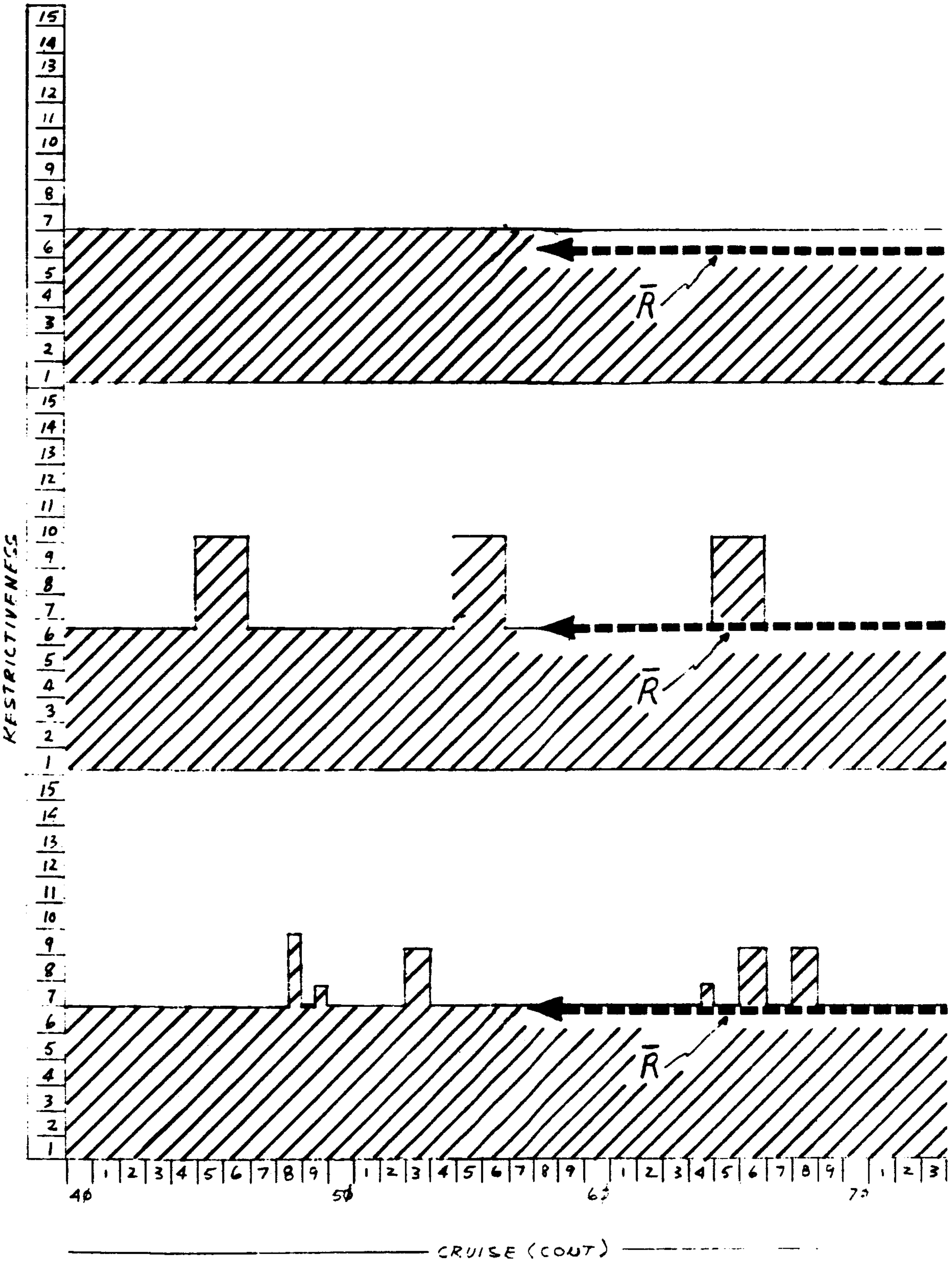


Figure 7b (Continued)

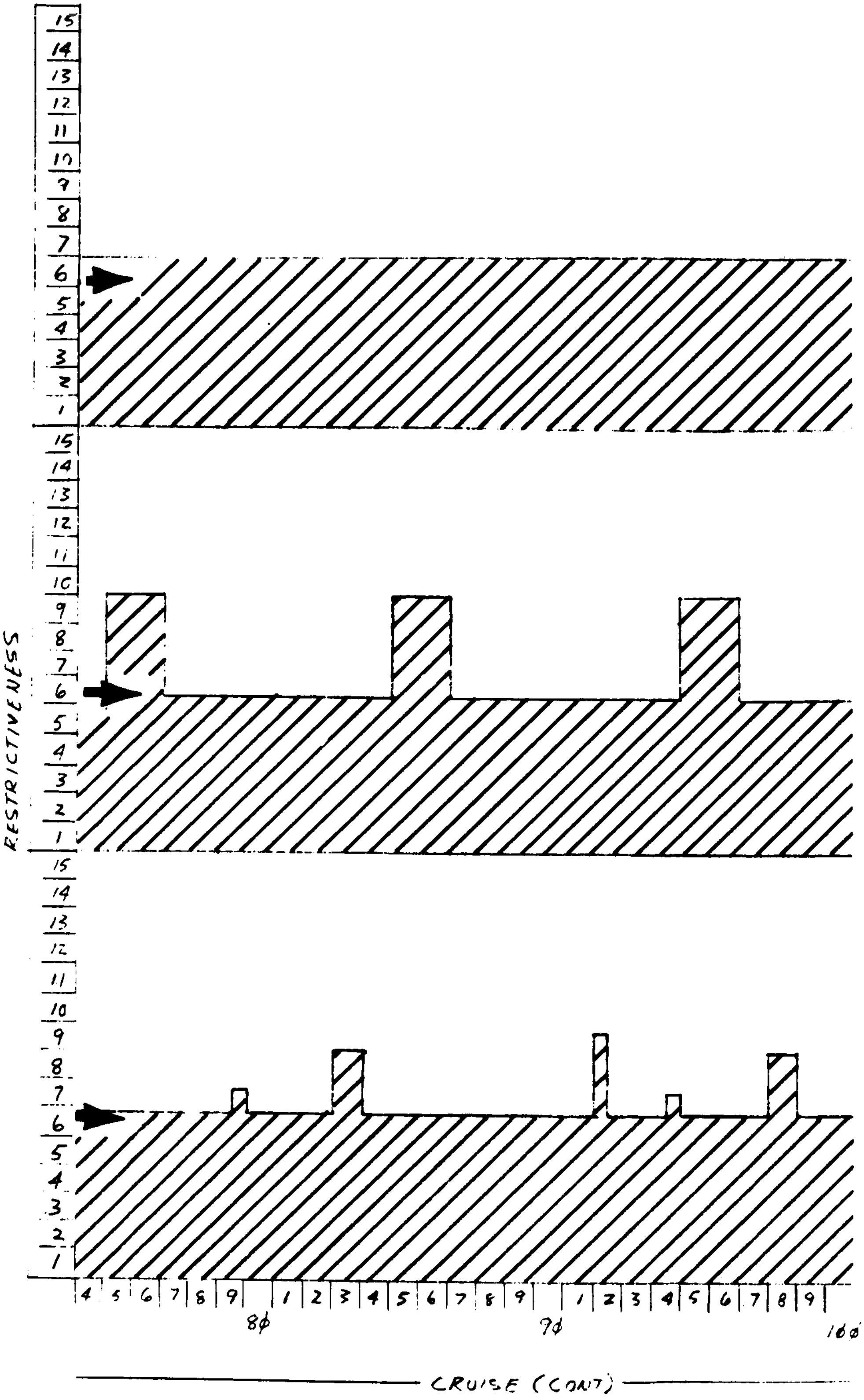


Figure 7b (Continued)

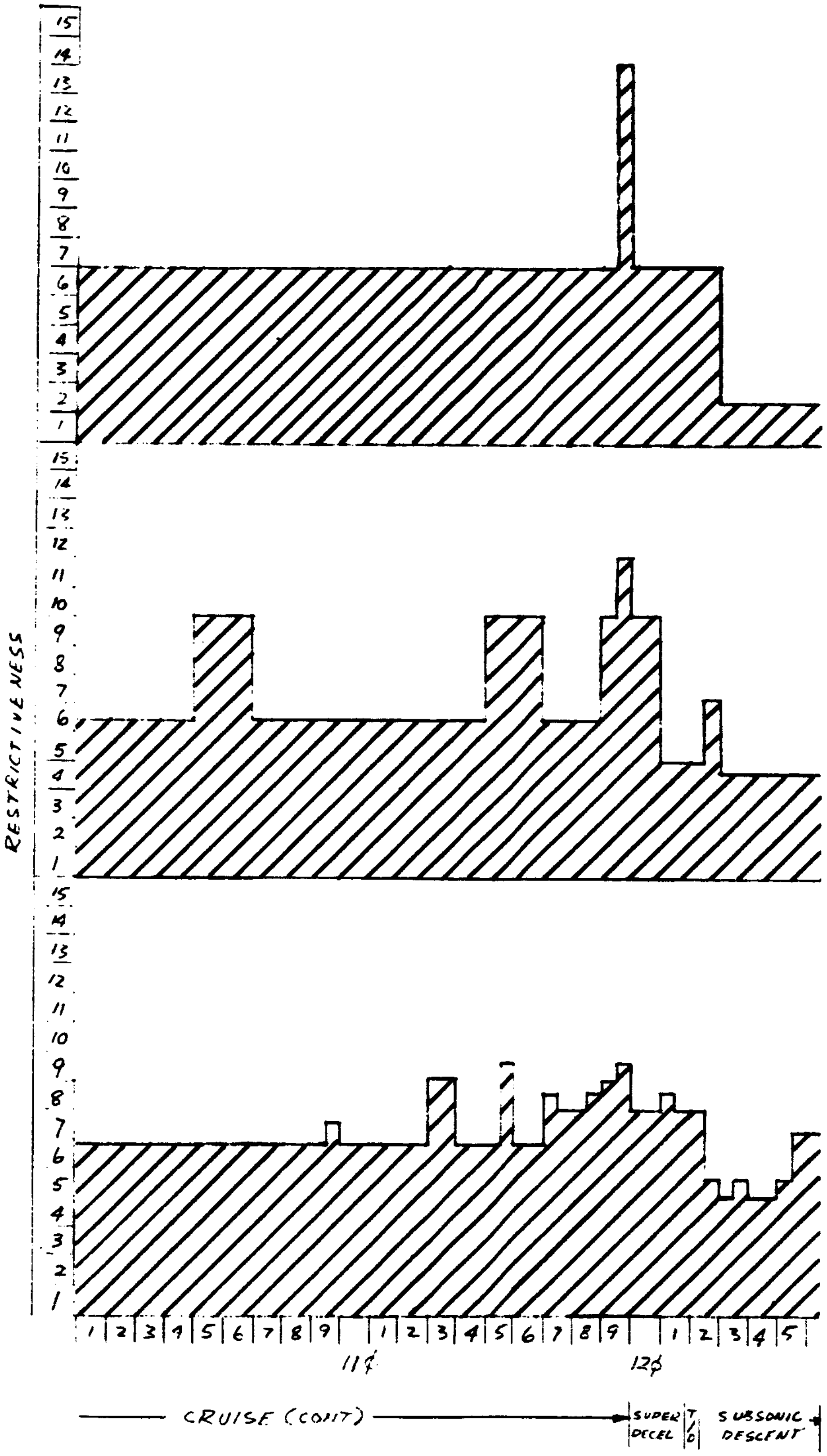


Figure 7b (Continued)

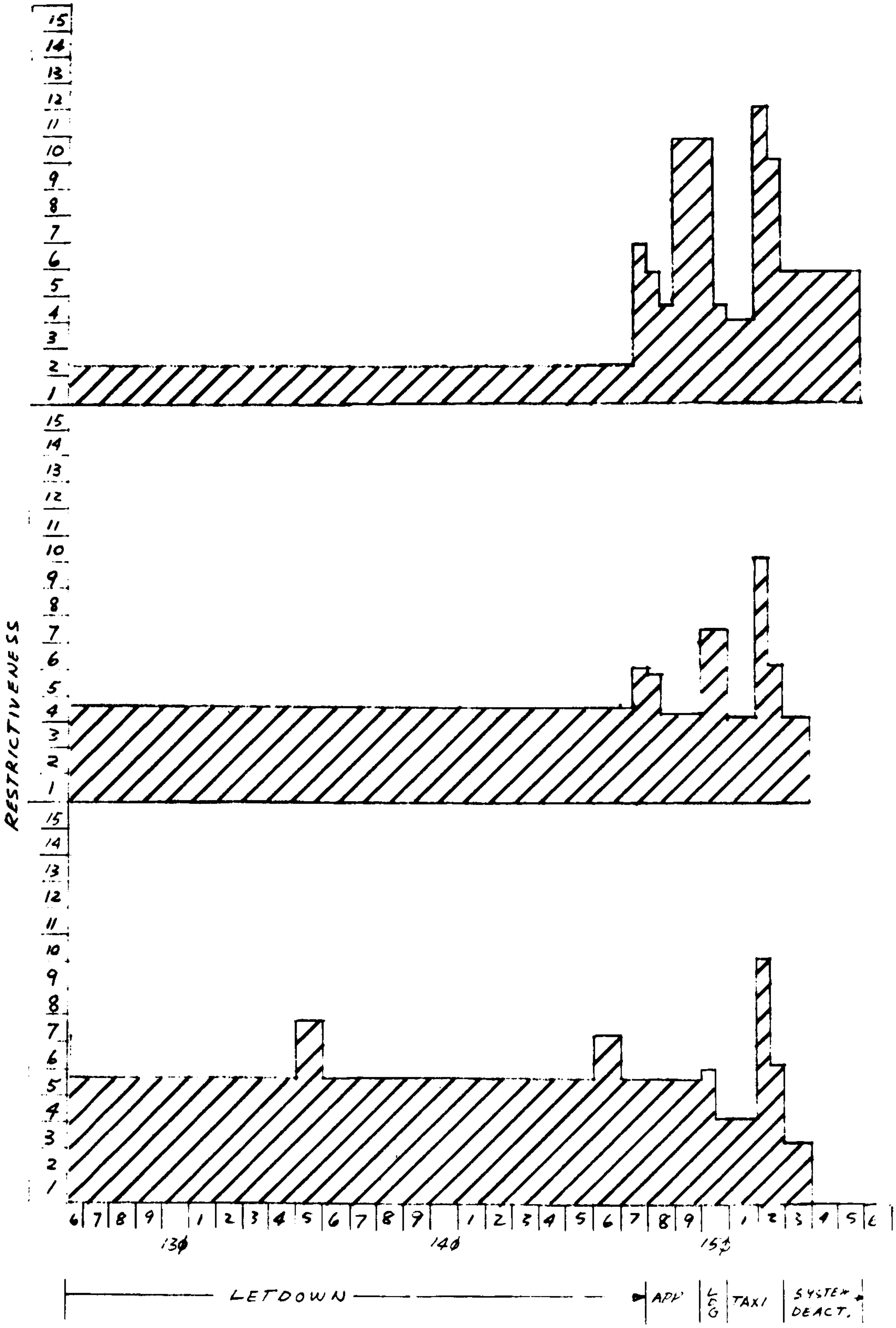


Figure 7b (Continued)

Figure 7c. Distribution and Workload for 4-Position Operation

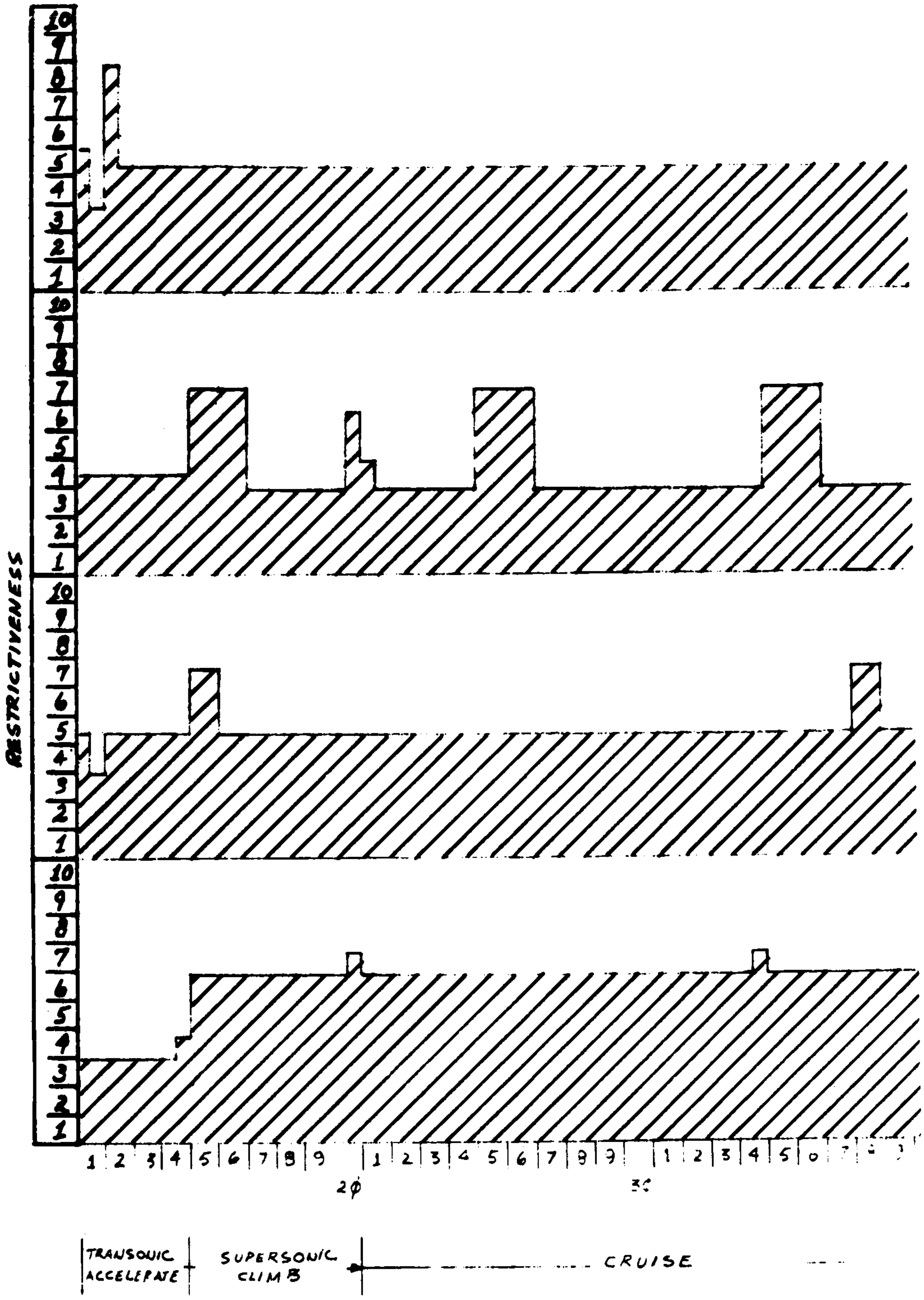


Figure 7c (Continued)

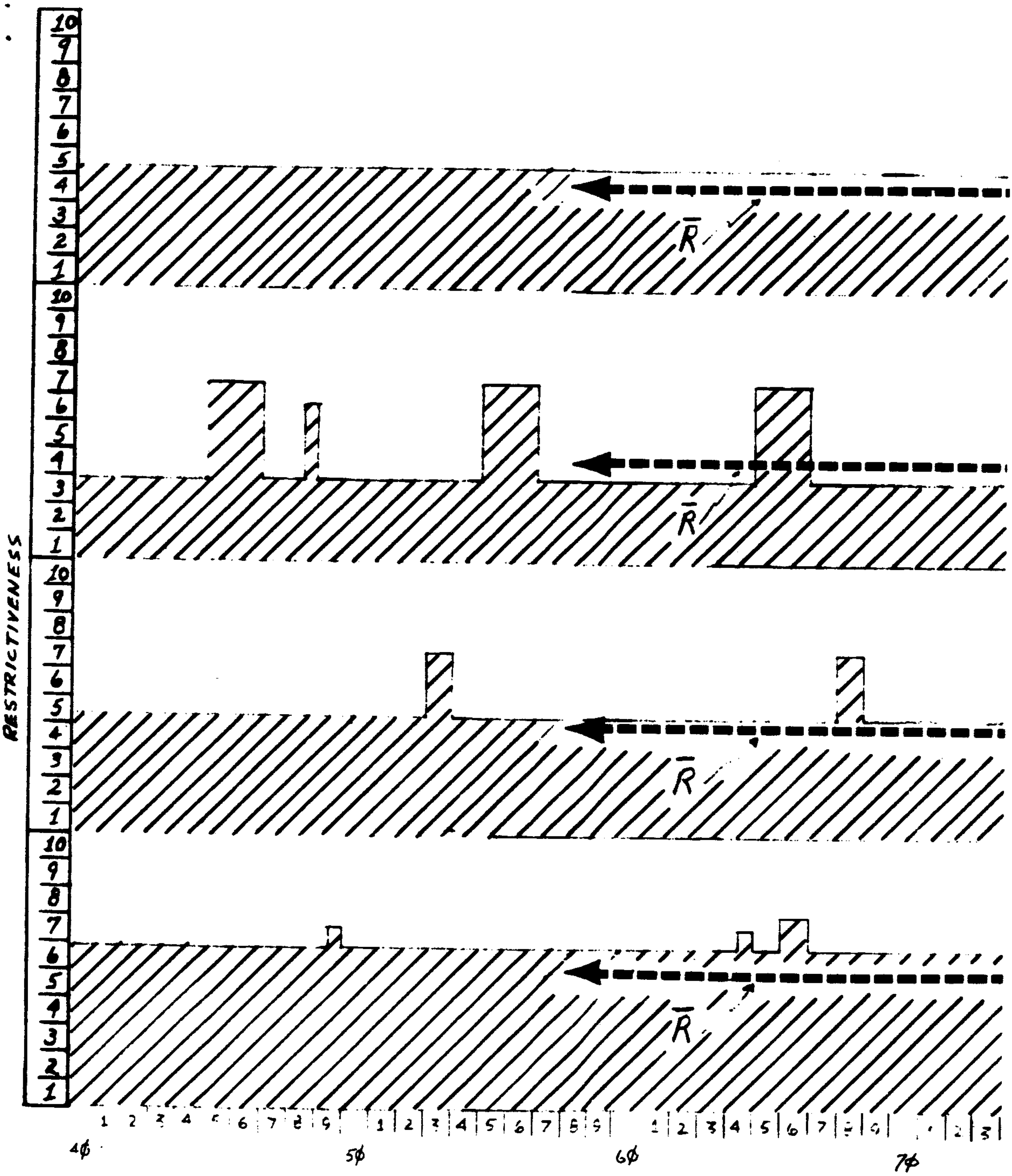


Figure 7c (Continued)

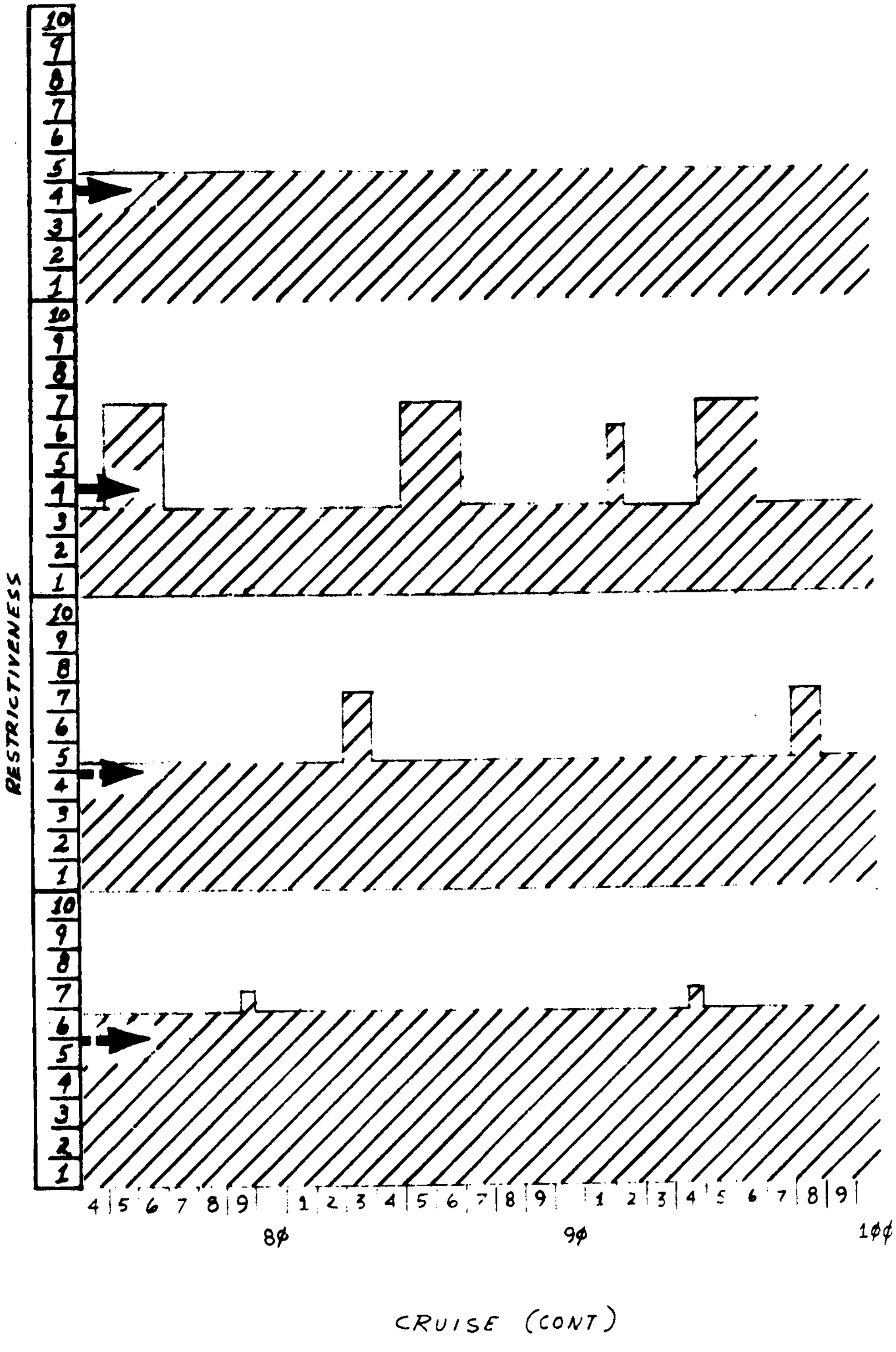


Figure 7c (Continued)

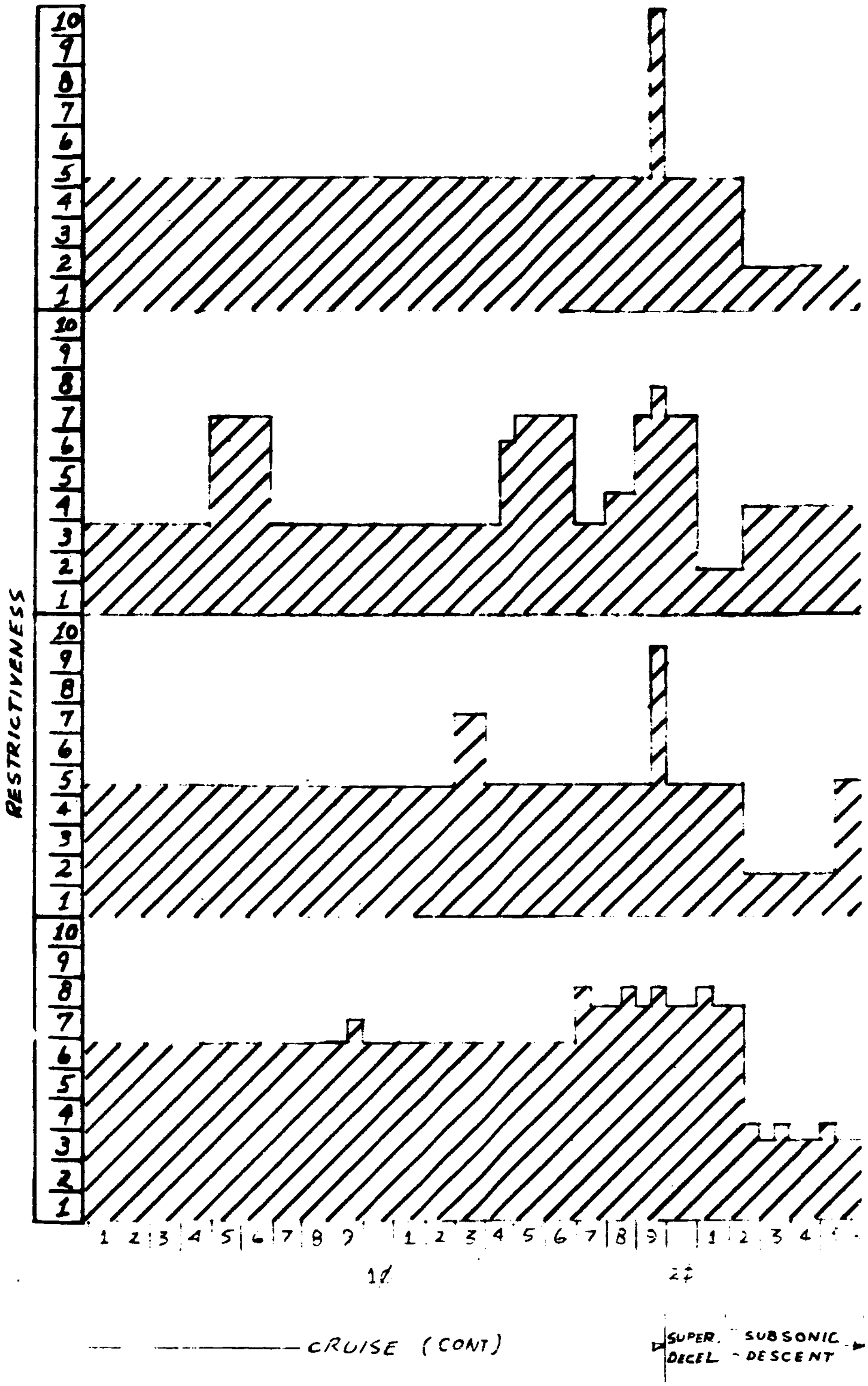


Figure 7c (Continued)

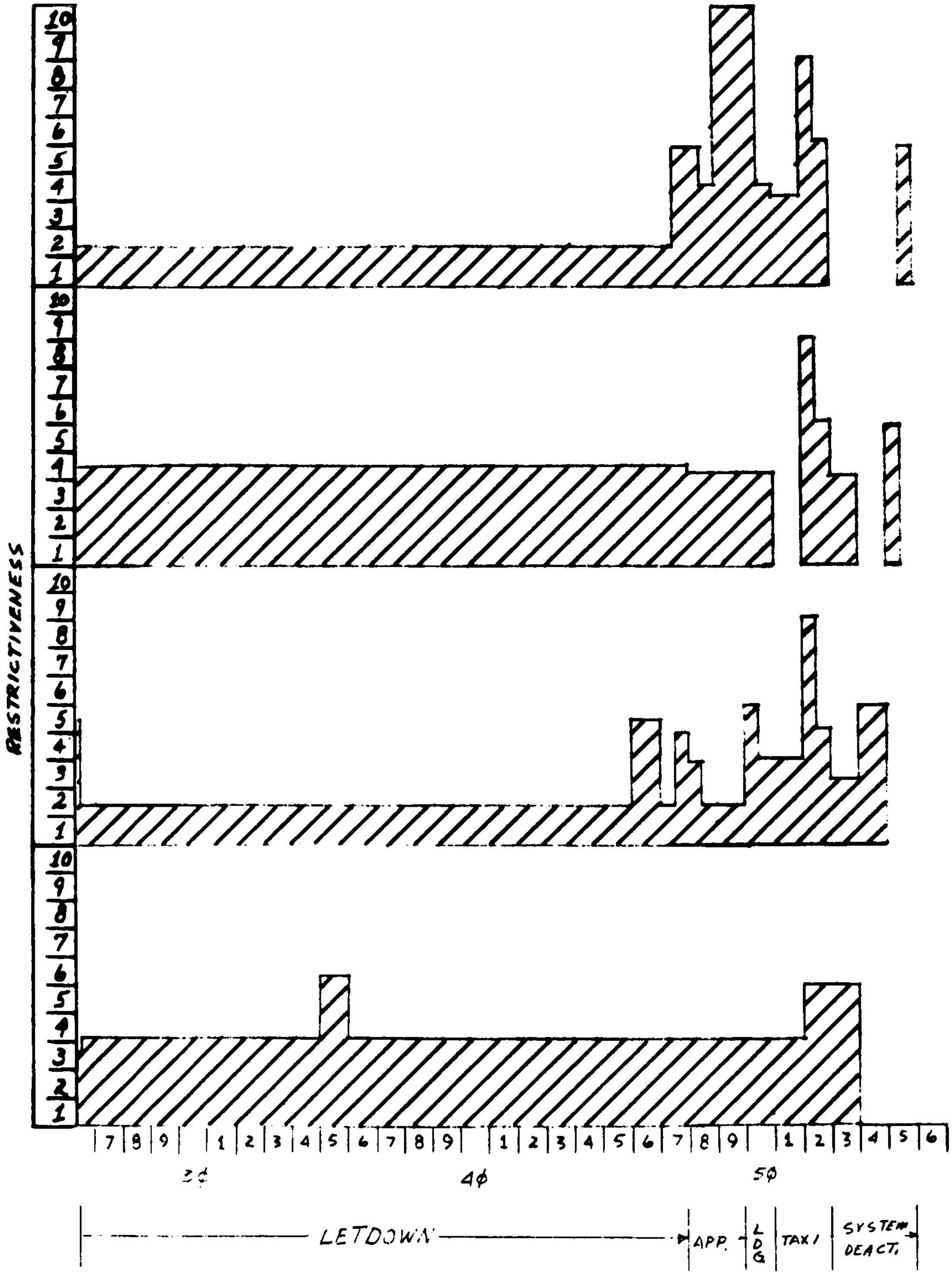


Figure 7c (Continued)

Table 4. Results of Grouping Activities and Functions into 2, 3, and 4 Positions

TWO MAN OPERATION

Position #1

a. Navigation sub-group 2
b. Navigation sub-group 3
c. Navigation sub-group 1
d. Communications (both sub-groups) (Majority)
e. Phase-oriented system checks

Position #2

a. Flight control activity
b. Power plant operation activity
c. Inlet nozzle configuration activity
d. Navigation sub-group 4
e. Communications (both sub-groups) (Minority)
f. Phase-oriented system checks

THREE MAN OPERATION

Position #1

a. Flight control activity
b. Power plant operation sub-group 2
c. Inlet nozzle configuration activity
d. Navigation independent function 7.10
e. Communications (both sub-groups) (Minority)
f. Phase-oriented system checks

Position #2

a. Navigation sub-group 2
b. Navigation independent function 7.11
c. Navigation sub-group 3
d. Communications (both sub-groups) (Minority)
e. Phase-oriented system checks

Position #3

a. Navigation sub-group 1
b. Power plant operation sub-group 1
c. Communications (both sub-groups) (Majority)
d. Phase-oriented system checks

Table 4. Results of Grouping Activities and Functions into 2, 3, and 4 Positions (Continued)

FOUR MAN OPERATION

Position #1

a. Flight control activity
b. Power plant operation sub-group 2
c. Inlet nozzle configuration activity
d. Phase-oriented system checks

Position #2

a. Navigation sub-group 2
b. Navigation sub-group 3
c. Communications (sub-group 2) (Majority)
d. Phase-oriented system checks

Position #3

a. Navigation sub-group 1
b. Power plant operation sub-group 1
c. Phase-oriented system checks

Position #4

a. Navigation sub-group 4
(Independent functions)
b. Communications (sub-group 1)
c. Communications (sub-group 2) (Minority)
d. Phase-oriented system checks

premature, and (2) such a conclusion can only be reached satisfactorily if supported by a well-designed simulation program. However, the implications of the workload distributions over typical SST flight profiles were spelled out in terms of workload-balancing assignments of functions to crew positions and of the ability of two, three, and four man crew complements to handle the estimated loadings. The results of the distribution are contained in Table 4. The implications of this distribution lead to the following additional results:

1. A three man crew can perform all the functions but their full time and attention is required (see Section 2). The basic distribution of responsibility among the three positions is as follows:

   Position 1 - Flight control, fuel operations, ETA estimation, and some communications and system checks.

   Position 2 - Navigation functions concerned with present position, terminal area navigation, and profile optimization; some communications and system checks.

   Position 3 - Navigation aspects of weather, throttle control, a majority of communications and some system checks.

   Positions 1 and 3 would be "up-front" as in todays pilot/copilot arrangement.

2. Under the same assumptions (as for a three man crew), it appeared certain that a two-man crew would be overloaded. The basic distribution of workload among the two positions is as follows:

   Position 1 - Navigation, communications and some system checks.

Position 2 - Flight control, engine operations, flight path optimization, and some communications and system checks.

3. A four-man crew could easily manage the workload distribution and this crew complement would provide a reserve capacity for handling non-routine task requirements and for crew relief. The basic distribution of the workload among the four positions is as follows:

   Position 1 - Flight control, engine operations, and some system checks.

   Position 2 - Navigation aspects concerned in the present position and terminal area, some communications, and some system checks.

   Position 3 - Navigation aspects of weather, throttle control, and some system checks.

   Position 4 - ETA prediction and flight path optimizations, a majority of the communications, and some system checks.

   Position 1 and 3 would be "up-front" as in todays pilot/copilot arrangement.

Discussion of these results, together with other results from Sections 1 through 4, is contained in Section 6 which synthesizes the results as the implied potential crew roles.

6.0 POTENTIAL ROLES OF SUPERSONIC TRANSPORT CREWS

This section synthesizes the results of the study which have implications for potential crew roles. The information is summarized in two ways in this section. First, the overall flight crew role in the implementation of major system functions is presented and second, the crew role for individual positions for two, three, and four man operation is presented.

6.1 OVERALL FLIGHT CREW ROLE IN IMPLEMENTING ACTIVITIES

In the analysis of SST operational functions, implementation concepts were examined for 89 system functions, distributed into the seven broader categories of Flight Management, Phase-oriented System Checks, Communications, Power Plant Operations, Flight Control, Inlet Nozzle Configuration, and Navigation. A brief characterization of flight crew participation in the performance of these functions, as reflected in this review of implementation concepts, is presented below for each of these categories.

FLIGHT MANAGEMENT

This set of functions is concerned with the ongoing requirement for assessing the overall flight situation and operating condition of the aircraft and for making decisions regarding the conduct of the flight and the manner in which controlled subsystems are employed in order to achieve established safety, flight planning and economic objectives. The more severe safety, passenger discomfort, and economic penalties of system mismanagement in the SST flight environment dictate increased emphasis on these functions. While improvements in the processing and display of system data are seen as essential to effective performance, it seems clear that flight management will be a mandatory crew function rather than a machine function. It will be the crew's responsibility to diagnose the situation as it develops (e. g., the flight is or is not proceeding according to plan, conditions actually encountered do or do not represent a flight hazard, etc.) and to exercise final authority over the control actions taken (e. g., reconfigure the aircraft for more efficient operation, deviate from the flight plan, etc.).

PHASE-ORIENTED SYSTEM CHECKS

These functions are concerned with setting up equipment and verifying system status and performance to insure that the aircraft is ready to initiate a specified flight phase or phase segment, e. g., take-off. Increased applications of automated checkout procedures and monitoring of aircraft configuration is expected here. The crew's role will consist of the selection and initiation of appropriate check sequences and the acceptance or rejection of check results. Manual repositioning of various cockpit controls and subsystem mode selectors in response to checklists and/or readouts of the results of automated check sequences will continue to be a crew responsibility.

COMMUNICATIONS

Four types of communication activity were considered: (1) Air Traffic Control communications, (2) intra-crew communications, (3) crew-passenger communications, and (4) company communications (e. g., to ground support personnel and dispatchers). Crew roles in intra-crew and company communications are not expected to change in SST operations. Requirements for crew communication with passengers is expected to increase somewhat in order to prepare passengers for unfamiliar conditions (e. g., during climb-out, transonic acceleration, descent, etc.) and to inform them on aircraft performance and the flight environment. However, the major change in crew role is expected in connection with ATC communications. Consideration is being given to automatic data link systems for control communications which will relieve the crew of routine control reporting and ATC clearance reception and copying. The crew's role here is expected to shift to one of monitoring data link operation. Conventional voice communication procedures will be used only for non-routine situations or when data link equipment malfunctions.

POWER PLANT OPERATION

Manual manipulation of throttle controls, regulation of fuel flow to the engines, and the operation of such devices as thrust reversers will continue to be a crew responsibility in the SST. However, for certain thrust schedule control requirements, such as maintaining an optimum flight profile, automatic throttle control will be available and the crew role will change to one of commanding the desired thrust control objective (i. e., maintain programmed optimum profile, constant mach cruise, selected final approach speed, optimum angle of attack and/or rate of descent during approach, etc.) and of monitoring system performance.

INLET DUCT/EXHAUST NOZZLE CONFIGURATION CONTROL

These functions are peculiar to propulsion systems developed for supersonic flight and derive from the requirement for matching intake and exhaust velocities to engine airflow requirements. It is generally accepted that control of inlet duct variable geometry and the exhaust nozzle will be automatic. The crew's role will be to initiate the operation of this control system for supersonic flight and to monitor its performance. No back-up manual control is envisioned which will allow the aircraft to continue in supersonic flight if this system should malfunction; the crew's role in this instance would be to reconfigure the aircraft for subsonic flight.

FLIGHT CONTROL

The extent to which flight control functions should be automated is one of the most controversial issues in projected SST operations. It is generally conceded that a fully-powered, electromechanical control surface actuation system, selectively controllable by an autopilot system which can be coupled to a variety of on-board and ground-based command systems, will be available and could provide for automatic flight control throughout the flight profile. The controversies revolve around such issues as system reliabilities, the economics of wider applications of automatic control, provisions for pilot intervention in critical flight phases, and pilot acceptance of automatic control. Perhaps the most conservative position to adopt is that increased automatic control capability will be available to the crew and that the crew's role will be to select both the control axes it will be applied to (e. g., course hold, pitch axis only, airspeed hold, approach and landing control, etc.) and the command system for various phases of flight. Command systems which might be coupled to the automatic flight control system include on-board navigation and "optimum profile generation" computers, data-link coupling to external traffic control or approach and landing control systems, and crew members. In the latter instance the crew role would include the insertion of commands such as altitudes, speeds, headings, and turns. Monitoring of system performance and the assumption of manual control at any time during the flight profile would continue to be a necessary crew role.

NAVIGATION

A fully integrated, automatic navigation system with provisions for system monitoring, manual data entry, and improved command steering, navigation situation, and selective data readouts is envisioned for the SST. The system is also expected to provide for direct coupling with autopilot and automatic throttling for optimum flight profile control. A wide range of mechanization concepts has been proposed for this system and Volume II must be consulted for a discussion of the more detailed implications for crew participation in navigation functions. In general, the crew's role will be to set up the navigation system for various flight phases and navigation objectives (e.g., departure, optimum cruise profile, holding pattern, etc.), to monitor steering commands and situation displays, and to manually override or reconfigure the system when flight plan changes are required. Failure of the primary system will require the crew to navigate by conventional techniques, but it is considered that the more stringent traffic control and profile optimization requirements of supersonic flight could not be met in this operating mode and a transition to subsonic speeds would be necessary.

6.2 CREW ROLE FOR INDIVIDUAL POSITIONS OF TWO, THREE AND FOUR MAN OPERATIONS

Tables 5, 6, and 7 present the results of distributing the SST operations among two, three, and four man crews. The tables list the function which each position is responsible for.

Major conclusions concerning potential crew roles are presented in Part III of this report.

TABLE 5 Potential Role Responsibility for Two Man Operation

POSITION 1

Maintain Take-off flight path
Maintain flight path for standard instrument departure
Monitor enroute weather conditions
Monitor destination and alternate weather
Provide differential in forcest/actual weather conditions
Calculation of overpressure being generated
Internal system position generation
External system position generation
Present position updating
Maintain flight path for standard instrument approach
Maintain flight path for all weather landing
Ground Handling Phase communications
Cockpit communications for take-off
Departure control communications
Activate/deactivate "no smoking" signs
Activate/deactive "fasten seat belt" signs
Initial position report
ATC communications for handoff
Enroute ATC communications
Intercom announcements
Enroute company communications
ATC communications for deceleration/initial descent
ATC approach control communications
Final approach communications
Destination ground handling communications
Visual traffic vigilance

NOTE: Both positions would be responsible for a specific areas of the phase oriented system checks. In most cases these would be dictated by the aircraft systems under the control of the particular position.

POSITION 2

Engine start and checkout
Thrust application=f(surface speed)-taxi
Thrust application=f(maximum power)-take-off thrust
Thrust application=f(surface speed)-thrust reversal
Thrust application=f(noise abatement) (V_2, PNdb)
Thrust application=f(optimum maneuver speed)-subsonic climb
Thrust application=f(optimum maneuver speed)-initial climb
Thrust application=f(sonic barrier penetration)-transonic acceleration
Thrust application=f(optimum air speed)-supersonic climb
Thrust application=f(transition to cruise)
Thrust application=f(constant Mach 3.0)-cruise
Thrust application=f(optimum air speed)-deceleration/descent
Thrust application=f(sound barrier penetration)-decelerating
Thrust application=f(optimum maneuver speed)-subsonic maneuvering
Thrust application=f(optimum maneuver speed)-let down
Thrust application=f(optimum maneuver speed)-level off
Thrust application=f(optimum maneuver speed)-initial approach
Thrust application=f(optimum maneuver speed)-final approach
Thrust application=f(maximum power)-missed approach
Thrust application=f(flare execution)
Thrust application=f(surface speed)-thrust reversal for braking
Thrust application=f(surface speed)-taxi to line
Accomplish power plant system deactivation
Taxi from line
Initial roll control-take-off
Take-off abort control
Take-off control - rotation, configuration change
Initial climb control-initial portion of standard instrument departure
Subsonic climb maneuvering
Transonic acceleration control
Supersonic climb control
Transition to cruise control
Cruise Control
Supersonic descent control
Transonic descent control
Subsonic descent control
Let down control
Level off maneuver
Initial approach control
Final approach control
Missed approach execution control operations
Flare maneuver execution
Rollout control
Taxi to line
Duct system configuration for supersonic climb
Duct system configuration for transition to cruise
Duct system reconfigured as required
Duct system configuration for supersonic descent operations
Duct system configuration for transonic deceleration/descent
Duct system reconfiguration for subsonic operations
ETA prediction
Optimum profile generation

TABLE 6 Potential Role Responsibility for Three Man Operation

POSITION 1

- Taxi from line
- Initial roll control - take-off
- Take-off abort control
- Take-off control - rotation, configuration change
- Initial climb control - initial portion of standard instrument departure
- Subsonic climb maneuvering
- Transonic acceleration control
- Supersonic climb control
- Transition to cruise control
- Cruise Control
- Supersonic descent control
- Transonic descent control
- Subsonic descent control
- Let down control
- Level off maneuver
- Initial approach control
- Final approach control
- Missed approach execution control operations
- Flare maneuver execution
- Rollout control
- Taxi to line
- Duct system configuration for supersonic climb
- Duct system configuration for transition to cruise
- Duct system reconfigured as required
- Duct system configuration for supersonic descent operations
- Duct system configuration for transonic deceleration/descent
- Duct system reconfiguration for subsonic operations
- ETA prediction
- Thrust application = f(sonic barrier penetration) - transonic acceleration
- Thrust application = f(optimum air speed) - supersonic climb
- Thrust application = f(transition to cruise)
- Thrust application = f(constant Mach 3.0) - cruise
- Thrust application = f(optimum air speed) - deceleration/descent
- Thrust application = f(sound barrier penetration) - decelerating

POSITION 2

- Maintain take-off flight path
- Maintain flight path for standard instrument departure
- Internal system position generation
- External system position generation
- Present position updating
- Optimum profile generation
- Maintain flight path for standard instrument approach
- Maintain flight path for all weather landing

NOTE: Both Position #1 and Position #2 would have the capability to perform parts of the communications activity. As such each position would be responsible for some specific area of each communication function. These positions are assigned the minority of the communications functions.

POSITION 3

- Monitor enroute weather conditions
- Monitor destination and alternate weather
- Provide differential in forecast/actual weather conditions
- Calculation of overpressure being generated
- Engine start and checkout
- Thrust application = f(surface speed) - taxi
- Thrust application = f(maximum power) - take-off thrust
- Thrust application = f(surface speed) - thrust reversal
- Thrust application = f(noise abatement) (V_2, PNdb)
- Thrust application = f(optimum maneuver speed) - subsonic climb
- Thrust application = f(optimum maneuver speed) - initial climb
- Thrust application = f(optimum maneuver speed) - subsonic maneuvering
- Thrust application = f(optimum maneuver speed) - let down
- Thrust application = f(optimum maneuver speed) - level off
- Thrust application = f(optimum maneuver speed) - initial approach
- Thrust application = f(optimum maneuver speed) - final approach
- Thrust application = f(maximum power) - missed approach
- Thrust application = f(flare execution)
- Thrust application = f(surface speed) - thrust reversal for braking
- Thrust application = f(surface speed) - taxi to line
- Accomplish power plant system deactivation
- Ground Handling phase communications
- Cockpit communications for take-off
- Departure control communications
- Activate/deactivate "no smoking" signs
- Activate/deactivate "fasten seat belt" signs
- Initial position report
- ATC communications for handoff
- Enroute ATC communications
- Intercom announcements
- Enroute company communications
- ATC communications for deceleration/initial descent
- ATC approach control communications
- Final approach communications
- Destination ground handling communications
- Visual traffic vigilance

NOTE: Position #1, Position #2, and Position #3 are all responsible for a portion of each of the phase-oriented system checks functions delineated in this analysis. The exact responsibility of of any crew member would be dependent upon the equipment placed under the surveillance of any particular station.

TABLE 7 Potential Role Responsibility for Four Man Operation

POSITION 1

- Taxi from line
- Initial roll control - take-off
- Take-off abort control
- Take-off control - rotation, configuration change
- Initial climb control - initial portion of standard instrument departure
- Subsonic climb maneuvering
- Transonic acceleration control
- Supersonic climb control
- Transition to cruise control
- Cruise Control
- Supersonic descent control
- Transonic descent control
- Subsonic descent control
- Let down control
- Level off maneuver
- Initial approach control
- Final approach control
- Missed approach execution control operations
- Flare maneuver execution
- Rollout control
- Taxi to line
- Thrust application = f(sonic barrier penetration) - transonic acceleration
- Thrust application = f(optimum air speed) - supersonic climb
- Thrust application = f(transition to cruise)
- Thrust application = f(constant Mach 3.0) - cruise
- Thrust application = f(optimum air speed) - deceleration/descent
- Thrust application = f(sound barrier penetration) - decelerating
- Duct system configuration for supersonic climb
- Duct system configuration for transition to cruise
- Duct system reconfigured as required
- Duct system configuration for supersonic descent operations
- Duct system configuration for transonic deceleration/descent
- Duct system reconfiguration for subsonic operations

POSITION 2

- Maintain take-off flight path
- Maintain flight path for standard instrument departure
- Internal system position generation
- External system position generation
- Present position updating
- Maintain flight path for standard instrument approach
- Maintain flight path for all weather landing
- Ground handling phase communications
- Cockpit communications for take-off
- Activate/deactivate "no smoking" signs
- Activate/deactivate "fasten seat belt" signs
- Intercom announcements
- Destination ground handling communications
- Visual traffic vigilance

POSITION 3

- Monitor enroute weather conditions
- Monitor destination and alternate weather
- Provide differentials in forecast/actual weather conditions
- Calculation of overpressure being generated
- Engine start and checkout
- Thrust application = f(surface speed) - taxi
- Thrust application = f(maximum power) - take-off thrust
- Thrust application = f(surface speed) - thrust reversal
- Thrust application = f(noise abatement) (V_2, PNdb)
- Thrust application = f(optimum maneuver speed) - initial climb
- Thrust application = f(optimum maneuver speed) - subsonic climb
- Thrust application = f(optimum maneuver speed) - subsonic maneuvering
- Thrust application = f(optimum maneuver speed) - let down
- Thrust application = f(optimum maneuver speed) - level off
- Thrust application = f(optimum maneuver speed) - initial approach
- Thrust application = f(optimum maneuver speed) - final approach
- Thrust application = f(maximum power) - missed approach
- Thrust application = f(flare execution)
- Thrust application = f(surface speed) - thrust reversal for braking
- Thrust application = f(surface speed) - taxi to line
- Accomplish power plant system deactivation

POSITION 4

- ETA prediction
- Optimum profile generation
- Ground Handling phase communications
- Cockpit communications for take-off
- Departure control communications
- Initial position report
- ATC communications for handoff
- Enroute ATC communications
- Intercom announcements
- Enroute company communications
- ATC communications for deceleration/initial descent
- ATC approach control communications
- Final approach communications
- Destination ground handling communications
- Visual traffic vigilance

NOTE: Although not included in any specific allocation of the functions to a station, those phase-oriented system checks are distributed among the crew members. The allocation will be dependent upon the systems involved (i.e., the location of specific controls), and upon the amount of other responsibility already assigned to a specific position.

PART II. IMPLICATIONS OF CREW ROLE AND WORKLOAD ANALYSES FOR COCKPIT INSTRUMENTATION REQUIREMENTS AND FLIGHT DECK LAYOUT

7.0 ANALYSIS OF CREW INFORMATION REQUIREMENTS

Study efforts discussed in this part of the report were concerned with the derivation of crew information requirements in the performance of operational functions identified in section 1.0, with the identification of feasible cockpit instrumentation concepts for satisfying these information requirements, and with the integration of the instrumentation concepts considered into projected SST flight deck configurations. The objectives of the initial effort were to identify the information parameters which must be represented in SST cockpit instrumentation, and to examine the characteristics of these parameters which can affect the manner in which they are displayed. In subsequent sections, available information regarding cockpit instrumentation was synthesized to identify feasible means of displaying each information parameter and of integrating the various instrumentation concepts into two-, three-, and four-position configurations of the SST flight deck.

It may be noted here that in the analysis of crew information requirements it was anticipated that feasible cockpit displays could be identified which would in fact reflect the current state-of-the-art in cockpit instrumentation and feasible cockpit layouts for the supersonic transport, and thus be useful to the NASA and to the aircraft industry in their SST simulation research programs. It was further anticipated that many new and untested display concepts would be considered which should be subjected to empirical study in either static simulators or in the dynamic models which are being utilized to study the handling characteristics, operational integration, etc., of the SST. Two important operational activities where such research on improved display concepts is expected are navigation and all-weather landing control. Therefore, in conducting the parametric analysis it was considered necessary to pay particular attention to these areas. Requirements for navigation and all-weather landing were derived separately and consideration was subsequently given to integrating display requirements so as to provide the crew with an optimum information environment, uncluttered with unnecessary instrumentation. This statement is not meant to infer that traditional instrumentation should be deleted from the cockpit without sufficient justification, and this justification should include consideration of the crew's acceptance of deleting such instrumentation. It will be noted in discussing the results of this effort that some instrumentation will be recommended primarily to obtain crew acceptance, and not because it provides required information.

As the analysis proceeded, it became clear that three categories of information requirements could be distinguished. One category is comprised of that information considered essential for the performance of an operational function and was classified as "basic" information. A second category consisted of that information considered essential for overall situation assessment and judgments and was classified as "demand" information. The third category distinguished that information considered "nice to have," or necessary for crew acceptance of their role, and was classified as "ancillary" information. Generally speaking, information in the basic category should be continuously available in the cockpit and that in the demand category lends itself to display concepts which advocate some degree of instrument sharing (e. g., a general purpose display). Ancillary information might require continuous display where crew acceptance factors are involved, but in general its non-essential character suggests that "space-sharing" concepts, as represented by general purpose displays, are appropriate for this category. This classification scheme was considered in the identification of feasible instrumentation concepts for the information requirement parameters derived in the analysis.

7.1 PROCEDURE AND ASSUMPTIONS

In conducting the parametric analysis, the following general method was employed:

--First, the operational functions were examined to determine the information necessary to accomplish the function;

--second, the functions were examined in the light of the previous analysis of feasible automatic and manual implementation concepts;

--third, the functions were grouped in accordance with these implementation concepts;

--and finally, those information parameters which appeared amenable to display in the cockpit were logically derived.

In each of these steps, rules were first established which formed the boundaries for the analysis and then the effort proceeded to fulfill the objectives. As each step is described in the material which follows, the rules and/or assumptions utilized will be presented to provide some insight into the analysis and the manner in which results were derived.

CATEGORIZATION OF FUNCTIONS

Broadly speaking, the operational functions derived in section 1 (see also volume II) can be placed in one of three categories. Category I includes those functions characterized by an automatic implementation concept with no manual back-up, automatic or self-monitoring, and alarm excitation when out-of-tolerance conditions occur. A subset of this category would include automated functions which can be manually monitored. Category II includes functions for which both automatic and manual implementation concepts have been identified as feasible and can be monitored either automatically or manually. Category III includes those functions which do not have a feasible automatic implementation concept and thus will be performed manually. Each category will be described below in greater detail and the rules regarding each grouping will be delineated.

Category I Functions

This group of functions includes those envisioned only in terms of fully-automatic implementation concepts and which require an interface with the crew only as necessary for them to ascertain the operating condition of associated equipment and indications of performance required for overall situation assessment and decision making. In assigning the functions to this category, it was assumed that the execution of these functions would be fully-automatic, and that, in most instances, both input and performance output would be automatically monitored. Provisions for alerting the crew when the performance exceeds some predetermined tolerance envelope would be included, and the crew would then become involved in order to obtain further information, assess the situation, and make corrective action decisions. For some of the functions placed in this category, the crew's role will be slightly different in that they would evaluate the input credibility or monitor output performance more directly. In such instances, the crew would require additional information and this information would be the same as that cited above as being necessary to complete the situation assessment and evaluation in the event of an alarm from an automatic monitoring system. Thus, in a completely automatic system, indications of an out-of-tolerance condition would be basic information for the crew whereas information used for situation assessment would be classified as demand information. In the case of monitoring an automatic function, crew information requirements are all basic.

The following operational functions were assigned to Category I:

Function 6. 1 - Duct system configuration for supersonic climb.

Function 6. 2 - Duct system configuration for transition to cruise.

Function 6. 3 - Duct system reconfigured as required.

Function 6. 4 - Duct system configuration for supersonic descent operations.

Function 6. 5 - Duct system configuration for transonic deceleration/descent.

Function 6. 6 - Duct system reconfiguration for subsonic operations.

Function 7. 1 - Maintain takeoff flight path.

Function 7. 6 - Calculation of overpressure being generated.

Function 7. 7 - Internal system position generation.

Function 7. 8 - External system position generation.

Function 7. 11 - Optimum profile generation.

Function 7. 13 - Maintain flight path for all-weather landing (AWL).

In analyzing these functions to identify crew information requirements, the automatic implementation concept forced the analysts to look at the products or information generated by the function, rather than at the input information. As the analysis proceeded, it became evident that the classes of output information which are amenable for display in the cockpit include "howgozit" information or that indicative of flight progress, information indicative of system operating status, and information which includes the operating condition of both the system under control and of the controlling mechanism. In addition, operating condition information includes indications of operational mode and the level of capability being utilized or available. In most cases information required on operating condition is of the GO/NO GO form.

On the basis of these general information requirements, the following rule was developed for deriving instrumentation requirements for Category I functions. For Category I functions, in general, the following information parameters will be required:

1. GO/NO GO operating condition of automatic equipment;
2. Information parameters indicating that system states controlled by performance of this equipment are (or are not) in tolerance;
3. Information parameters indicating that the flight is (or is not) proceeding according to plan.
4. Information parameters indicative of the status of the flight operating environment (the operating environment is construed to include atmospheric phenomena and/or other traffic).
5. When automatic monitoring with alarm excitation is employed, two types of information are required: (1) a primary, GO/NO GO display of total system status and (2) secondary information called up in the event of a NO GO situation.

Category II Functions

This group of functions includes those envisioned as having both automatic and manual implementation concepts. In most situations, functions which require a manual back-up were automated to alleviate or lessen the crew's workload rather than to extend their capabilities. In Category I functions, wherein only automatic implementation concepts are feasible, the required performance is considered to be beyond the capabilities of human operators, thus automatic devices represent an extension of man's capability. As indicated above, the only information required for these functions is that reflecting system performance and operating status. If for some reason system performance exceeds tolerance limits, the crew must re-evaluate the system's capabilities in the light of such conditions and determine the corrective action necessary to maintain the total system's integrity. For example, if the reconfiguration of the duct system is accomplished only by automatic means, then a malfunctioning of the duct control system will have various consequences, depending upon the aircraft's position along its flight profile, and it will be necessary for the crew to assess the situation and derive an optimum solution to the problem. This same reasoning does not apply to Category II functions, since the crew has the capability to manually perform the function.

For Category II functions, then, it is no longer sufficient to provide only that information indicative of the automatic system's operating condition; the crew now requires information which will enable them to override the automatic mode of operation and to assume manual control. The main problem encountered here is the possible loss of orientation during the transition from automatic to manual control. If the crew is relying on the operation of the automatic system and is not monitoring its performance, then the time lag due to an unexpected control transfer requirement increases. Adequate instrumentation in this instance is that required to reduce the loss of capabilities to as close to zero as possible during the transfer operations. This increment of loss of system capability has varying implications when evaluated in the light of the functional performance required. For example, during phases of the flight when the safety of the aircraft will not be adversely affected by a loss of one hundred feet of altitude, such a loss incurred during a control transfer could probably be tolerated. However, during some critical phase of the flight, such as the final approach to landing, a 100-foot altitude loss during a control transfer might be disastrous. Thus, even when automatic implementation is assumed for Category II functions, cockpit instrumentation requirements should be predicated upon the fact that the crew may have to perform the function manually.

The following operational functions were assigned to Category II:

Function 3. 6 - Initial position report.

Function 3. 7 - ATC communications for handoff.

Function 3. 8 - Enroute ATC communications.

Function 3. 10 - Enroute company communications.

Function 3. 11 - ATC communications for deceleration/ initial descent.

Function 4. 1 - Engine start and checkout.

Function 4. 6 - Thrust application = f (optimum maneuver speed) - initial climb.

Function 4. 7 - Thrust application = f (optimum maneuver speed) - subsonic climb.

Function 4. 8 - Thrust application = f (sonic barrier penetration) - transonic acceleration.

Function 4.9 - Thrust application = f (optimum air speed) - supersonic climb.

Function 4.10 - Thrust application = f (transition to cruise).

Function 4.11 - Thrust application = f (constant Mach 3.0) - cruise.

Function 4.12 - Thrust application = f (optimum air speed) - deceleration/descent.

Function 4.13 - Thrust application = f (sonic barrier penetration) - decelerating.

Function 4.14 - Thrust application = f (optimum maneuver speed) - subsonic maneuvering.

Function 4.15 - Thrust application = f (optimum maneuver speed) - let down.

Function 4.16 - Thrust application = f (optimum maneuver speed) - level off.

Function 4.17 - Thrust application = f (optimum maneuver speed) - initial approach.

Function 4.18 - Thrust application - f (optimum maneuver speed) - final approach.

Function 4.20 - Thrust application = f (flare execution).

Function 5.6 - Subsonic climb maneuvering.

Function 5.7 - Transonic acceleration control.

Function 5.8 - Supersonic climb control.

Function 5.9 - Transition to cruise control.

Function 5.10 - Cruise control.

Function 5.11 - Supersonic descent control.

Function 5.12 - Transonic descent control.

Function 5.13 - Subsonic descent control.

Function 5.14 - Let down control.

Function 5.15 - Level off maneuver.

Function 5.17 - Final approach control.

Function 5.19 - Flare maneuver execution.

Function 5.20 - Rollout control.

Function 7.2 - Maintain flight path for standard instrument departure (SID).

Function 7.3 - Monitor enroute weather conditions.

Function 7.4 - Monitor destination and alternate weather.

Function 7.5 - Provide differential in forecast/actual weather conditions.

Function 7.9 - Present position updating.

Function 7.10 - Estimated time of arrival (ETA) prediction.

Function 7.12 - Maintain flight path for standard instrument approach (SIA).

The rule developed for Category I functions was applied to certain Category II functions. In addition, however, judgments had to be made concerning the information required to perform the same function manually, and the information necessary to optimize the transfer of control. The derivation of information required for effective control transfer represented a difficult methodological problem and should be pursued in empirical studies. One approach to this problem would be to present only the basic information and then evaluate crew performance in control transfer situations. Additional information could then be added and performance evaluated on the same tasks until an optimum instrumentation concept was identified. Functions assigned to Category II posed the most difficult analysis problem and, for that reason, were subjected to more rigorous treatment. In subsequent sections, the information requirements derived for these functions and associated instrumentation concepts will be supported by more lengthy rationale statements, since a general rule could not be consistently applied. Each parameter delineated had to be examined in view of its role in the overall operation of the aircraft. Because of the dual implementation concepts, there is a continuum of man-machine capability which exists, and the selection of suitable instrumentation depends upon the particular mode of operation assumed. The results of the study indicate that the manual implementation concept will dictate the instrumentation requirements, even though the function has a high probability of being completed automatically (i. e., the reliability of the automatic system is such that it is unlikely that the crew would be required to manually implement the function). Despite this low probability of crew participation, provisions for displaying the information required to perform the function manually must be made, and in many instances this information must be continuously available.

Category III Functions

This group of functions includes those envisioned only in terms of manual implementation concepts, since no automatic concepts were considered feasible and cost-effectiveness considerations preclude their use. The performance of a function in this category is assigned to the crew, and instrumentation requirements will therefore involve those necessary for the crew to control designated systems and to assess and evaluate their performance. The discussion of Category II functions brought out the problems involved in determining crew information requirements functions for which both automatic and manual implementation concepts are feasible. It was pointed out that in most cases the final selection of instrumentation for parameter display will be predicated upon the requirements to perform the function manually. The rationale for deriving information parameters for Category III functions will therefore be the same as that used for the Category II functions. The main differences between the two categories are that information indicative of the performance and operating condition of automatic equipment, and those parameters necessary for optimum transfer from automatic to manual control, are not required for Category III functions.

The following operational functions were assigned to Category III:

Function 3. 1 - Ground handling phase communications.

Function 3. 2 - Cockpit communications for takeoff.

Function 3. 3 - Departure control communications.

Function 3. 4 - Activate/deactivate "no smoking" signs.

Function 3. 5 - Activate/deactivate "fasten seat belt" signs.

Function 3. 9 - Intercom announcements.

Function 3.12 - Air Traffic Control (ATC) approach control communications.

Function 3.13 - Final approach communications.

Function 3.14 - Destination ground-handling communications.

Function 3.15 - Visual traffic vigilance. (NOTE: In the event that some type of proximity sensor is utilized to assist in both traffic search and traffic avoidance, then this function becomes a Category II function and additional information is required).

Function 4.2 - Thrust application = f (surface speed) - taxi.

Function 4.3 - Thrust application = f (maximum power) - take-off thrust.

Function 4.4 - Thrust application = f (surface speed) - thrust reversal.

Function 4.5 - Thrust application = f (noise abatement), (V_2, PNdb).

Function 4.19 - Thrust application = f (maximum power) - missed approach.

Function 4.21 - Thrust application = f (surface speed) - thrust reversal for braking.

Function 4.22 - Thrust application = f (surface speed) - taxi to line.

Function 4.23 - Power plant system deactivation.

Function 5.1 - Taxi from line.

Function 5.2 - Initial roll control - takeoff.

Function 5.3 - Takeoff abort control..

Function 5.4 - Takeoff control - rotation, configuration change.

Function 5.5 - Initial climb control - initial portion of standard instrument departure.

Function 5.16 - Initial approach control.

Function 5.18 - Missed approach execution control operations. (NOTE: In the event of a missed approach, instrumentation is now being developed which will attempt to optimize the crew's performance. In most cases this is a function of the plane's angle of attack and is displayed via the flight director. While the implementation is essentially manual, the crew is provided with a command display which guides their performance).

Function 5.21 - Taxi to line.

DELINEATION OF COCKPIT DISPLAY PARAMETERS

Within the context of the generalized SST flight profile presented in section 1, each of the operational functions categorized in the foregoing discussion was examined to determine crew information requirements. As anticipated, a considerable amount of redundancy occurs when crew information requirements are separately derived for each function, so the results of the analysis were consolidated into a single set of information items which should be available for display to the crew throughout the flight profile. For convenience, these items will be referred to as cockpit display parameters and include both qualitative and quantitative expressions of crew information requirements which should be provided for in any SST cockpit instrumentation concept.

In deriving these parameters, it became apparent that a large number of crew information requirement items consisted of operating status indications and more or less standard performance readouts for certain basic aircraft subsystems. Since these requirements did not appear to represent an area of significant change in the SST over those provided for in conventional jet transports, they were generally excluded from the analysis and do not appear in the set of parameters listed in the results. The information required to monitor these subsystems will be dependent upon the particular system installed and it is assumed that adequate instrumentation will be provided. This assumption covers the following aircraft subsystems:

1. Electrical system;
2. Hydraulic system;
3. Pneumatic system;
4. Fire protection system;
5. Smoke detection system;
6. Fuel heating system;
7. Ambient lighting system (interior/exterior);
8. Fuel dumping system;
9. Oxygen regulating system;
10. Ice and rain protection systems;
11. Environmental control systems;
    a. Air conditioning (temperature, humidity, and airflow).

    b. Toxicant control system (ozone, CO_2, etc.)

12. Cabin pressurization system;
13. Doors system.

7.2 RESULTS

The cockpit display parameters which were derived are identified in Table 8. A brief description of each parameter is provided, indicating the characteristics of the information referent and, where appropriate, the range of values the parameter can assume. Also associated with each parameter is a statement of the accuracy required of the crew in resolving different values or aspects of the referent in the performance of operational functions. This latter characteristic is referred to as performance accuracy and was included to provide a basis for determining display accuracy requirements in the subsequent consideration of instrumentation concepts. No particular organization or level of specificity was adopted in presenting the cockpit display parameters in Table 8. Since the navigation activity was considered first, parameters associated with navigation functions appear in the first part of the table and those associated with flight control, engine operation, communications, and other crew activities follow.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters.

DISPLAY PARAMETER	CHARACTERISTICS
1. Desired/Required Ground Track	This is a qualitative parameter, usually represented by a line over some geographic referent (e.g., a track line traced on a map). Required tracks include such ATC procedures as standard instrument departures, standard instrument approaches, as well as instrument landing system approaches. The performance accuracy required in representing this parameter will vary in the different portions of the flight profile and will be a function of both the resolution and orientation of the referent. The crew's requirement is to be able to determine their position relative to the desired/required ground track so that suitable corrections may be made. In terminal area operations, where separation requirements are more direct, greater accuracy is required.
2. Angle of Aircraft's Longitudinal Axis with North Reference	This is a quantitative parameter, usually expressed in degrees from 0 to 360. It is commonly referred to as heading, e.g. true north, magnetic north. The performance accuracy required for this parameter will vary in different portions of the flight profile. The accuracies required in the SST operations are more exact than in current subsonic flights. It appears that the crew will require accuracies on the order of 1°in the subsonic speed regimes, and 1/2° in the supersonic speed region.
3. Aircraft Displacement from Track in Lateral Plane	This is a qualitative parameter, usually expressed as a deviation left or right from a specified track line. If the desired track and the aircraft's position are displayed concurrently, the displacement in the lateral plane will be evident. The performance accuracy required for this parameter is difficult to establish since it is a function of the control task involved in eliminating such deviations. This is, in essence, a tracking task, wherein the crew attempts to minimize excursions from the desired track and the general crew requirement is to detect small deviations.
4. Vertical Speed	This is both a qualitative and a quantitative parameter, with direction expressed qualitatively (e.g. up or down), and rate expressed quantitatively in feet per minute. The performance accuracy required for this parameter has been established at about 100 feet per minute. The limitations placed on this parameter will, in general, be a function of such things as the flight performance envelope of the aircraft, the requirements of other systems (e.g., the pressurization system), and the "g" loading which will be acceptable to both the crew and the passengers. For this reason the exact range of the parameter has not yet been defined. However, it does not appear likely that this range will exceed 10,000 feet per

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
	minute. It should also be noted that during all-weather landing performance there may be the requirement to change scale so as to obtain feet per second information during the flare maneuver.
5. Airspeed	This is a quantitative parameter, usually expressed in knots (nautical miles per hour) or an equivalent Mach number. The range of this parameter is from 0 to the speed capability of the aircraft. The performance accuracy required for this parameter has been established at about 1 knot in the takeoff and landing phases of flight, and about 5 knots during the remainder of the flight. The crew also requires performance accuracies of 0.01 Mach during high speed flight.
6. Groundspeed	This is a quantitative parameter, usually expressed in knots (nautical miles per hour). The range of this parameter is from 0 to the speed capability of the aircraft plus an allowable speed for the highest expected wind velocities. The performance accuracy required for this parameter is about 10 knots. It is used primarily during the enroute portion of the flight to assist in evaluating deviations from an estimated time of arrival (ETA) at designated reporting points. During terminal area operations (departures and approaches), ATC radar coverage provides information concerning deviations in the longitudinal plane caused by unpredicted winds.
7. Altitude	This is a quantitative parameter, usually expressed in feet or thousands of feet from some reference level. In current operations, this reference is sea level, but it could also be the local terrain. The range of the parameter is from 0 to the altitude capabilities of the aircraft. In the case of the first generation supersonic transport it should be safe to assume that this will not exceed 100,000 feet. The performance accuracy required for this parameter appears to be 100 feet during most of the flight profile. The vertical freedom which may be allowed the SST in the high altitude regions may reduce these accuracy requirements to 500 feet. During the final portion of the landing phase, i.e., from 300 feet above the ground until touchdown, it becomes necessary for the crew to ascertain their altitude above the ground to within about 5 feet.
8. Airway Marker Beacon Passage	This is a qualitative parameter, representing the occurrence of an event, i.e., aircraft passage over the marker beacon.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
9. Passenger "g" Loading	This is quantitative parameter, usually expressed in units of "g," i.e., the force of gravity. Under normal conditions a person senses a force of 1 "g" but when exposed to accelerations, the force may vary in either a positive or negative direction. Passengers are not expected to be willing to tolerate "g" loadings outside of a -1/2 to about +2 envelope. The performance accuracy required for this parameter is about 0.1 "g" during most of the flight operations. Since man's tolerance to positive "g" is greater than to negative "g", the accelerations experienced during the takeoff, the transonic acceleration, and during the high speed cruise should not cause any great concern. However, during level-off maneuvers there is the possibility that negative "g" will be generated if the rate of change in vertical velocity is too great.
10. Fuel Consumption Rate	This is a quantitative parameter, usually expressed in pounds of fuel consumed per hour. The range of the parameter is from 0 to whatever the design of the power plant dictates. This fuel flow is also indicative of power output of the engine when checked against engine performance curves. The performance accuracy required for this parameter is about 100 pounds per hour throughout the flight. Since fuel management on the SST will be one of the prime areas of concern, accurate indications of fuel flow will be necessary. Fuel management includes the solution to such problems as fuel sequencing, fuel distribution, fuel "howgozit," and simple economics.
11. Signal from Ground Navigational Aid Station (Signal Source)	This is a quantitative parameter, usually expressed in forms of radio frequencies. Navigation aid sources include automatic direction finding (ADF), very high frequency(VHF), and ultra-high frequency (UHF) equipment. The performance accuracy required for this parameter is a fixed value representing the transmitting frequency of a designated navigational aid. Since each navigational aid is identified by a specific frequency in addition to some identification code, it is essential that the crew be able to ascertain the frequency of the station to hundreds, tens, units, and tenths of megacycles.
12. On-line Configuration of the Navigation Equipment	This is a qualitative parameter which identifies the equipment subsystems which are being used to drive the navigation displays, e.g. the VOR/DME equipment may be on-line and driving the position indicator.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
13. Indicated Position fix	This is a quantitative parameter, usually expressed in terms of lattitude and longitude coordinates. The performance accuracy required for this parameter will vary along the flight profile, generally in accordance with the ATC separation minima. In the terminal areas performance accuracies of 1/2 mile can be expected. However, during the enroute portions of the flight, and especially on oceanic flights, performance accuracies of 5 miles (circular error) or more may be acceptable.
14. Position Relative to a Ground Navigational Aid Station (Directional Vector)	This is a quantitative parameter, usually expressed in terms of bearing and range. Bearing information is expressed in degrees from 0 to 360, and slant range is expressed in nautical miles. The performance accuracy required for this parameter is about 2^{o} of bearing and 1/4 mile of range.
15. Aircraft Aerodynamic Center Relative to its Center of Gravity	This is a quantitative parameter expected to be expressed in inches of displacement from the center of gravity. The range of the parameter will be dependent upon the design of the aircraft. The movement of the aerodynamic center at supersonic speeds has introduced stability problem areas which are being solved on the Concorde by redistributing the fuel supply in an attempt to relocate the center of gravity. The performance accuracy required for this parameter has not been established.
16. Total Fuel Remaining	This is a quantitative parameter, usually expressed in pounds. The performance accuracy required for this parameter is about 500 pounds.
17. Status of Fuel Reserves	This is a quantitative parameter, expected to be expressed as a deviation in pounds from fuel reserves required by regulations or those estimated during preflight planning. Performance accuracy required for this parameter has not been established.
18. Individual Fuel Cell Quantity	This is a quantitative parameter, usually expressed in pounds of fuel per tank (fuel cell). The performance accuracy required for this parameter is about 100 pounds.
19. Aircraft Fuel Profile	This is a quantitative parameter, expected to be expressed in terms of indicated fuel as a function of elapsed time, or arrival at intermediate points along the flight profile. The performance accuracy for this parameter has not been established. The general requirement is to compare preplanned fuel utilization to actual usage in an attempt to identify deviations which are significant for fuel management during flight.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
20. Aircraft Velocity Schedule	This is a quantitative parameter, usually expressed in terms of knots or equivalent Mach number relative to a time base. The performance accuracy required for this parameter is about 1 knot in flight phases where indicated airspeed is used, and about 0.01 Mach during high speed flight.
21. Ambient Temperature	This is a quantitative parameter, usually expressed in degrees Centigrade. The range of this parameter will probably be from -70° to $+50^{\circ}$. The performance accuracy required for this parameter will vary during different phases of flight, but should be about 5° in the take-off phase and 1° for high speed flight phases.
22. Turbulence	This is a qualitative parameter, usually expressed in five categories from "light" to "severe."
23. Precipitation	This is a qualitative parameter, usually expressed along a continuum from "light" to "severe," and the form in which it occurs, i.e., rain, snow, sleet, freezing rain, and hail.
24. Clouds	This parameter is expressed both qualitatively and quantitatively. Clouds are described in terms of the amount of cover, the type of clouds, the base height of the clouds, and the height of the tops of the clouds. The performance accuracy for this parameter has not been established.
25. Radiation Level	This is a quantitative parameter, usually expressed as a potential dose rate in milliroentgens per hour. Performance accuracy for this parameter has not been established. The control of the radiation level in the SST will be an automatic function with alarm excitation in the event safe levels are exceeded or are approaching the maximum allowable. The selected levels will be flown, and the geographical latitude at which the aircraft will be flown.
26. Weather Front Activity	This is expressed both qualitatively and quantitatively and includes information concerning the general location and movement of fronts.
27. Estimated Magnitude of Shock Wave at any Point Directly Beneath the Aircraft and Along the Dispersion Pattern	This is a quantitative parameter, expected to be expressed within ACCEPTABLE and UNACCEPTABLE ranges in pounds per square foot. The performance accuracy required for this parameter is about 0.1 pounds per square foot. The ACCEPTABLE range of the parameter has recently been revised by the FAA as follows: For legs up to 3000 miles, overpressures during transonic acceleration cannot exceed 2.0 psf., and during initial cruise, 1.5 psf. For legs over 3000 miles, transonic acceleration overpressure cannot exceed 2.5 psf., and initial cruise, 1.7 psf.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
28. Predicted Magnitude of Shock Wave at any Point Directly Beneath the Aircraft and Along the Dispersion Pattern, Over the Remainder of the Supersonic Flight Phases	This is a predictive parameter and can be described as either a qualitative or a quantitative parameter. It can be displayed in terms of ACCEPTABLE/UNACCEPTABLE, or some magnitude in psf can be displayed as a function of time. The performance accuracy described above is applicable to this parameter.
29. Operating Condition of Associated Navigation Equipment	This is a qualitative parameter usually expressed as a GO/NO GO indication.
30. Source of External Signal	This is a qualitative parameter expressed in terms of the identification code for the navigation facility being used.
31. Externally Derived Position Fix	This is a quantitative parameter, expressed in terms of range and bearing for or from a designated navigation facility. This parameter differs from the indicated position fix parameter in that it is derived from an external navigational aid. The performance accuracy required for this parameter is about 5 miles.
32. Up-dated Position Fix	This is a quantitative parameter representing a correction to the indicated position fix based on a more accurate externally derived position fix.
33. Estimated Time of Arrival at Destination Terminal and/or Any Way Point	This is a quantitative parameter, expressed in time units. The performance accuracy required for this parameter will be about 1 minute. Current regulations for subsonic jets require reporting if an estimated time of arrival (ETA) within plus or minus 3 minutes does not appear feasible. The reduction to about 1 minute for the SST would appear required to permit ATC sufficient reaction time to reconcile any traffic conflicts.
34. Deviation of ETA's from Flight Plan Estimates	This is a quantitative parameter, representing the difference, if any, between ETA derived from inflight navigation data and those reported to ATC on the traffic on the flight plan. The performance accuracy required of this parameter will be about 1 minute.
35. Optimum Flight Profile. Based on Preflight Planning	This parameter defines the intended flight altitude profile as a function of time, as determined from preflight calculations.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
36. Optimum Flight Profile Generated During Flight	This parameter defines the optimum flight path for the aircraft in both the lateral (track) and vertical (altitude profile) planes. It is based on stored aircraft performance data, flight control objectives, and inflight data. This is a qualitative and a quantitative parameter which will be expressed in those units indicative of the three dimensional system chosen to display this information. In all likelihood, the horizontal plane will be described in terms of some map coordinates (e.g., Longitude and Latitude), while the vertical plane will be in terms of altitude versus time.
37. Situation Assessment Data	This is an undefined category of display parameters included to identify requirements for calling up special data formats for situation assessment and the evaluation of action alternatives.
38. Aircraft Passage Over ILS Marker Beacons	This is a qualitative parameter, indicating aircraft passage over ILS marker beacons in GO/NO GO fashion. In addition to conventional outer and middle markers, a runway threshold marker may be included if certain all-weather landing systems are adopted. Marker beacons are utilized to establish an exact point over the ground on the final approach to landing. If landing systems become more sophisticated, and distance measuring equipment (DME) from the end of the runway is used, the requirement for marker beacon passage may be eliminated. However, until such time the provision must be made for presentation of marker beacon passage. It should be pointed out that because of the discrete nature of this informational requirement, it is quite feasible that some sort of a time-shared display could be utilized to present this information.
39. Aircraft Deviation from Glide Slope	This is a qualitative parameter, usually expressed as a vertical displacement above or below the glide slope. The performance accuracy required for this parameter is about 10 feet.
40. Proximity of Aircraft to Flare Initiation Point	This is a quantitative parameter associated with automated all-weather landing systems. It indicates the final approach altitude, distance-to-go to touchdown, or time in the final approach for initiating the flare maneuver. Performance accuracies have not been established, but are expected to be very precise for this critical flight maneuver.
41. Pitch Angle	This is a quantitative parameter, expressed in degrees. It is the angular deviation of the longitudinal axis of the aircraft from a horizontal reference plane. The performance accuracy required for this parameter is about 1° in the low speed region of flight, and about $1/2^{\circ}$

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
	in the supersonic speed regime. During takeoff optimum rotation results in a lengthening of the takeoff roll requirements, so that provisions for a takeoff flight director are being considered. Because of the SST's greater length and the inherent lag in gyro sensors, the crews need a better control guide in the vertical plane.
42. Roll Angle	This is a quantitative parameter expressed in degrees. It is the angular deviation of the lateral axis of the aircraft from a horizontal reference plane. Performance accuracy for this parameter is about 5°.
43. Yaw	This is a quantitative parameter expressed as a deviation from a null point. It is the angular deviation of the longitudinal axis of the aircraft from a vertical reference plane. The performance accuracies for this parameter have not been established.
44. Position of Flaps and/or High Lift Devices	This is a quantitative parameter, usually expressed in degrees of travel from a faired position. In most cases, flaps are set for a prescribed position via a series of premarked detents which correspond to degrees of travel from the cord of the wing.
45. Elevator Control Tab Position	This is a quantitative parameter, usually expressed in degrees of pitch trim. It represents the angular displacement of the elevator control tab from its 0° reference position. Performance accuracies are approximately 1°. With the advent of high speed flight, control tab actuated flight surfaces are now utilized. Therefore the range of control available in each control axis is a function of the angular displacement of the control tabs.
46. Aileron Control Tab Position	This is a quantitative parameter, usually expressed in degrees of roll trim. Performance accuracies are about 1°.
47. Rudder Control Tab Position	This is a quantitative parameter, usually expressed in degrees of rudder trim. Performance accuracies are about 1°.
48. Position of Landing Gear	This is a qualitative parameter, indicating that the gears are fully extended or retracted.
49. Brake System Hydraulic Pressure	This is a quantitative parameter, usually expressed in pounds per square inch of hydraulic pressure. Performance accuracies have not been established.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
50. Autopilot Status	This is a qualitative parameter, usually expressed in terms of the operating condition of the system and the selected mode of operation of the system.
51. Autotrim System Status	This is a qualitative parameter, usually expressed in terms of trim tab control position relative to predescribed limits of travel.
52. Autopilot Mode of Operation	This is a qualitative parameter, expressed in terms of the control mode and/or control axis selected.
53. Landing Gear Limits	This is a quantitative parameter, expressed in terms of airspeed limitations on landing gear extension.
54. Flap Operation Limits	This is a quantitative parameter, expressed in terms of airspeed limitations on flap extensions.
55. Status of the Automatic Inlet Duct Configuration System	This is a qualitative parameter indicating operating condition in GO/NO GO terms.
56. Status of the Automatic Fuel Control/Exhaust Nozzle System	This is a qualitative parameter, usually expressed as a GO/NO GO indication of operation status.
57. Axial Velocity of the Air Flow to the Power Plants	This is a quantitative parameter, usually expressed in terms of a Mach number. The performance accuracy required for this parameter is about 0.1 Mach.
58. Exhaust Gas Velocity	This is a quantitative parameter, usually expressed in terms of a Mach number. The performance accuracy required for this parameter is about 0.1 Mach.
59. Automatic Throttle System Status	This is a qualitative parameter indicating that the autothrottle system is engaged or disengaged.
60. Inlet Compressor Speed of Rotation (N_1)	This is a quantitative parameter, expressed as a percentage of the maximum rotation, i.e., %RPM. The performance accuracy required of this parameter is about 1%.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Continued)

DISPLAY PARAMETER	CHARACTERISTICS
61. Exhaust Compressor Speed of Rotation, (N_2)	This is a quantitative parameter, expressed as a percentage of the maximum rotation capability of the compressor, i. e. , %RPM. The performance accuracy required of this parameter is about 1%.
62. Engine Exhaust Temperature	This is a quantitative parameter, expressed in degrees Centrigrade. The performance accuracy required of this parameter is about 10°.
63. Quantity of Lubricant for Power Plant System	This is a quantitative parameter, expressed in U. S. gallons.
64. Temperature of the Lubricant	This is a quantitative parameter which is usually expressed in degrees Centigrade.
65. Pressure of the Lubrication System	This is a quantitative parameter, expressed in pounds per square inch. The performance accuracy required for this parameter is about 2 psi.
66. Thrust Indication	This is a quantitative parameter, usually expressed as a rating of the thrust being developed for the engines in pounds. The performance accuracy required for this parameter is about 1% of the available thrust.
67. Engine Pressure Ratio	This is a quantitative parameter expressed as a ratio to provide an index of the performance capabilities of the power plant. The performance accuracy required for this parameter is about .01.
68. Status of Thrust Reverser System	This is a qualitative parameter indicating that the system is either engaged or disengaged.
69. Operating Condition of the Communication Equipments	This is a qualitative parameter indicating that communications equipment is either on or off.
70. Communication Transceiver Channel	This is a qualitative parameter expressed in terms of the frequency or identification of communications facility.
71. On-line Configuration of Communication System	This is a qualitative parameter indicating the communication equipment currently in use.

Table 8. SST Crew Information Requirements Expressed in Terms of Cockpit Display Parameters. (Concluded)

DISPLAY PARAMETER	CHARACTERISTICS
72. Indication of SELCAL Usage	This is a qualitative parameter which indicates that a message has been addressed to the aircraft via the selective calling system (SELCAL).
73. Data Link Operating Status	This is a qualitative parameter indicating that the data link equipment is receiving or sending data.
74. Operational Mode of the Transponder	This is a qualitative parameter indicating the operating status of the beacon equipment.
75. Operational Code of the Transponder	This is a qualitative parameter indicating the selected channel of operation of the beacon equipment.
76. Smoking Indicator	This is a qualitative parameter indicating that the "No Smoking" sign has been illuminated.
77. Seal Belt Indicator	This is a qualitative parameter indicating that the "Fasten Seat Belts" sign has been illuminated.
78. Traffic Alert Display	This is a quantitative parameter indicating the presence of other traffic in the immediate vicinity of the aircraft. Most of the literature survey has revealed that the state-of-the-art in detection is still such that a feasible design has not yet been proposed. There are warning systems (e.g., military nose and tail radar), but without a full surveillance capability these do not really furnish a solution to the problem. With aircraft flying at Mach 3 speeds the closing speeds decrease the reaction time to seconds. For this reason every effort must be made to provide an operational environment (i.e., ATC structure) where this factor can be eliminated. However, until such time the crew will, in all likelihood, continue to scan the skies where possible. If and when such a sensor is developed, then not only must the crew be alerted, but they must be given instructions as to the defensive which must be taken to avoid such traffic.

8.0 COCKPIT INSTRUMENTATION CONCEPTS

In the previous section, crew information requirements associated with the performance of the operational functions derived in Section 1 were identified in terms of cockpit display parameters. With the exception of certain information requirement items which were not included consisting of equipment operating status indications and more or less standard performance readouts for certain basic aircraft subsystems, these parameters represent the information items which should be provided for by any SST cockpit instrumentation concept that may ultimately be adopted. In Volume II of this effort, the results of examining feasible implementation concepts for each of the operational functions is presented. The purpose of the effort reported in this section was to identify feasible major instrumentation concepts which would satisfy the information requirements identified in Section 7 within the implementation concepts identified in Volume II. As a first step in the effort, a review of instrumentation concepts associated with each cockpit display parameter identified in Section 7 was conducted, and the results of this review are presented in Appendix IV to this report. Discussions of alternative instrumentation concepts contained in Appendix IV should be useful as a point of departure for identifying research problem areas for new SST display concepts.

The information contained in this section is not intended to provide recommendations for major SST instrumentation concepts, but rather is intended to identify representative instrumentation concepts which are necessary as a basis for considering the integration of instrumentation concepts into basic SST flight deck layouts for two, three and four-man operation. It is expected that the instrumentation concepts identified here and integrated into the basic flight deck layouts as described in Section 9 will be representative of a general SST cockpit configuration and should therefore be used as the basis for SST simulation research on the effectiveness of different numbers of crew members. It should be emphasized that only major instrumentation concepts are identified here. The actual flight deck layouts contained in Section 9 will depict additional instrumentation, based on the material in Appendix IV. The major instrumentation concepts presented here are those which are likely to represent the greatest change from present day commercial jets and the more conventional or system-specific instrumentation is not identified.

In the subsections which follow, the major instrumentation concepts envisioned for four display requirement areas are presented. These are:

1. Navigation
2. Flight Control and Power Plant Operation
3. All-weather Landing
4. General Purpose Displays.

8.1 INSTRUMENTATION CONCEPTS FOR NAVIGATION

The discussion of implementation concepts for the navigation activity presented in Volume II of this report provides extensive documentation of the trend toward an on-line computer-based, integrated navigation system for the SST, using self-contained position and optimum flight path determination techniques. A completely automatic system would incorporate a tie-in with flight control and power plant control subsystems to maintain the aircraft on a preplanned or computed optimum flight path throughout the flight profile. Whether these developments are fully realized or not in the final SST design, there seems to be a consensus that significant improvements in the display of navigation situation and control information will be required.

Cockpit instrumentation concepts adopted in the present study as representative are based on a somewhat conservative position that the principal change in displays will be the provision of some sort of pictorial situation display and a special purpose display for monitoring optimum flight profile computations and making appropriate flight path adjustments. Basic data for achieving navigation objectives will still be obtained from such conventional instruments as the flight director, horizontal situation indicator (HSI), DME indicators, airspeed indicators and ground speed readouts. Additional data, arranged in special formats, may also be provided in a general purpose display for assessing navigation situation data and deciding to alter the flight plan.

This general instrumentation concept for navigation is illustrated in Figures 8 and 9, in order to introduce the principal navigation displays which are considered in the integration of flight deck instrumentation presented in Section 9. For purposes of this discussion, the arrangement of these displays on the instrumental panel and such design details as the overall size of the instrument, the indicated presentation format, and display symbology should all be ignored. The major instrumentation concept illustrated in Figure 8 is the pictorial display of navigation situation data located on the center panel accessible to both pilot positions. This display will provide a continuous representation of present aircraft position and actual track superimposed on a readily interpreted complex of significant geographical reference features, position reference coordinates, traffic control data, and navigational facilities. In addition, desired and/or required routes, track projections, reporting points, updating position fixes established using external reference systems, destination and waypoint locations, ETA's, range capability, etc., will be available, perhaps selectively, to provide a comprehensive representation of the navigation situation. In automatic modes of operation, this display would be used to monitor the performance of navigation functions and to determine that the flight is proceeding in accordance with the flight plan and ATC clearance instructions.

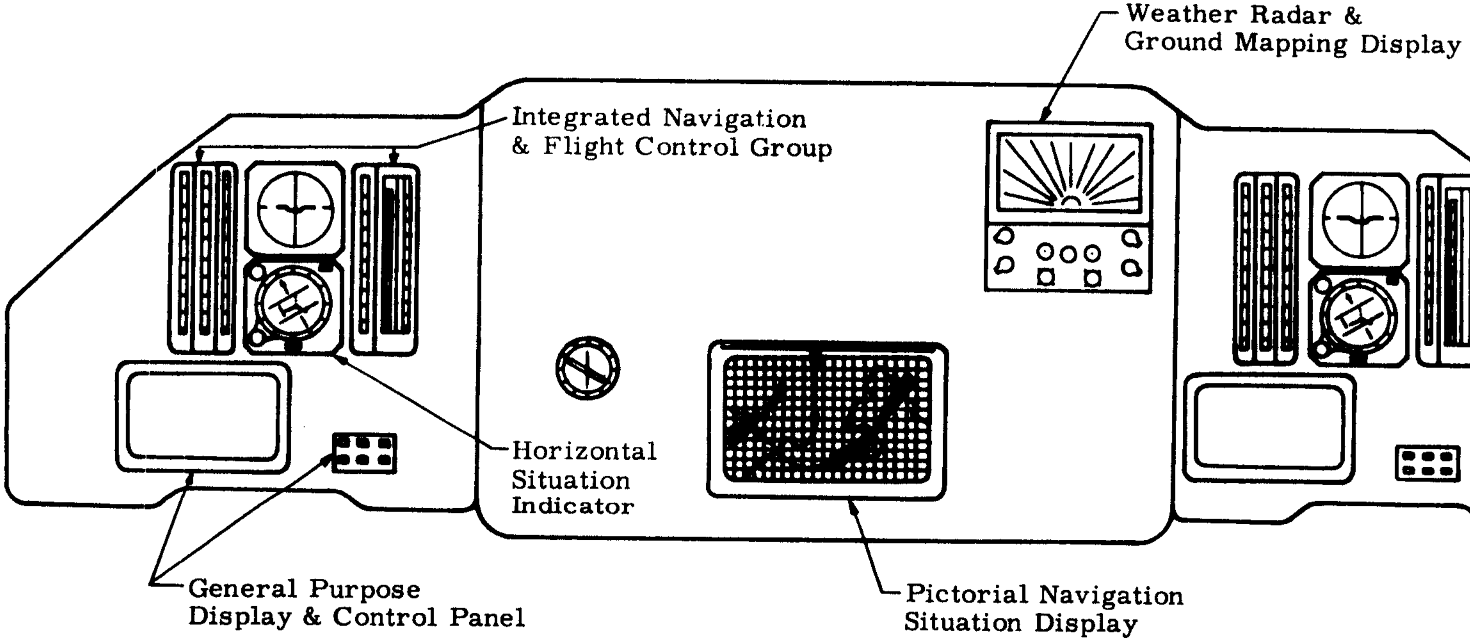


Figure 8. Major instrumentation for navigation functions.

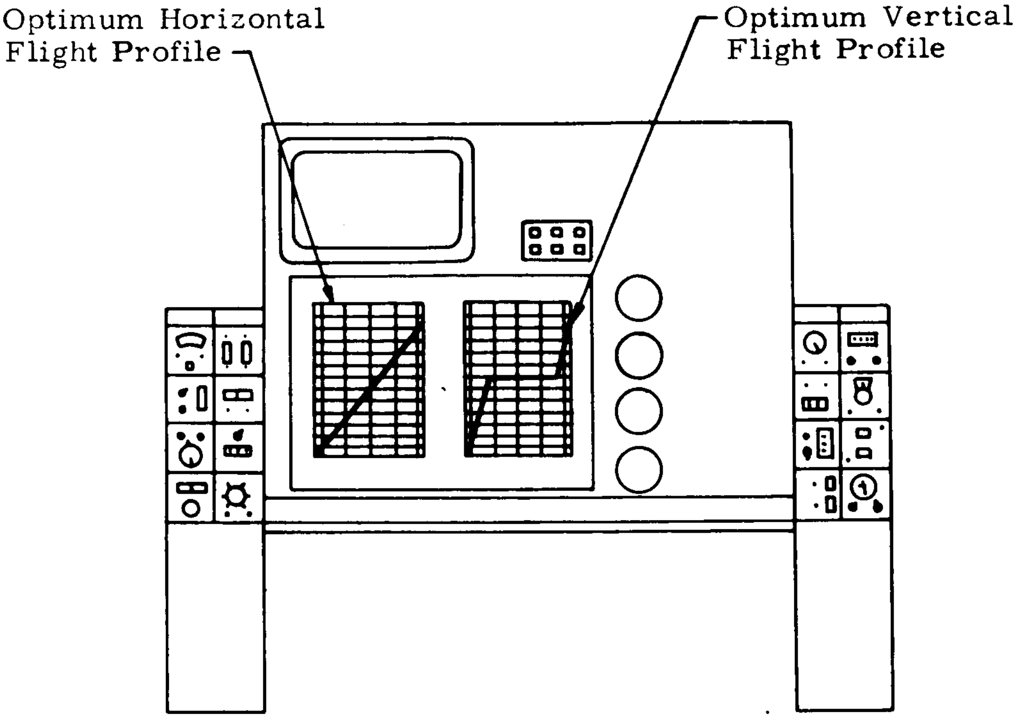


Figure 9. Display for optimum flight profile navigation functions.

Display parameters concerned more with the control of the aircraft to achieve navigation objectives are represented by display elements in the flight control group. These parameters include present aircraft heading, command heading and/or steering information, selected course readouts, distance and bearing to selected navigation facilities, airspeed, etc. Also shown in Figure 8 is an airborne radar display intended primarily for the determination of actual enroute weather conditions ahead of the aircraft. Cloud cover and such associated phenomena as turbulence are inferred from radar returns on this display. In many instances, the radar display will incorporate a ground mapping mode and thus provide for the orientation of the aircraft with respect to prominent terrain features.

The major display instrumentation concept illustrated in Figure 9 is the optimum flight profile display. This display is shown separately to indicate that it will be used only in three or four-position flight deck configurations. An alternative instrumentation concept, and one which would probably be adopted if only two crew positions are considered, would incorporate optimum flight path data into the pictorial situation display or as elements of such instruments as the HSI, airspeed indicator, nd vertical speed indicator. If used, optimum flight profile displays would represent a new concept in flight path control, one adopted primarily to assure the most economic operation of the SST. For the most part, this means optimization of fuel utilization but the existence of such constraints as requirements for minimizing noise and sonic-boom effects, weather, traffic control, acceptable g force loadings, etc., combine to complicate the determiniation of appropriate routes and altitude profiles. This problem is discussed in detail in Volume II; at this point it is sufficient to note that preflight planning and inflight computations may be directed toward establishing more precise flight path control in both the vertical and horizontal planes. Precise speed-altitude scheduling as well as more accurate track control is envisioned and a display is required to indicate deviations from this optimum scheduling in both dimensions. The contents and format for such displays has not been worked out. It could conceivably entail some sort of three dimensional display. For present purposes, however, a separate display is shown in Figure 9 for representing the optimum horizontal and vertical situation.

The horizontal display would present the lateral deviations to facilitate comparisons with the preplanned track or revisions computed in flight. Any large excursions would be immediately noted, and information could be obtained which verified the validity of such a deviation. The horizontal display could also be used to show capabilities based on fuel remaining and then on fuel reserves. The vertical situation display would present the profile in vertical cross-section, and would provide information concerning the vertical scheduling of the flight. When compared to the preplanned schedule, deviations would be immediately obvious. To illustrate its use, the computer may calculate that because of the unforecast weather conditions it would be more appropriate to delay the acceleration to supersonic speeds. This could be translated into a new speed-altitude schedule which would enable the crew to anticipate flight control changes, if automatic control is employed, or manually fly a more appropriate climb schedule during certain segments of the flight profile.

8.2 INSTRUMENTATION CONCEPTS FOR FLIGHT CONTROL AND POWER PLANT OPERATION

As was true for the navigation display concepts discussed above, Volume II of this report goes into some detail concerning concepts for implementing the activity of the flight control and power plant operation for SST. Appendix IV contains the results of the survey of current instrumentation techniques which are applicable to each of the display parameters associated with the performance of flight control and power plant operation activities. Generally, the information required was considered to be of a format and type which paralleled current information and as such current display techniques could be utilized to present the data. Since the purpose here is to develop a representative display concept which can be used in the basic flight deck layouts considered in Section 9, the only suggestion advocated over current instrumentation is that vertical scale indicators be adopted in lieu of the present dial type as (in the opinion of the authors) they decrease the space requirements, relieve the cluttered panels, assist in optimizing scan patterns, and allow for easier detection of deviant readings.

In current aircraft pilots are provided with some basic flight control instrumentation. The SST will utilize a similar grouping as depicted in Figure 10 which will include:

1. An attitude gyro which provides for pitch and roll indications, glide slope deviations, yaw information and rate-of-turn data;
2. An air speed indicator;
3. A Mach indicator;
4. An angle of attack indicator;
5. A vertical speed indicator;
6. An altimeter (barometrically derived); and
7. A radar altimeter for all-weather landing or low level flying.

In addition to the above instrumentation the necessity to fly in the VOR environment requires that the pilots be provided with a horizontal situation indicator which would display selected courses, localizer deviations,

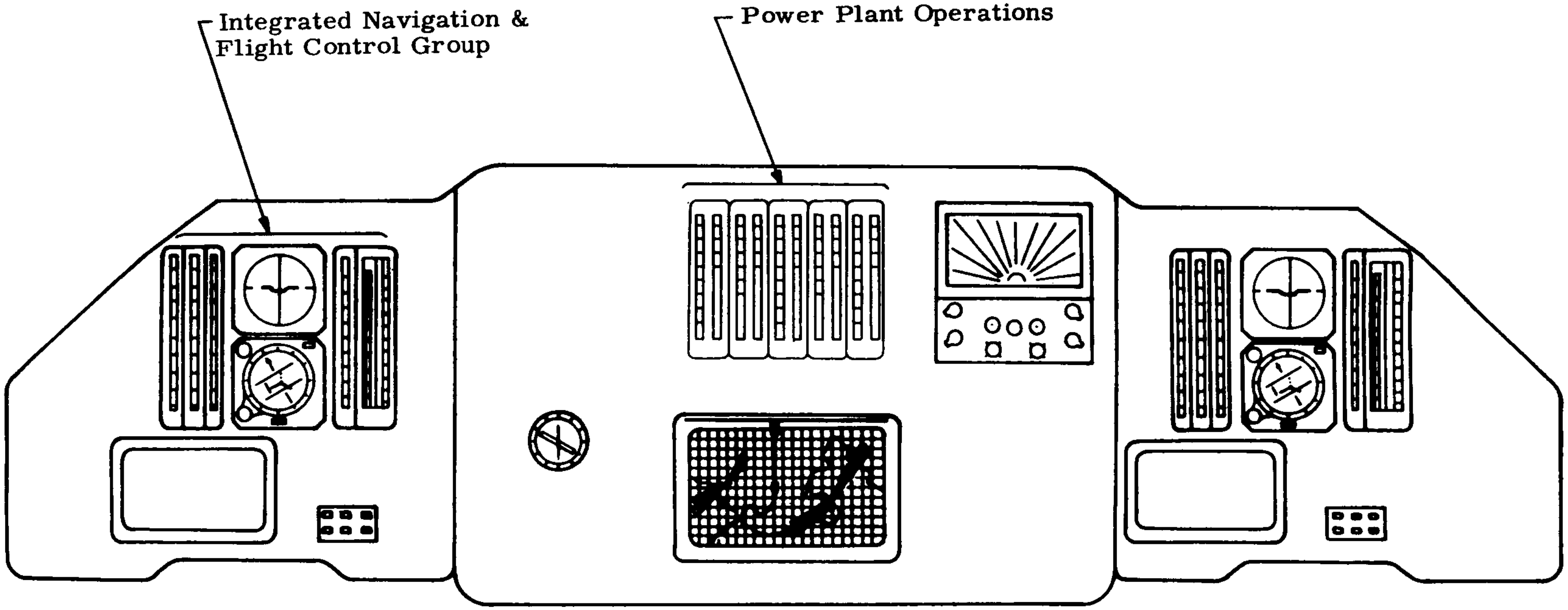


Figure 10. Major instrumentation for flight control and power plant operations.

heading, and range readouts from distance measuring equipment, and a radio magnetic indicator to provide bearing information to some selected station. With this instrumentation the pilot is able to perform any flight control task (e. g., climbs and descents, turns, level flight, and any combination of these), since information is available for positioning the aircraft in all three dimensions.

The other area of concern of the pilot is the control and efficient utilization of the power plants. For the actual control of the power plants specific information is required and is usually presented as a basic grouping of instruments. See Figure 10. Those instruments which are usually utilized for each engine include:

1. Engine pressure ratio;
2. Exhaust gas temperature;
3. Percentage RPM--N_1;
4. Percentage RPM--N_2; and
5. Fuel flow.

In reviewing instrumentation it was concluded that the use of vertical scale indicators provides a more efficient display technique for power plant information.

In both of these areas the instrumentation is quite similar to that which is currently utilized. The placement of the groupings will remain relatively unchanged, with the only suggested change being the use of vertical scan indicators. In many cases the instruments described above will have varied modes of operation to provide command and flight director information.

8.3 INSTRUMENTATION CONCEPTS FOR ALL-WEATHER LANDING

It is reasonable to assume that the design of the SST will include the latest developments in cockpit aids and control systems for minimum visibility (ICAO Category III) approach and landing. This discussion is concerned with general instrumentation associated with the crew's role in these systems, but it is beyond the scope of the present effort to derive new display concepts for all-weather landing systems. Many studies have been, and are being, conducted into the landing task, airline operating problems associated with low visibility and ceiling conditions, the inherent weaknesses of the electronic equipments to be utilized in the landing systems, the acceptance by the crew of the automatic concepts, and other aspects of the all-weather landing problem. Serendipity Associates has been associated with many of these areas and the present discussion will draw upon the results of previous analytical and empiral studies. Much of what follows is taken directly from a study conducted by R. Behan and F. Siciliani (Ref. 82) and is included primarily to provide the necessary background on the landing task and the type of display which could be used to obtain optimum crew performance in a Category III landing system. Behan and Siciliani investigated jet transport landing task and pilot acceptance of displays for landing in reduced weather minimums. In their study they described the landing task, defined the information requirements, evaluated many of the current display concepts in terms of crew acceptance and optimum human factors engineering, and synthesized a display concept. The general character of the man-machine interface envisioned for these landing systems is described by Behan and Siciliani as follows:

> There is always some finite probability, no matter how small, that automatic equipment will fail. Thus, the pilot will always be there, if only to back-up an automatic system. Now, the nature of the landing task requires that the pilot have certain information displayed to him, if he is to adequately back-up an automatic system. Furthermore, the pilot cannot, if he is to obtain this information play the role of a passive monitor of the automatic system. If he does he will not acquire the information he needs. Thus, we use the term display in a much broader sense than it is conventionally used, i. e., visual display. Further, in utilizing these kinds of information the pilot is not concerned alone with what the aircraft is doing. He uses this information along with a knowledge of the aircraft handling characteristics to infer what the aircraft will do in the immediate future. He behaves in such a way as to stay ahead of the aircraft. Thus, even if the automatic route should be adopted, the possibility of electronic failure is such that an adequate man-machine interface will require an information display which provides visual, kinesthetic and motion cues which afford a present denotation and an intention for the immediate future. Without such, the pilot cannot stay ahead of the aircraft.

This man-machine interface will have even greater significance in the SST, where the landing system will have the greatest capability, the maximum use of automation will be utilized, and man will be relegated the role of a monitor primarily. However, the display chosen to provide the crew with their essential information will in all likelihood incorporate many of the ideas presented in this earlier study. Even though the aircraft may be controlled by an autopilot with auto-throttling, and coupled to a ground approach landing system, the crew will continue to require sufficient information about the approach to allow a safe and expeditious takeover from the automatic system. It should be noted that no definite statements are available in the literature which advocate that the crew have the capability to manually land the aircraft in zero-zero weather.

With respect to display requirements, Behan, et al found that,

> The display for landing in reduced visibility should be developed with one overriding consideration in mind. The landing comes at the end of the flight. In all likelihood, the pilots will have flown the aircraft for a period of time ranging from 4 to 8 hours. They will be tired. The aircraft may be low on fuel. The runway, when they get to it, may be wet, icy, fog bound or snow covered. The pilots will be using the display in the worst possible conditions, and it must be developed for use in those kinds of situations.
>
> The analysis of the landing task, which was presented in the second section, is the source of the information requirements for the display. The content suggested was information to:
>
> 1. Determine when to initiate the final approach;
> 2. Achieve an appropriate glide angle;
> 3. Warn of overshooting or undershooting the aiming point (departure from glide angle);
> 4. Maintain an appropriate angle of attack;
> 5. Maintain an appropriate sink rate;
> 6. Maintain an appropriate roll attitude;
> 7. Maintain an appropriate course;
> 8. Indicate amount of crab required to maintain course;
> 9. Determine when to initiate the flare maneuver;
> 10. Maintain aircraft heading during roll-out.

Taking these informational requirements into consideration, in addition to previous pilot preference studies conducted by Serendipity Associates, the elements of the display were defined. Behan and Siciliani state that, The display consists of the following elements:

1. Director cross;
2. Fast-slow airspeed indicator;
3. Aircraft ground track symbol;
4. Horizon line with runway heading marker;
5. Runway with aiming point and center line;
6. Crab bar;
7. Radar altitude and flare initiation symbol;
8. Distance-Altitude readout.

A concept for a projected, head-up display that meets these requirements is shown in Figure 11.

The concept developed by Behan and Siciliani appears to contain sufficient information to allow the crew to monitor operation of the all-weather landing system. However, the problem remains of evaluating the other possible methods of presentation (i. e., other than a heads-up display). Considerable work is currently being conducted in the development of contact analog displays which attempt to simulate a real world presentation. These display concepts should also be considered for operation in conjunction with the all-weather landing system. In evaluating alternative display concepts, various combinations and crew provisions should be considered. For example, the use of a heads-up display for the senior pilot and the copilot. The pilot controlling the aircraft would first utilize a symbolic display as described in the Behan and Siciliani report (ref. 82). The copilot would have a projected presentation of the essential flight control parameters which would allow him to assist in monitoring landing, and also allow him to look for the runway (i. e., transition from instrument flying to contact flying). This evaluation should then be repeated using a contact analog type of heads-up display.

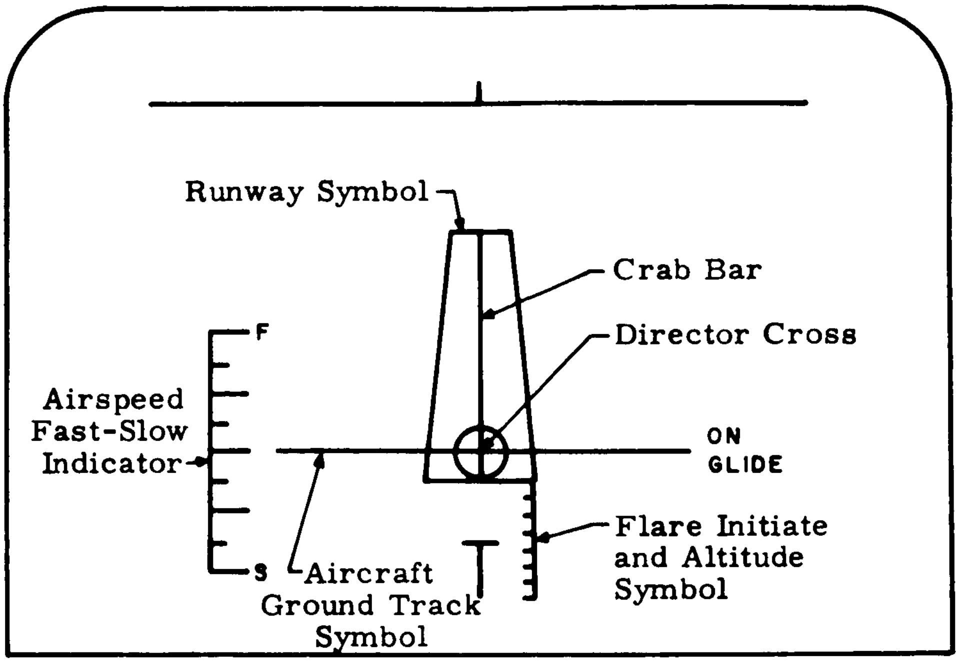


Figure 11. Elements of an all weather landing system display.

Another combination would provide one pilot with an extension of current instrumentation to fly the final approach while the second pilot monitored using a heads-up display. In this situation, the pilot controlling the aircraft would have the same information as is currently available (although to a more precise degree), and the pilot using the heads-up display could take over when visual contact with the runway was established. This combination should also be repeated using a contact analog type of display instead of the conventional instrumentation.

In addition to evaluating different combinations of heads-up displays, new types of instrumentation, such as the contact analog display, should be evaluated in the present location of flight director instruments on the panel. Although many studies have indicated that the use of a heads-up display appears to offer the best characteristics, its applicability to the supersonic transport is yet to be determined. Other areas which require investigation before a final landing display concept is adopted include such factors as the approach angle of the SST, the amount of visibility during the landing phase, and the performance characteristics of the aircraft.

8.4 APPLICABILITY OF GENERAL PURPOSE DISPLAY CONCEPTS TO SST INSTRUMENTATION REQUIREMENTS

In section 7, mention was made of crew information requirements which were not considered essential for the performance of specific operational functions, but were necessary for overall situation assessment and decision making. It was further pointed out that since continuous display of this information is not required, it should not be necessary to add more individual instruments to an already overly crowded flight deck. In considering instrumentation requirements for such parameters, then, the concept of shared instrumentation or some type of "general purpose display" evolved. Although the concept is not new, its application to the cockpit of the supersonic transport would represent a significant change over current instrumentation.

Before proceeding any further, it might be well to clarify the concept of "general purpose display" so that a frame of reference will be established for what is to follow. The term is probably a misnomer and a phrase such as "shared space display" is perhaps a better descriptor. In other words, if the requirement for information is such that it can be attached to a time profile, then display parameters required during the same time segments should be displayed at the same time. However, at times when such information is not required, the same display space could conceivably be utilized to present other time discrete information. Our concept goes another step to include that information which is not time-dependent, i.e., it can be used at any time during the operational profile, but timing requirements cannot be specified. This usually is the information necessary for situation assessment and judgments, or what has been classified as "demand" information. It is likely that this sort of information is currently provided for by reference materials or must be stored in the crews' heads. If a general purpose computer is used to assist in meeting navigation requirements, then it is reasonable to assume that this same computer could be used to store such information and to display it whenever called upon. The presentation technique is still to be determined, but it is likely to involve some form of CRT display.

The parameters developed in section 7 fell into several categories; namely,

1. those requiring continuous display;
2. those requiring display at some discrete time;
3. those not routinely required (e.g., contingent upon the occurrence of some malfunction) but requiring continuous display when they are needed;

Additional instrumentation problems stem from the increase in aircraft speeds, the increased use of automation in the cockpit, and the decreasing role of man in the control loop. This has been noted by Majendie (ref. 76):

> The problems of building a suitable complex of controls and indicators for a supersonic airliner, using a mixture of human and automatic systems, does not seem to need any great extension of the techniques which are now becoming available. However, as we move into regions of ever increasing operational performance, the possibility of continuing to use direct control by human pilotage will become less and less attractive, and finally impossible. It will become increasingly necessary to turn our attention away from the direct problem of how to control the situation, and more and more to turn towards the indirect problems of how to manage an automatic control system designed to handle the operational task with an ultra-human capability.
>
> In providing a human operator with suitable displays to monitor and manage such a control system, it is clear that presenting him with the objective facts of the operational situation will be quite inadequate for the purpose. As the situation is by assumption quite literally beyond his capability, presenting it to him cannot conceivable achieve the desired result. Much work has been carried on in recent years in some quarters on the design and development of so-called contact analogue displays, which set out to synthesise a normal visual pictorial display apposite to whatever may be the particular tracking task being demanded of the human operator. This type of approach, for the reasons given above, must eventually lead into a complete cul-de-sac in application, and it is important that we do not delude ourselves into thinking that any easy solution to out (sic) difficulties can be achieved along these lines.
>
> What is urgently important is that experts in the design of automatic systems, in the interpretation of operational requirements, and in the capabilities and limitations of human beings, should get together and discuss their mutual problems. Most of those related to human efficiency and airborne systems for future supersonic and hypersonic airliners will be more concerned with the conception and design of automatic systems, than with the in-flight tasks of the human pilot.

> Nevertheless such aircraft will continue to carry human pilots for very good reasons, and the correct relationship between these and the automatic systems is going to be our most difficult and important field of study.

If this position is adopted it becomes apparent that current instrumentation is not going to provide the crew the kinds of information they will need to perform their role effectively in a highly automatic system. H. P. Ruffell Smith has considered another aspect of this problem (ref. 77):

> The relegation of the pilot from his position of skill to one of a monitor and decision taker (sic), with the need for improvement in the presentation of the data for both these purposes is already upon us, but there is a further step to come which is probably of even greater import. There is already evidence of shortcomings in the pilot's ability to compute short-term situations. An excellent example occurs at take-off in aircraft which are critical during this phase. Temperature, humidity, windspeed and direction, acceleration, distance, angle of incidence and airspeed all have their effect--pre-computation used to suffice, but now take-off monitoring systems have become necessary, because conditions such as windspeed and direction may vary at the critical time. Man is then in the position not of taking the decision but of asking the question.

The foregoing quotes all point up the need for better and more adequate instrumentation concepts (i.e., display techniques). Some of the instrumentation in current aircraft reflects an attempt to solve this problem, but in most cases the solution is added to the existing instrument panel; thus giving redundant information and a very cluttered instrument panel. Crews will usually compensate for this by using only those instruments which they feel furnish them the necessary information and completely ignoring the other instruments.

What then, is the solution to the problem? The derivation of solutions will require extensive analytical and empirical study and might reasonable include a study of current instrumentation to determine how integrated instrumentation is being utilized, a survey of current display techniques, the development of a display console which could be tested empirically, and finally a real time test to determine the effects of the time compression introduced by high speed flight. Integrated instrumentation and general purpose display techniques are closely related. Attempts to integrate various cockpit display elements underlie the development of the general purpose display concept. It would not be feasible to assign each of the large number of display parameters identified in section 7 to individual instruments. Even if such a set of instruments were possible, safety and reliability considerations dictate that many of the instruments be duplicated and in some cases triplicated. This, of course, is an impossible situation. The solution is to combine some of the parameters and to display them on the same instrument.

A related problem, and one which has been aggravated by the time compression introduced by high speed flight, is the problem of time lag due to display interpretation. In most instances the crew must scan various instruments, interpret the information to appreciate the situation represented, and then react to the situation. Integrated instrumentation does not alleviate this problem, although it does alleviate scan problems (i.e., if five instruments were combined into one, then the crew member only needs to view one area for the same information). Thus, it appears that integrated instrumentation may help solve the clutter problem and relieve certain difficulties connected with scan patterns, but that some new type of display technique may be necessary to reduce the time lag between pilot scan and pilot reaction. In the SST it appears that there will be various types of general purpose displays. These probably can be classified as follows:

1. Integrated instrumentation;

2. Situation displays;

3. Pictorial displays, and

4. Special format readout displays (e.g., event profiles, graphic analyses, etc.).

4. those associated with recurring events and thus requiring periodic display, and

5. those used for situation assessment and requiring display on demand.

The display of parameters in each of these categories can be incorporated, to some degree, in the concept of a general purpose display as it is used here. There are various categories of information, then, which are either "demand" in nature, or require concurrent display, and each category can include many parameters. The use of separate instruments for the continuous display of each of these parameters would result in a very unwieldy cockpit area. As Dr. W. Dybowski points out (ref. 76):

> The modern development of all kinds of aircraft makes them more and more complicated. The front of the cockpit instead of being perfectly free, permitting the pilots to have a free and open view in all directions, is partially obstructed by an enormous number of dials and gauges. It is not unusual to see a cockpit with more than 200 different gadgets, all requiring attention at some time, from either the pilot or the copilot. As human attention cannot be divided to so many points simultaneously, most of the dials are disregarded, and attention concentrated on a few dials considered, by the pilot, most important.
>
> If these trends develop further in the same way, we will see cockpits with more than 200 to 300 dials and guages. This is a blind alley, leading to more and more errors and disasters.

Dr. Dybowski's point provides a sufficient basis for a complete reevaluation of thinking in the design of cockpit instrumentation. Cockpit complexity cannot be relieved simply by deleting instruments which in some instances have been used effectively in cockpits for many years. However, it is clear that new concepts must be developed which will provide adequate instrumentation without this complexity and clutter.

In the development of improved display concepts for the SST, the problem for designers will be complicated by the fact that the task of the crew is shifting from one of skilled psychomotor control to an almost completely cognitive activity, and the crew will require new categories of information requirements. For example, present situation information will be inadequate, since the state of the system will be changing too rapidly, and the crew will require predictive information so that they can "stay ahead of the aircraft" and thus make timely decisions. This change in the type of information required, or the presentation format, is the reason display techniques such as general purpose displays are considered. As used here "general purpose displays" is a generic term which includes integrated instrumentation, time-shared instrumentation, space-shared instrumentation, and time-history or projected time instrumentation.

9.0 INTEGRATION OF INSTRUMENTATION INTO SST COCKPIT AS BASIC FLIGHT DECK LAYOUTS

The efforts reported in the previous sections have investigated the information requirements of the crew (section 7), have discussed major instrumentation concepts (section 8), and have recommended distribution of specific operational functions on the basis of two-, three-, or four-man crew complements (section 5). This section represents the summation of these efforts in the form of basic SST cockpit layouts. It should be reiterated that the instrumentation concepts are representative and not necessarily recommended, as the principal purpose of this effort was to develop flight deck concepts suitable for incorporation into a simulation research program. These concepts and layouts may be different than those chosen by the manufacturer finally selected to build the SST. Until the final decision is made on the type of systems which will be utilized in the SST, definition of the crew interface requirements are entirely a priori. The final concepts will be the results of many trade-off analyses, and will be based in part on empirical studies conducted both in current types of aircraft and in SST simulators. Thus, the objectives of this effort were to define basic cockpit layouts for an SST simulator and integrate major instrumentation concepts into these layouts which would fulfill the information requirements of a two-, three-, and four-man crew complement. It should also be pointed out that the results of the workload analysis (section 2) indicated that the utilization of a two-man crew did not appear to be feasible on the basis of the workload which the crew would be subjected to (i. e., the crew would be heavily loaded). However, basic cockpit layouts are presented for two-, three-, and four-man crew complements so empirical research in simulators can be conducted to ascertain the validity of these analyses.

The flight deck layouts based on a specific number of crew members considered some "real world" constraints. Ideally, the required instrumentation should be located at the crew station concerned with the performance of the specific functions needing that information. Although this approach should be used when looking at the system parameters, it is clear that the location of some instrumentation will be independent of the crew size, e.g., usually most of the control functions dealing with the operation of the aircraft will be performed at a pilot's station. However, the workload analysis (section 2) was examined, as were the results of the function distribution (section 6), in an effort to correlate the information requirements to the specific functions and then to specific crew stations.

9.1 TWO-MAN CREW COMPLEMENT

From Table 5, section 5 it would appear that the division of the duties between two men closely matches the division utilized by the military on some current two place supersonic aircraft, i.e., pilot and navigator. In the SST it seems reasonable for a two-man operation that the instrumentation will have to be distributed so as to provide this relationship. The assumption that both crew members would be required to be pilots is certainly valid and this then requires that adequate control and displays be provided to both crew members for basic aircraft operation. The major feature in cockpit layout will be the allocation of the navigation equipment control panels to that area adjacent to the copilot position whose main responsibility is the navigation activity, and the incorporation of an all-weather landing display at the pilot's position. Figure 12 is a basic flight deck configuration for a two-man crew. Station 1 on this drawing has the responsibilities of position 1 as described in section 6. Station 2 has the responsibilities of position 2. Figure 13 shows the basic flight deck layout with major instrumentation integrated into it.

The two stations will share the pictorial navigation display which will be located on the forward panel between the two pilots. The controls should be located so that the pilot in the right-hand seat can perform

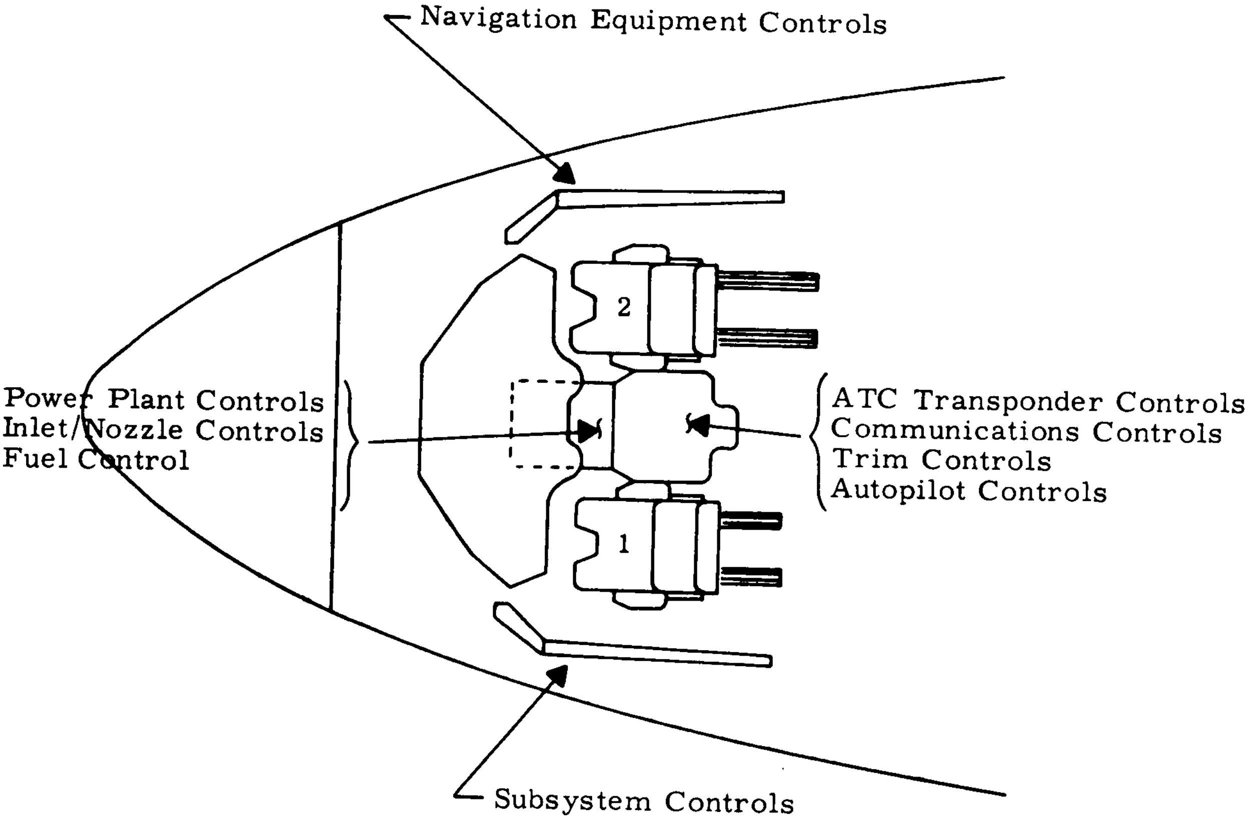


Figure 12. Two-man cockpit configuration.

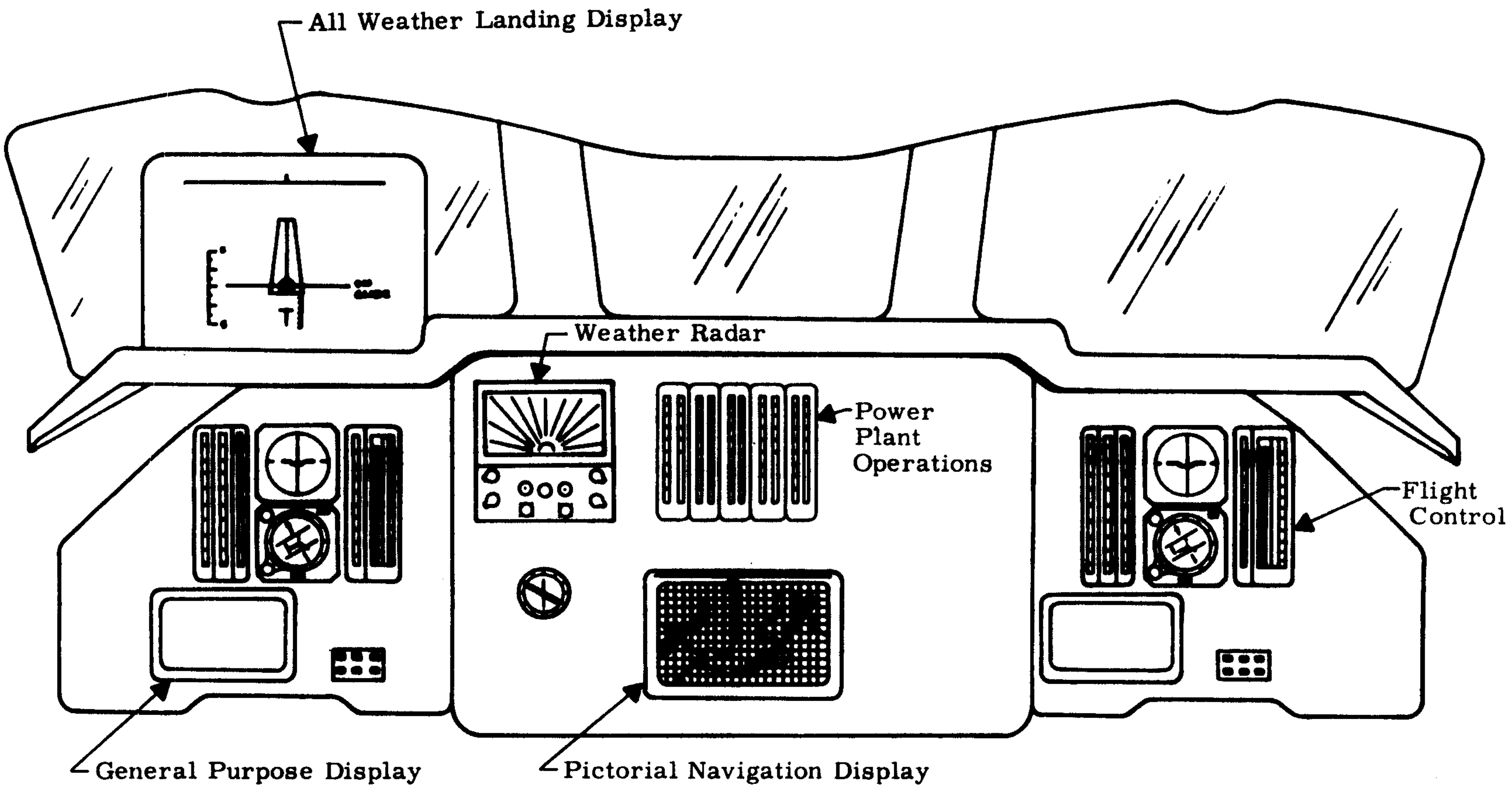


Figure 13. Stations 1 and 2 basic layout for two-man operation.

the necessary equipment set-up. Since most all of the navigation systems currently being developed present their information via digital readouts on the control panels as well as provide inputs to the pictorial navigation display, this will be available to the "pilot-navigator."

The right-hand seat station will be responsible for the majority of the navigation functions, and will control the equipment utilized to obtain internal and external fixes. The control panels for the chosen navigation equipment, as well as the control panels for the communications and the transponder equipment, will be on the center pedestal, the forward panel, and on the pilot's side panel. This station may also require a general purpose display since much of the navigation data which is sampled must be evaluated to make appropriate judgments.

The left-hand seat,or station 1 will direct the management of the flight and will be provided with a general purpose display as well as the appropriate data insertion controls for utilizing the computer. Depending upon the space allocation of the chosen SST design, and the type of control column utilized, the display and control panel should be directly beneath the basic flight grouping of instruments, or possibly offset slightly to the left (i. e., away from the center pedestal). This station would also require the appropriate data in the event the aircraft must change course because of adverse weather. Thus, the weather radar display should be placed so that it can be utilized while controlling the aircraft. Strictly from a space allocation solution, it would appear that the area directly to the right of the basic instrument grouping would fulfill the requirements.

Assuming that the requirement exists for dual pilots, then provisions must be made to design each of the stations in a two-man concept with adequate controls and displays to accomplish the flight control functions and power plant operations. Under the two-man concept, the left-hand station is responsible for the actual management and general system operation of the flight. As such, this station will require all instrumentation concerned with the actual operation of the aircraft. Because of the close proximity to the right-hand station some controls should be located so that they can be shared when necessary (e.g., the power plant control pedestal). During those phases of the flight profile where it is envisioned that man will actually be in the control loop and will fly the aircraft manually (e.g., during the takeoff and initial climb, and during the latter portions of the instrument approach), the navigation functions which need to be performed are almost nonrestrictive. This permits the crew member at the right-hand or navigation station to assist in the flight control function to the extent that landing gear and configuration control (e.g., flaps) may be controlled by that crew member. For that reason the gear control and configuration controls should be located on the forward panel, but offset to the right. This is also true of the placards utilized to present information on the limitations of these systems. The all-weather landing display is provided at the pilot's position in accordance with the rationale presented in section 8.

The crew will also be responsible for the maintenance of the other aircraft systems. This means that the assumptions made earlier concerning the instrumentation necessary to monitor and control the basic systems indicated that such standard instrumentation will have to be divided between the two stations. These will have to be integrated into the space which is remaining on the forward panel, the overhead panel, and the side panels.

9.2 THREE-MAN CREW COMPLEMENT

Figure 14 is a basic flight deck configuration for a three-man crew. On the basis of crew roles defined in section 6,position no. 1 at station 1 would be the flight manager, position no. 3 at station 2 would control the aircraft (i.e., the flight control functions), and position no. 2 at station 3 would navigate. The addition of a third crew member and the shift of the responsibility for the navigation functions from the second pilot will also

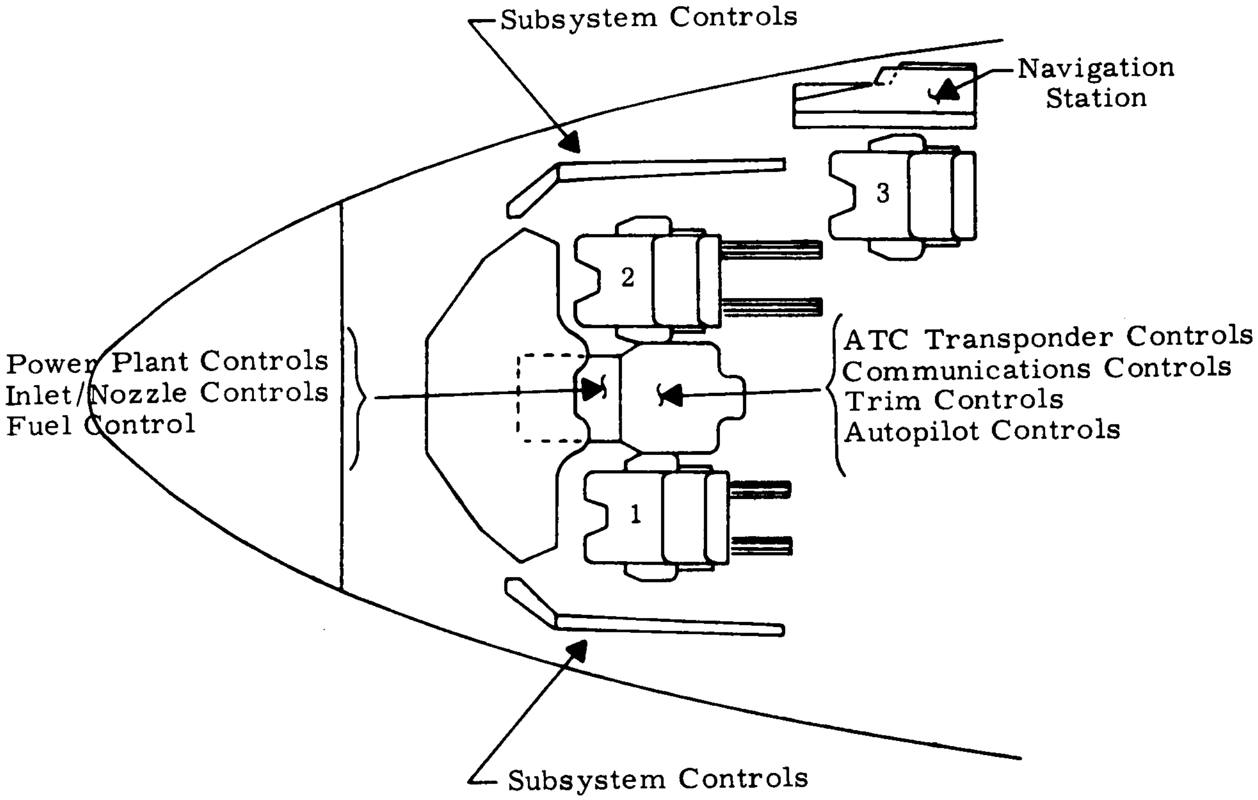


Figure 14. Three-man cockpit configuration.

help to relieve the cockpit frontal area of some navigational control panels. Figure 15 is the basic flight deck layout for stations 1 and 2. Figure 16 is the basic layout for station 3.

The layout of the front panel for the left-hand station will be almost identical to that described in the preceding section on the two-man crew. The flight manager (station 1) will require the ability to utilize the on-board computer, and will require a general purpose display and associated control panel. However, the shift in the responsibility due to the function description deems that the location of the weather radar should be shifted to an area right of center. The only navigation function which is performed by the crew member in the left-hand station is the ETA prediction (an evaluative function), but the position continues to require adequate navigation information to maintain cognizance of the flight's status. Those parameters dealing with the fuel system and its status are considered to be part of the navigation information. For this reason only those fuel instruments necessary for the control of the power plants would be left on the forward panel, and the remainder would be placed at the third position since the fuel profile is part of the navigation task. It would be assumed that under this concept the flight manager would have the capability either of directly seeing the instruments, or could utilize the general purpose display to obtain the necessary data concerning the status of the fuel system (e.g., the fuel distribution or the fuel "howgozit").

The layout of the front panel for the right-hand station also will be similar to that described for the two-man crew. The weather radar has been moved from the left-hand side of the front panel to the same relative position on the right side of the front panel (i.e., offset to the right of center to the same degree as it was offset to the left in the two-man concept). Because of the responsibility for most of the weather data at this position, if a hard copy printer is to be utilized, it could be placed on the front panel in place of the general purpose display. The majority

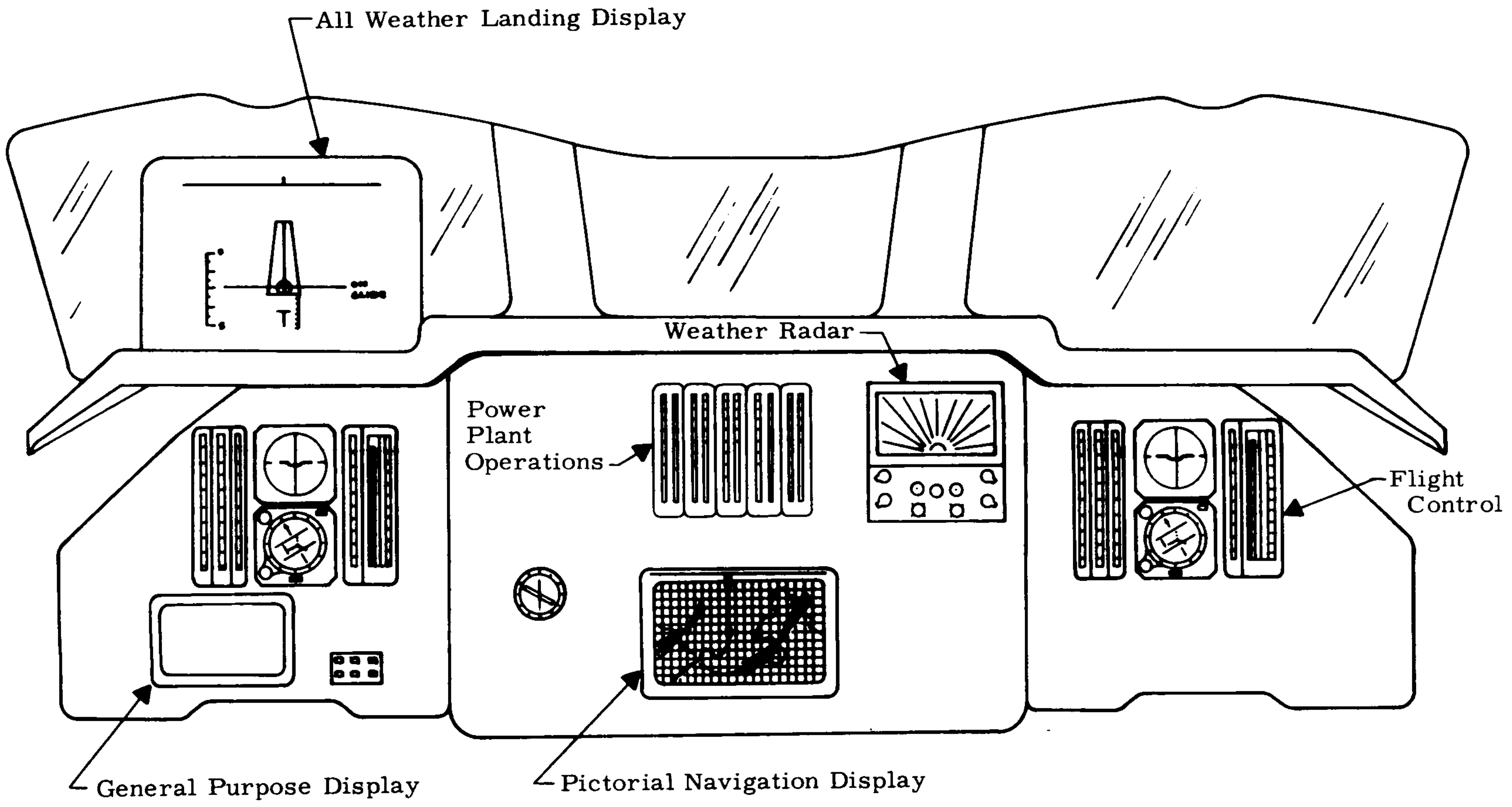


Figure 15. Stations 1 and 2 basic layout for three-man operation.

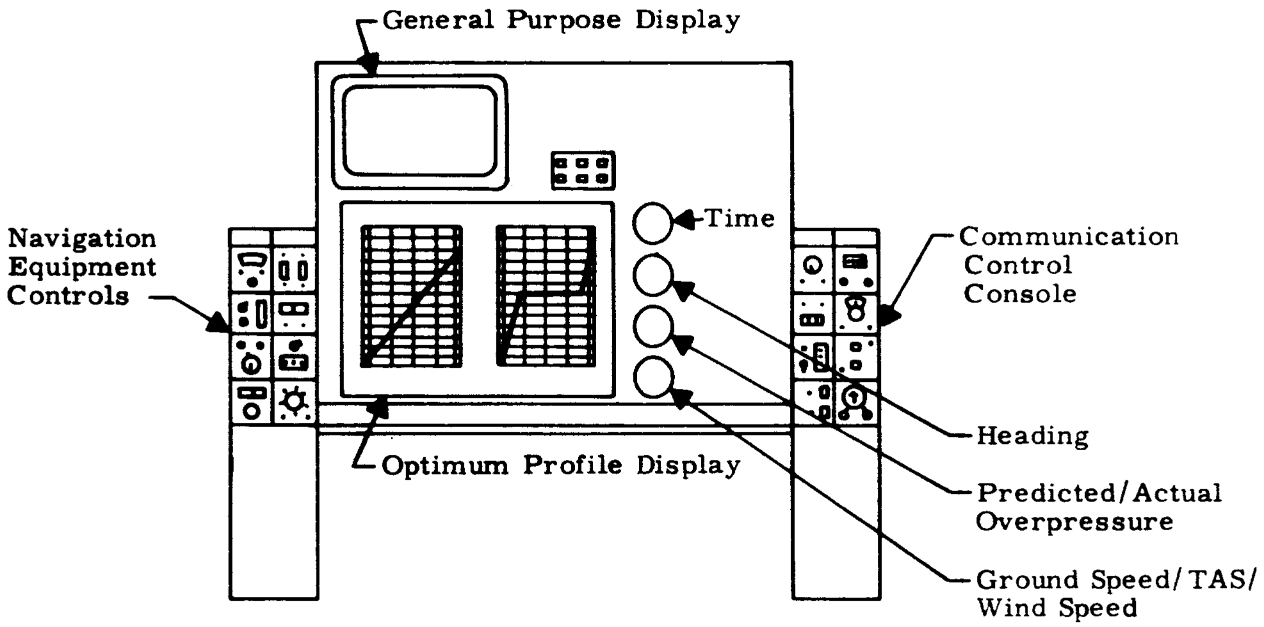


Figure 16. Station 3 basic layout for three-man operation.

of the navigation equipment control panels will be moved from the area of control of station 2 to station 3.

The center pedestal will continue to contain the power plant controls, the autopilot and autothrottle controls, and most of the communication equipment controls. These will be used by both of the up-front pilots.

The third man's station should be situated to the rear of station 2 (see Figure 14) and have the instrumentation and controls located along the right bulkhead. The seat should be moveable to allow the crew member to perform his activities at his station and also to coordinate with the rest of the crew. The physical size of the station will be dependent upon the navigation equipment chosen and the necessary instrumentation to monitor performance.

It would appear that the third station would need to have the following information:

1. Heading (integrated radio magnetic indicator)
2. Ground speed (ground speed indicator)
3. Altitude (altimeter--barometric and radar)
4. Fuel system data (total fuel and distribution)
5. Weather data (wind, temperature and radiation)
6. Estimated overpressure
7. Time
8. Horizontal and vertical profile situation

Most of the above information can be displayed via instrumentation which is currently available and familiar to most of the crew members. The major new instrumentation concept is the optimum profile display as shown in Figure 16.

It should be noted that there was also some discussion of exchanging navigation duties such that the pictorial display would be at the third station and the optimim profile displays moved to the forward panel, although this configuration is not shown.

9.3 FOUR-MAN CREW COMPLEMENT

The three stations described for a three-man crew generally reflect the characteristics of three of the stations in the four-man crew. Some changes are necessary, of course, to fulfill the requirements of each crew member utilizing his station to perform specific functions. The addition of a fourth crew member suggests a new concept wherein station 4 actually becomes a "systems manager" and although not controlling the aircraft (per se), could be responsible for its operation. On this basis, the center of responsibility could shift in the cockpit from the left-hand seat of the two- and three-man crew concept to the no. 4 station. This concept in itself would have transitional acceptance problems, but follows the thinking that high performance aircraft, or any highly automated systems for that matter, are causing a change in the nature of the task that the crew is performing. The neuromuscular performance is being replaced by a more cognitive type performance, and this in itself could be justification for a purely evaluative, judgmental, and decision making position. Figure 17 is a basic flight deck configuration for a four-man crew. The four positions defined in section 6 correspond for the four stations shown on the figure as follow: station 1 - position 1, station 2 - position 3, station 3 - position 2, station 4 - position 4. Figures 18 - 20 are the basic layouts for the four positions.

Station 1 and station 2 are readily seen as the two up-front positions. As such they will be instrumented in much the same manner as outlined in the previous paragraphs for the two- and three-man crews. The major deletion will be the communication control console from the center pedestal, as the communication functions are performed by the other two stations. This concept removes the responsibility to control the equipment, but does not prevent the two up-front crew members from utilizing the equipment. In most aspects, the other instrumentation will resemble the layout of the three-man concept. Because of the fact that there is an

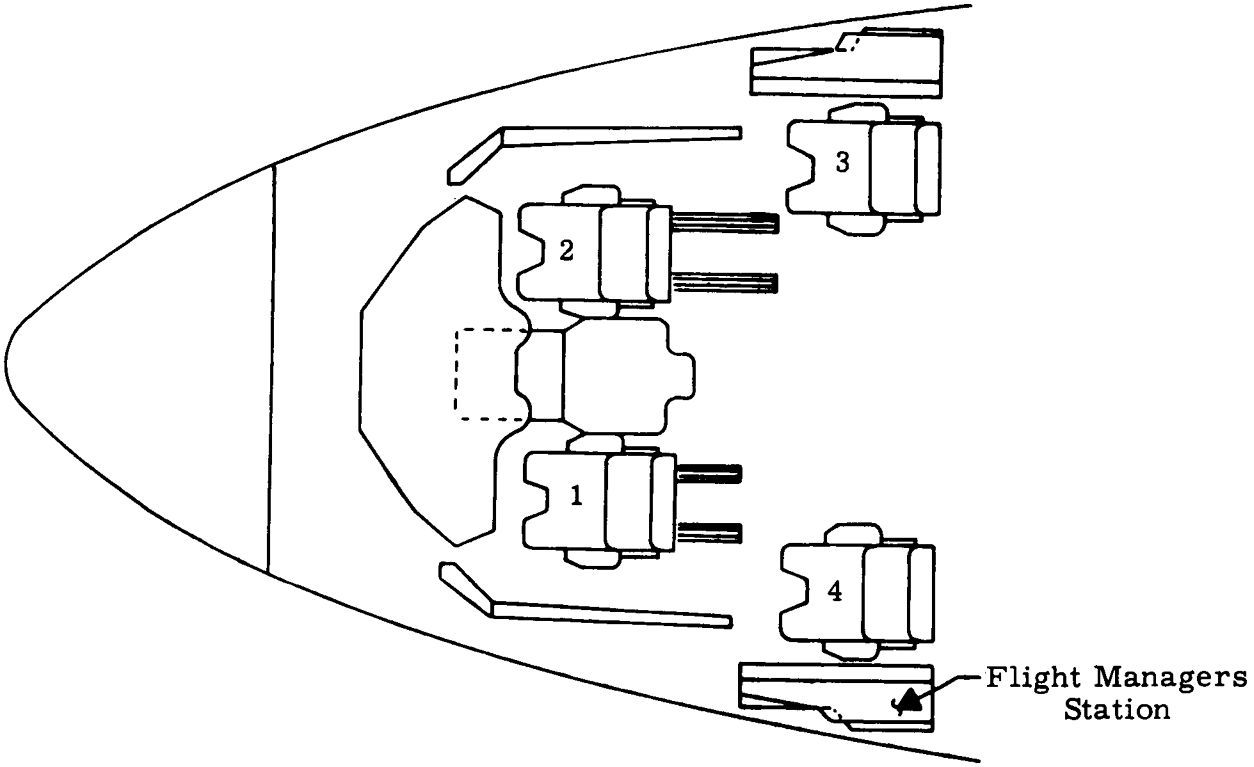


Figure 17. Four-man cockpit configuration.

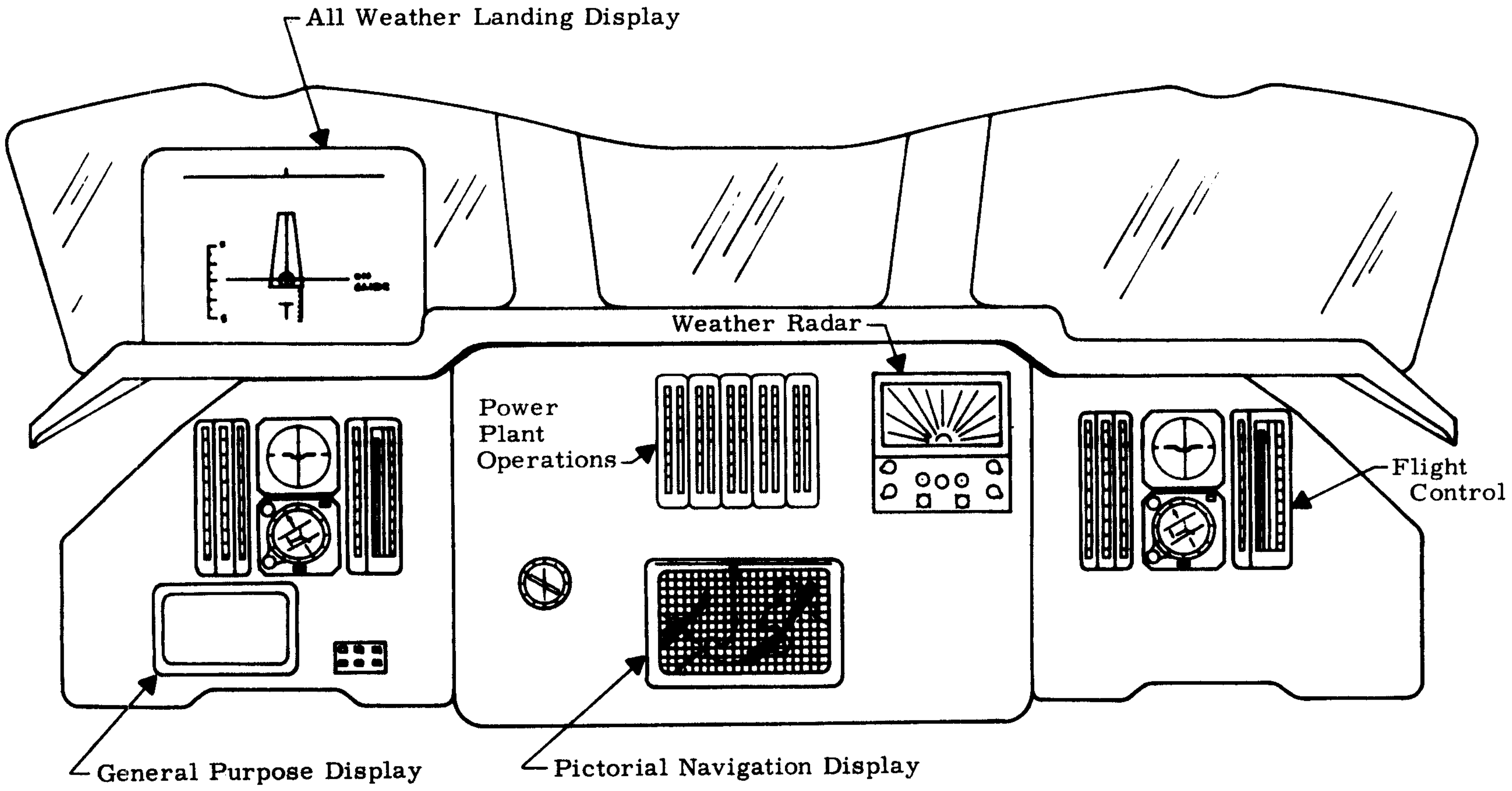


Figure 18. Stations 1 and 2 basic layout for four-man operation.

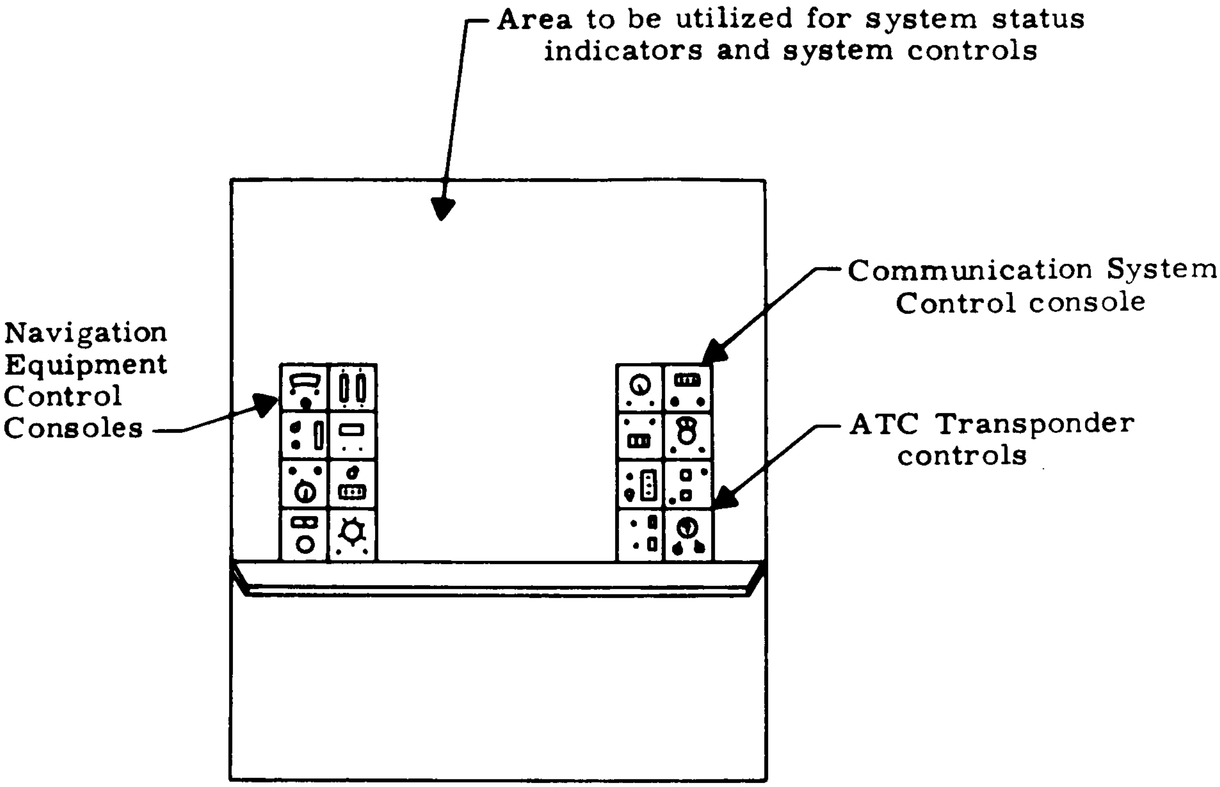


Figure 19. Station 3 basic layout for four-man operation.

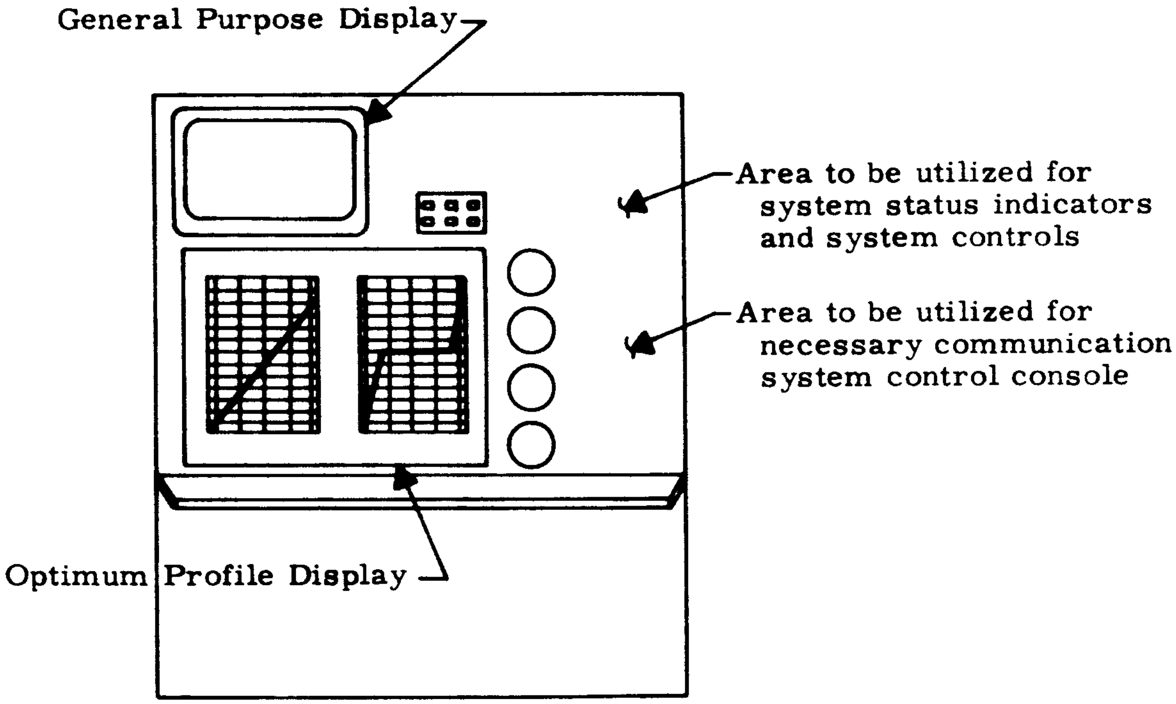


Figure 20. Station 4 basic layout for four-man operation.

added crew member, the distribution of the phase-oriented system checks will mean that some of the instrumentation and controls connected with the control of the various aircraft systems will be moved to new locations on the flight deck.

The major difference appears to be in the other two stations. The "navigator's station" (or station 3) in the three-man concept will change to the degree that the functions performed at that station no longer require the capability to monitor the horizontal and vertical situations. Generally, the responsibility of this station will be to control the various navigation equipments which are generating position information, and to monitor the credibility of their outputs. Under such a concept, the deletion of both the general purpose display and the horizontal/vertical situation display from station 3 must be considered. The information required to perform the functions at station 3 is primarily the operating condition of the navigation equipment, and the on-line configuration of the navigation system.

Just as station 3 was located on the right bulkhead behind the right-hand seat position, station 4 will be located on the left bulkhead behind the left-hand seat position. Now that the responsibility for the flight path management has been shifted to the fourth station, the displays will be as described for the third station in the three-man concept. The horizontal/vertical situation display will occupy the area of precedence, and above and slightly offset from center will be the storage and retrieval display and its associated controls. That information which was essential to evaluate the output of the optimum profile generator and would be furnished via suitable instrumentation, will also be required at this station.

For the most part station 4 will be an information generation station. The information will then be analyzed to ascertain the implications on the flight. These implications will be combined with knowledge and experience, and the computer will be utilized to provide a source of feasible alternatives. The "flight manager's" task will be to evaluate the computerized solutions, and to choose the optimum. The flight manager will direct the operation of the aircraft and will make the major decisions. During takeoff the landing operations, his task will be to oversee the performance of the rest of the crew and add his experience to the accomplishment of the task.

It should be noted that similar to the three-man operation there was also some discussion of exchanging navigation duties such that the pictorial navigation display would be at the fourth station and the optimum-profile display moved to the forward panel, although this configuration is not shown.

PART III.

CONCLUSIONS AND RECOMMENDATIONS

10.0 CONCLUSIONS AND RECOMMENDATIONS

This section contains the conclusions and recommendations based on the results obtained throughout all the study efforts. This section is divided into five subsections, namely, SST Operations and Workload, Monitoring and Flight Management, Malfunctions, Potential Crew Roles, and Instrumentation and Flight Deck Layout. These subsections conform generally to the efforts conducted during the study, and specific conclusions and recommendations are placed within the context of one of these five subsections. In general, an attempt has been made to state the results obtained from some portion of study effort, draw some conclusions from these results, and recommend research based on these conclusions. Greater discussion of the results or rationale is, of course, contained in the body of this report.

10.1 SST OPERATIONS AND WORKLOAD

The conclusions and recommendations in this subsection are drawn primarily from the work efforts presented in sections 1 and 2 of this report, Volume II, and the first report under this contract, NASA CR-146(1).

10.1.1 WORKLOAD REALISM

The initial effort in this contract, reported in NASA CR-146, developed and synthesized basic requirements and constraints relevant to SST operations and potential crew roles. These requirements and constraints were not limited to those concerned with operating the aircraft, but were extended to include all aspects of a commercial supersonic transport operation. Based on these requirements and constraints, a total of seven activities and 89 functions were derived for operation of the SST in normal air carrier operations. These 89 functions are the basis for development of a "realistic workload" for potential crew performance in a supersonic commercial air transport.

It is a conclusion of this study that a realistic workload must be developed and included as part of the operating environment for any SST simulation research which is conducted for the following two reasons:

1. Empirical validation of crew performance and associated workloads cannot be accomplished unless the tasks the crew has to perform are compatible with the total set of tasks necessary to operate a supersonic transport in a commercial air carrier operation.

2. Empirical research utilizing simulators to evaluate instrumentation concepts and procedures will not be generalizable to commercial air carrier operations unless a realistic workload is imposed as one of the independent variables.

The above conclusion is supported by the following excerpt taken from the IFALPA Report of the Symposium on Supersonic Transport, London, November 1963 (ref. 4).

> Captain Alcaraz (Mexican Air Line Pilots' Association) asked whether, from experience in simulators, it was considered that the work load in an SST would be equal to that of present day aircraft.
>
> Mr. Tymczyszyn (FAA Western Region SST Manager) replied that they had not had total simulation in the sense of a complete crew, a complete cockpit, and a complete mission profile. Exercises in the United States had been carried out, in which a simulated SST flight had been fed into the actual Air Traffic Control environment, and had been handled by Air Traffic Control as though it were an existing aircraft. Also, military supersonic aircraft had been used in the Air Traffic Control environment to study the capability of the system to handle the SST. Though there had not yet been the opportunity to evaluate SST crew work loads, the crew of this military aircraft experienced no great difficulty even at peak work load periods.

Captain Rea (American Air Line Pilot's Association) asked whether it was intended that whole task simulation should be "real" in the sense of using the current types of charts and chart displays, of changing clearances in the middle of high speed descents, of requests to expedite descent and so on, or whether it would, in fact, be only a partial task simulation.

Mr. Tymczyszyn replied that he hoped not. SST, he said, is a total effort; it was not concerned only with stability controlled structures and flight environment, but with navigation equipment and facilities also. FAA had a program to study advanced navigation aids for the SST, and these would be operated in present day aircraft to test their integration into Air Traffic Control. He said that much had been learned about navigation from Mach 2 bomber crews, who were using some advanced navigation equipment, and that they had given papers at a Navigator's Symposium some two years ago in which they clearly specified the navigational requirements for supersonic flight. Research was in progress on advanced new navigation systems, and he was sure that these would be an integral part of the SST. In this context Mr. Halaby had publicly announced that he was relatively confident that the airline pilot would have clearance for a curved airway, i.e., varying altitudes along the flight path to achieve maximum aircraft efficiency.

It is recommended that an SST simulation scenario be developed which could be used to support whole mission simulation or part-task simulation and which would identify task variables to be represented and the task environment to be represented. The following aspects should be included in the simulation scenario.

1. Flight Profile - The definition of the flight profile should include origin point, flight route, destination point, alternates, SID data, SIA data, speed/altitude schedule for climbout, transition area, acceleration schedule, meteorological considerations, all necessary parameters required for completing flight release forms, load manifests, maintenance forms, etc., control law data for deceleration/descent scheduling, and data consistent with all-weather landing under zero/zero conditions. It should also include recommendations for introducing traffic vigilance problems.

In view of the proposed utilization of the SST, the flight profile should be designed to consider whole mission simulation, which appears both feasible and highly desirable. The profile should provide the framework for scenario development by providing a time-oriented referent for the introduction of all of the other aspects of the scenario in an orderly and organized fashion.

2. Aircraft Performance Envelope - The definition of a set of "acceptable" aircraft performance characteristics in terms of attitude control parameter envelopes, including consideration (within safety margins), (b) acceptable aircraft attitudes for passenger accommodation, e.g., "g" loading, apparent cabin tilt, etc., and (c) engine performance envelopes.

The development of these parameters should provide the flight simulator with a set of operationally acceptable attitude control parameters for the assessment of crew performance in responding to given situations. These parameters could be utilized in the development of judgment problems with care taken to introduce problems containing the possibility of a wrong choice between safety and passenger acceptance.

3. Communications Requirements - Time-oriented requirements in the area of communications, with particular emphasis on the introduction of a typical set of ATC constraints over the total mission profile, primarily during the enroute phase. Such should include typical requirements for departure delays, altitude holds, changes in clearance, storm avoidance procedure, etc.

Introduction of these requirements into the scenario should serve the purposes of: (1) assuring more realistic crew workload requirements; (2) providing the framework for elements of profile optimization problems; and (3) providing operational realism in the interests of obtaining phenomenal equivalence. Special problem areas such as partial loss of communications capability should be called out, and evaluative techniques specified to measure effects.

4. Navigation Requirements - To include consideration of the various techniques derived for the total navigation system concept; accuracy requirements, i. e. , track-keeping accuracy, position fixing accuracy, ETA accuracy; a definition of the fuel management problem in terms of consumption and transfer; definition of placement and type of available ground aids to navigation; definition of vertical and horizontal wind and temperature gradients along the flight route and identification of typical weather phenomena which could be expected both enroute, and in terminal area; "acceptable" sonic disturbance limits over the supersonic portion of the profile; PNdb requirements in the terminal zones. Also included should be sets of typical profile optimization problems. Also included should be realistic parametric descriptions of typical "all-weather" landing conditions where approach patterns are varied, terrain obstructions defined, existing aids specified, meteorological conditions varied, and existing runway lengths and orientation defined as well as other pertinent airport facilities (e. g. , visual aids, high-speed turnoffs, etc.).

Results of analyses conducted under this contract indicate that the navigation requirements for the SST could result in crew workload problems. In fact, it is a reasonable conclusion that solutions to this problem will involve some radical changes in instrumentation, data display, and crew performance. Care should be exercised in the derivation of this aspect of the scenario in view of: (a) its criticality to the crew problem and the resultant requirements for extensive empirical research; (b) the resultant necessity of realism in the interests of obtaining phenomenal equivalence in the simulation research program.

5. System Reliability Problems - The definition of a set of realistic crew/equipment malfunctions which could be anticipated, and methods/techniques for determining system effectiveness following the introduction of either an equipment failure, or crew incapacitance, or both.

The completed scenario should be accompanied by suggestions for optimizing its utilization. These suggestions will include techniques for varying the profile, or certain aspects of the scenario, in a systematic manner in order to obtain maximum utilization of the scenario as a function of flight simulator operating time.

10.1.2 SPECIFIC INVESTIGATIONS OF HIGH WORKLOAD AREAS

The results obtained from the workload analysis effort described in section 2 indicate that:

1. Extensive automation must be used in the implementation of the SST functions, and
2. The cumulative workload imposed on the crew, even with extensive automation, has significant high and low points over the flight profile.

It is a conclusion of this study that the cumulative workload was generally higher than expected, and specifically higher during the cruise portion of the flight than anticipated. It was further concluded that the high cruise workload was accounted for by the large number of monitoring tasks required during cruise (this is discussed as a separate problem in paragraph 10.2.1). Another area of high workload not fully expected was concerned with prestart checks and this could have a significant effect on turnaround time for SST. All areas of indicated high workload could similarly be areas of marginal safety and have a significant effect on total crew complement and qualifications.

It is recommended that specific research programs be designed and carried out to assess the validity of the workload profile presented as Figure 3 of this report. Specifically, research should be conducted in the context of (1) whole mission simulation to see if smoothing effects can be expected to produce a more stable crew workload and if the cumulative values are realistic, and (2) part-task simulation and/or detailed analytical studies should be done for those areas of the flight profile which indicate an excessive workload. Any simulation research should, of course, be conducted in a realistic workload environment as recommended in 10. 1. 1.

10. 1. 3 WORKLOAD ANALYSIS TECHNIQUE

The workload analysis technique utilized for this study was developed and applied as objectively as possible without regard to such things as projected number of crew members or expected high workload areas. It is a conclusion of this study that the technique was useful and predictive although there is some concern about the absolute values derived. It is further concluded, however, that the general technique could be refined and validated by development and application of the technique to current commercial jet aircraft operations, and that the resulting refined technique could be used to predict workload in future aircraft and other manned systems.

It is recommended that an analytical and field research study be conducted for the purpose of developing a refined workload analysis technique which could be used for (1) predicting the workload in future aircraft and other manned systems, and (2) validating the absolute workload values developed in the present study. It is further recommended that the technique be developed utilizing current commercial jet operations as a basis, and that cooperation be solicited from such organizations as the International Federation of Airline Pilot's Association, the Airline Pilot's Association of the United States, the Flight Engineer's International Association, the International Airline Navigator's Council, the International Air Transport Association, the Air Transport Association of America, major airline companies, and other organizations concerned with commercial aviation.

10.2 MONITORING AND FLIGHT MANAGEMENT

The conclusions and recommendations in this subsection are generally related to the results reported in section 3 of this report and volume II of this report.

10.2.1 MONITORING WORKLOAD

The results of the workload analysis indicated a higher workload during cruise than expected. Examination of this revealed that this was due to the large number of monitoring tasks and the cumulative restrictiveness values that were assigned to these tasks. A brief examination of monitoring performance (section 3) results in the conclusion that the design of monitoring systems for SST can have a significant effect on crew workloads and performance proficiency. It is recommended, therefore, that specific research applicable to the design of monitoring systems for SST be conducted in the following areas:

1. Because of the large number of continual real-time monitoring tasks and known decrement in performance in vigilance tasks, consideration should be given to the use of human senses other than vision for monitoring.

2. Consideration should be given to "advance monitoring" capability which would permit the crew to investigate in advance the effects of decision alternatives. This capability could be in the form of a computer simulation model of the SST operations which could be part of the on-board facilities and permit the crew to test in advance the effects of various decision alternatives.

3. A study of crew acceptance problems with respect to different techniques for monitoring different functions should be conducted. This research is important not only from the more obvious aspect of crew confidence in the monitoring systems, but also because of potential effects of crew intervention in the automated control of critical flight maneuvers and/or subsystem performance. This latter aspect of acceptance is critical because of the increased applications of automatic control and processing techniques for SST as described in volume II of this report. The extent to which crew members should be permitted to intervene in the operation of these automated systems is a widely discussed and debated issue. To contribute to the resolution of such issues, research is needed to determine the effects or consequences of various degrees of crew "management" or "override control." Again, in the context of realistically simulated SST operational requirements and constraints, the automatic control of such critical flight control tasks as final approach, landing control, and flight path optimization could be examined to determine the ability of the crew to accurately determine the need to intervene and to adequately perform the task manually when override control is exercised. Studies of this sort seem particularly important in the resolution of issues concerning when and how pilots should be able to override automatic landing control systems under category III visibility conditions.

10.3 MALFUNCTIONS

The conclusions and recommendations contained in this subsection are generally related to the results of the effort described in section 4 of this report.

10.3.1 APPLICATION OF CURRENT JET MALFUNCTION DATA

Current malfunction data from mechanical reliability reports (MRR) and mechanical interruption summaries (MIS) for a six-month period were obtained and statistically summarized. These data are presented as the failures per 1000 hours of flight for each major aircraft system, and the percentage of failures within the various subsystems of each major system. While it is a fact that these data are for current commercial jets and not for SST, it is a conclusion of this study that these data can be used for (1) indicating where emphasis should be placed in design, human engineering, and training for the SST to alleviate problems apparent in current jets, and (2) as a basis for programming or scheduling malfunctions in SST simulation studies.

With respect to the use of current malfunction data to indicate why emphasis should be placed in design, human engineering, and training no specific research recommendations are made here. However it is stressed that such data can be useful to those concerned with research, development, and design of the SST to identify problem areas in our current jet aircraft and to minimize the problem areas in the supersonic transport. Another point to be emphasized for those concerned primarily with human factors was made by Mr. W. M. McLeish, Chief Aeronautical Engineer for the Canadian Department of Transport, who recently stated "The airlines in general do not train crews for emergencies, other than system malfunctions of the type where a back-up (system) exists. . ." As can be seen from the data presented in section 4, there are many malfunctions which occur in systems for which there are no back-up, but for which presumably there are optimum procedures and control techniques which should be utilized.

With respect to use of current jet malfunction data as a basis for programming or scheduling malfunctions in SST simulation research, no specific research recommendations are made but it is again stressed that such data are useful for this purpose.

10.3.2 CREW INCAPACITATION

One area which was merely identified in this study is the possibility of "human malfunction." Some limited data obtained as a result of a questionnaire circulated by the ALPA and reported in section 4 indicated something in the order of an incapacitating incident every 32,500 flying hours. Since this figure is for captains only, the incident rate would be higher when considering entire flight crews. No further interpretations were drawn from this data as they could be misleading. It is a conclusion of this study that because of the severe economic and safety considerations in SST operations, the incidence of crew incapacitation should be considered as one factor in the final design of aircraft systems and procedures. It is further concluded that simulation research concerned with crew effectiveness should include also the simulated effect of crew incapacitation as well as equipment malfunctions.

It is recommended that an analytical and field research study be conducted to collect the necessary data and develop a thorough analysis of the projected cause and distribution of crew incapacitation. (The study could also consider the merits of keeping aircrew together as a team and replacing the whole crew if one member becomes incapacitated before departure. This technique is apparently used by the U.S.S.R.) This study can be conducted by investigating potential sources of data available through the ALPA, Civil Aeronautics Research Institute, airline company medical records, etc. Further, informal discussion of this topic with the ALPA and the IFALPA has revealed that they would be willing to cooperate in the conduct of such a study by making access to their membership.

10.3.3 MANNING FOR MALFUNCTIONS AND COST EFFECTIVENESS

Utilizing the data on current jet aircraft malfunctions and making certain assumptions, as explained in section 4, it was determined that an average expected increase in manning per flight to handle major malfunctions was .025 men per flight. This value, translated into a more useful figure, indicates that the average increase in manning per malfunction turns out to be close to one man. Thus, it was generally concluded that if a major malfunction occurred, and the flight was to continue on its intended flight profile, utilizing more manual control, that one additional crew member would be required. This did not consider the possibility that less stringent control of such activities as navigation or air traffic control would be tolerated. It is possible that the total workload could be reduced and the flight still continue according to the original flight plan with some relaxation of control or reduction of noncritical duties such as, record keeping, passenger communications, etc. The present study did not attempt to include all of these considerations, but was concerned primarily with the significance of a malfunction on potential manning. Again the conclusion is reiterated that major malfunctions could have a significant effect on manning.

It is therefore recommended that a cost-effectiveness study should be conducted to provide a mathematical model and the data concerning a trade-off analysis of the economics of an increased crew complement versus the possibility of having to fly subsonic or having to abort when malfunctions occur. Such a study should include both equipment reliability data and human reliability data. The economic criticality of SST operations, considered together with the potential of committing erroneous judgments, would seem to warrant a more quantitative method for evaluating effects of crew complement.

10.4 POTENTIAL CREW ROLES

The conclusions and recommendations contained here are generally related to the results of the efforts presented in sections 5 and 6 of this report. It should be noted also that any of the recommended research conducted in this area would by definition interact with the research recommended in the other areas of this section.

10.4.1 CREW COMPLEMENT

The potential role of supersonic transport crews includes consideration of the crew complement (that is the number of crew members), the qualifications of each crew member, and the specific responsibility and authority of each crew member. It is difficult to separate these aspects in this discussion as obviously they are quite related. For simplicity, however, conclusions and recommendations concerning crew complement will be discussed first and crew qualifications discussed next.

The workload analysis (section 2) resulted in a cumulative workload roughly equivalent to the capacity of three crew members, utilizing automated implementation concepts. This, of course, is compatible with the general SST community thinking. However, historically the crew complement issue has not been resolved by research, but more by tradition and arbitration of the divergent viewpoints of the airline operators and the crew unions. Also, it is apparently true that no well-founded data has been available to determine the effectiveness of various crew complements prior to design decision fixing the flight deck configurations. It is a strong conclusion of this study that the issue of crew complement should be subject to considerable analytic and empirical research to provide a basis for making final decisions considering crew cost-effectiveness criteria as well as considerations of tradition and vested interests. Because of this conclusion, the cumulative crew workload developed was distributed among two-, three- and four-man operations (section 5) as a basis for permitting empirical evaluation of the cost-effectiveness of these various crew complements.

It is recommended that a full-crew simulation capability be developed to evaluate the effectiveness of various crew complements in carrying out SST operations under both normal and emergency conditions. Further, it is recommended that the workload imposed on the various crew complements be realistic as recommended in paragraph 10.1.1 of this section, and that the flight deck layout be specifically configured to optimally accommodate the particular crew complement being evaluated. This latter statement simply means that if simulator evaluations are being conducted concerning the effectiveness of a four-man crew complement then the simulator flight deck should be configured with instrumentations and layouts to provide for optimal interfacing at all four stations. The cost of four stations as opposed to three or two must also be considered in the cost effectiveness trade-off. A full-crew, full-mission simulator could of course be used for part-crew, part-task evaluations as appropriate. Such a simulator could also provide valuable insight into the requirements of a training simulator which by definition must be a full-crew simulator.

10.4.2 CREW QUALIFICATIONS

The distribution of the total workload among two-, three- and four-man crew complements was carried out objectively with no preconceived notions for such things as navigator's stations, communications operators, flight engineers, etc. As stated in section 5, however, it was recognized that the two stations in the front of the aircraft would have to have pilot qualified personnel. All other duties were distributed on the basis of logical criteria presented in section 5. With respect to crew qualifications, this distribution resulted in the third position of a three-man crew complement having a majority of the navigational tasks along with flight-path management responsibility. For the four-man crew complement, the third position was concerned mainly with navigation and communication, and the fourth position was concerned primarily with flight-path management or overall aircraft operations management. It is a conclusion of this study that unique qualifications may be required for SST crew members that are not necessarily compatible with existing crew careers, generally identified today as "specialist navigators" and "flight engineers." A two-man crew complement would certainly require extensive training over and above pilot training for both crew members. A three-man operation would appear to have two positions reasonably well-related to the pilot and copilot concept of today, but the third position would be unique in his qualifications. A four-man crew complement would require somewhat unique qualifications of the third and fourth crew member with the possibility existing that the fourth crew member might be the senior or more experienced crew member and actually be responsible for flight operations management.

It is recommended that additional research is needed to ascertain crew qualifications and the consequent selection, training, and flight deck layout considerations. Any research conducted in this area is, of course, related to the crew complement problem as discussed in section 10.4.1 above. Specific research plans must be developed in cooperation with current flight crew unions and the airline operator representatives to define not only the requirements, but particularly the constraints which will exist with respect to crew qualifications.

10.4.3 NAVIGATION AND THE CREW ROLE

While not a specific result of any single effort of this study, it is a general conclusion that the crew role with respect to navigation is the least defined of all SST activities and implementation concepts. While it is almost universally agreed that an inertial navigation system will be the primary source of navigation data, the specific role of the crew in the utilization of this data, and the role of the crew as far as secondary or tertiary navigation systems are concerned is ambiguous. This, of course, is due in part to the lack of firmness concerning secondary and tertiary navigation system concepts or equipment, but the reverse, of course, is also ture. Thus this situation is somewhat the "chicken and egg" situation, or what gets decided first. It is also the conclusion of this study that operational experiences in supersonic military aircraft equipped with very expensive navigation systems indicate that well-trained operators with appropriate aids may do a better job than the automatic systems in some instances, and just about as well in many more instances. This general conclusion is supported by a statement form the Summary of Proceedings of the Sixteenth IATA Technical Conference in 1965 devoted to aircraft navigation. In a section labeled as "human factors," the summary states in part:

> . . . it might be concluded that, in any group of airlines, varying degrees of navigational performance are likely to be found, depending upon the experience, natural ability, and the degree of training of the flight crew. Therefore, in designing navigation equipment, cockpit layout, or establishing track keeping requirements and navigational procedures and techniques, it is important that the true nature of the human limitations be taken into account.

Therefore it is recommended that more research be conducted with respect to the navigation and the crew role. The general research problem area should be one of determining the boundaries of effective crew performance in cockpit navigation tasks when a set of alternative system mechanization concepts are considered which represent a continuum from the most feasible manual implementation to the most feasible automatic implementation of the navigation function. The general objective of this effort should be to evaluate and compare crew performance for the various mechanization concepts in a common simulated SST operational environment representing realistic demands and constraints on the performance of navigation tasks. Results of such a study would be useful both for establishing a more objective basis for assigning specific navigation tasks to man or machine, and for defining the particular man-machine interactions which produce the better system performance.

10.4.4 ALL-WEATHER LANDING AND THE CREW ROLE

As with navigation and the crew role discussed above, no specific results of this study are concerned with all-weather landing, although it is a general conclusion of the study that all-weather landing and the crew role need more definition. The problems of automation relevant to navigation as discussed above and elsewhere in this report, of course apply also to all-weather landing. The IFALPA has adopted as policy a requirement for a heads-up display for Category III all-weather landing operations. It is also a conclusion of this study that a head-up display will be required for Category III all-weather operations. It is recommended that further research is necessary to define the crew role which is acceptable to the crew members with respect to all-weather landing. In general, the problem to be researched is one of allocation of responsibility between the pilot and copilot and was expressed by Mr. A. P.W. Caine of S. Schmidt and Sons Ltd. at a recent Air Line Pilots' Association Safety Forum as follows:

> We have a main worry with the U.S. approach to lower landing minimums. ... Your emphasis has been on training the pilot, while in the United Kingdom we think of training

> the pilots--as an integrated crew. ...We've found that you have to have a clean definition of duties in the cockpit. We (in the UK) have to have a 'heads-up' man and a 'heads-down' man.
>
> The 'heads-up' man, the pilot, is the over-all decision-maker. He monitors the descent and makes a 'yes' or 'no' landing decision possible. If it's possible to land he takes over and lands. If it's not and the 'heads-down' man has had no decision to land, then he--meaning the 'heads-down' man--automatically overshoots.

10.5 INSTRUMENTATION AND FLIGHT DECK LAYOUT

The conclusions and recommendations contained here are generally related to the results of the efforts presented in sections 8 and 9 of this report.

10.5.1 INSTRUMENTATION

This study was not concerned with instrumentation concepts for SST per se. The efforts of sections 7 and 8 of this report investigate the crew information requirements which must be satisfied by instrumentation and further review instrumentation concepts. Those instrumentation concepts developed in section 8 are meant to be representative and not necessarily recommended concepts. These representative concepts were intended primarily for use in developing the flight deck layouts of section 9. It can, however, be stated that if a full-crew simulation facility is to be developed, the representative instrumentation concepts of section 8 would be satisfactory for SST crew studies, unless a specific aircraft configuration (e.g., the Boeing or Lockheed SST) is decided upon.

The issue of conventional versus more revolutionary instrumentation for SST is one which has not been resolved and cannot be resolved without specific empirical research. It is the conclusion of this study that further research to settle this issue is warranted. If the U.S. and our industry are going to accept the SST as just another aircraft, then perhaps research in the area of new instrumentation is not justified. However, the extra time which is being devoted to the development of the entire aircraft and the attendant cost of this aircraft seem to indicate that the SST is being considered as a new level of aircraft. As such each area of the aircraft should warrant research which will allow the aircraft to reflect the latest in technology not only in equipment but in man-machine integration.

It can be concluded further that even if the trend is toward conventional instrumentation for SST, two areas are almost certain to require new instrumentation concepts. These are (1) navigation and (2) all-weather landing. A new display itself, of course, is not justification for extensive research and development. However, as discussed in section 10.4 above, the displays for navigation and all-weather landing must be considered in the context of the total man-machine integration problem or more specifically, in the context of total SST cost-effectiveness. As discussed in section 10.4 and section 10.2, an important consideration of the crew's effectiveness will be the crew's acceptance of any new displays. Thus, it is recommended that specific studies should be conducted to determine the crew acceptance of potential new navigation and all-weather landing displays. This study can be conducted first as an analytical and field research study to develop specifically acceptable display concepts. These display concepts can then be evaluated in an empirical research situation and appropriate trade-offs made between acceptance, performance, and cost.

10.5.2 FLIGHT DECK LAYOUT

The flight deck layouts in section 9 of this report were specifically developed to accommodate the potential crew roles developed in section 6. Thus, these concepts are not recommended as flight deck concepts unless specific crew roles, as defined in section 6, are assumed. The flight deck concepts are those basic configurations and layouts recommended for incorporation into a full-crew simulation facility _if_ evaluations are to be conducted on the cost effectiveness of two-, three- and four-man crews as recommended in paragraph 10.4.1. As a general recommendation, however, it can be strongly emphasized that the flight deck layout should be designed for optimum man-machine interface for whatever flight crew complement is decided upon. There are too many commercial jet aircraft in operation today in which one crew member (typically the third crew member) does not have a specifically designed station and is usually peering over or around the pilot and copilot to obtain information necessary to his job. This type of situation certainly cannot be the most effective for the man-machine interface viewpoint. The design of each station on the flight deck should be compatible with the specific duties assigned to that station, regardless of what information is duplicated or repeated at another station (typically the captain because he wants "all" information in order to exercise effective command of the aircraft).

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~~APPENDIX I~~

TABLES OF FUNCTION WORKLOAD ASSIGNMENT FOR BOTH AUTOMATED AND MANUAL IMPLEMENTATION

This appendix contains the tables developed for determining crew workload for both automated and manual implementation concepts. The tables for the automated concept are presented first and the tables for the manual concept follow. An explanation of each column in the tables follows below:

Column 1: Function	Number and name of the function and identification of the primary means for implementing the function and identification of any significantly different alternate means for implementation. Where automation is not considered an alternative, the table entry reflects the manual means envisioned and the appropriate weighting factor.
Column 2: Time of Initiation	Elapsed time in minutes along the flight profile when the function is initiated. When the function occurs intermittently throughout the profile, initiation times for each occurrence are presented. The guideline used is that any given performance will be initiated precisely at the time appropriate for that performance.
Column 3: Duration	Duration of the function in minutes and seconds.
Column 4: Time of Completion	Elapsed time in minutes along the flight profile when the function is completed.
Column 5: Related Tasks or Rules	Related tasks from the sample of current jet tasks used to gather the restrictiveness data presented in Table A2; and/or the relevant procedure rules from those listed in Section 2.1. Relevant current jet tasks are identified by P (Pilot) or N (Navigator) and are defined in Table A2. Relevant

procedure rules are identified as "Rule ___." Where none of the current tasks or procedure rules was considered relevant the column was left blank. On the other hand, if more than one task or procedure was considered relevant all of them were included.

Column 6: Restrictiveness Value Assigned	Restrictiveness value derived for the function. A restrictiveness value of 5.0 represents the full-time attention of one man. A value greater than 5.0 means more than one man is required. Where more than one relevant task or rule was considered relevant to the SST function, the highest value for any of the tasks or rules considered relevant was used.
Column 7: Rationale Remarks	Rationales for the assignment of restrictiveness values are included here to reflect the analysts' judgment. Clarifying remarks appropriate to any column are included as necessary.

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility).

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
2.1 Pre-Start System Checkout	T_0-24	15 min.	T_0-9		25.0	A total of 75 man-minutes was associated with performance of this function. This effort was spread over the duration of the longest time duration associated with a given element of the checkout, i.e., navigation system (platform erection and alignment time 15 minutes). Obviously, this load can be diminished proportionally by increasing the time period for checkout prior to engine start.
2.2 Post-Start System Checkout	T_0-9	1.5 min.	T_0-7.5		16.0 (30 sec.) 15.0 (30 sec.) 5.0 (30 sec.)	Assuming that all performance begins as soon as it is feasible, this requirement calls for 3.2 personnel for 30 seconds, 3 personnel for the next 30 seconds, and one person for the remaining 30 seconds. Obviously, smoothing can occur by sequencing some of the performance required.
2.3 System Set-Up For Take-off	T_0-5	5 min.	T_0		10.0 (1 min.) 5.0 (4 min.)	Same as for 2.2.
2.4 Post Take-off Check	T_2	1 min.	T_3		15.0 (30 sec.) 10.0 (30 sec.)	Same as for 2.2.
2.5 Pre-Transition Phase System Checkout	T_{10}	1 min.	T_{11}		6.0 (30 sec.) 5.0 (30 sec.)	Same as for 2.2.
2.6 Pre-Deceleration/ Descent Phase System Checkout	$T_{119.5}$	30 secs.	T_{120}		11.0 (30 sec.)	Same as for 2.2.
2.7 Pre-Landing System Checkout	$T_{147.5}$	1 min.	$T_{148.5}$		6.0 (30 sec.) 5.0 (30 sec.)	Same as for 2.2.
2.8 Accomplish System Deactivation Procedures	T_{152}	4 min.	T_{156}		20.0 (30 sec.) 10.0 (30 sec.) 5.0 (3 min.)	Same as for 2.2 and 2.1.
						The majority of the communications functions will indicate two entrys in restrictiveness when only one set of means is indicated. This is due to the visualization of the communication activity as a two-part activity, i.e., frequency guarding, and active communication.
3.1 Ground Handling Phase Communications	T_0-24	24 min.	T_0			

Table **A1** Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
<u>Means</u>: Standard communication equipments						
a. Frequency guard					1.0	
b. Active communication				P3	3.17	
3.2 Cockpit Communications for Take-off	T_0	1 min.	T_2			
<u>Means</u>: A. Intercom system				P7, P4, P21	2.72	
B. Direct voice				P7, P3	3.17	
3.3 Departure Control Communications	T_0	4 min.	T_5			
<u>Means</u>: VHF/UHF communication equipment						
a. Active communication				P3	3.17	
b. Frequency guard				P24	2.63	
3.4 Activate/Deactivate "No Smoking" Signs						
(Activate)	$T_{119.5}$	30 secs.	T_{120}			
(Deactivate)	T_4	30 secs.	$T_{4.5}$			
<u>Means</u>: Console switch				Rule 3	1.0	
3.5 Activate/Deactivate "Fasten Seat Belt" Signs						
(Activate)	T_{119}	30 secs.	$T_{119.5}$			
(Deactivate)	T_{21}	30 secs.	$T_{21.5}$			
<u>Means</u>: Console switch				Rule 3	1.0	
3.6 Initial Position Report	T_5	4 min.	T_9			
<u>Means</u>: Data link/standard communication equipment						

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
a. Active communication				P21, Rule 3	2. 13	
b. Frequency guard				P24	2. 63	
3. 7 ATC Communications Handoff	T_{9}	1. 5 min.	$T_{10.5}$			
Means: Data link/standard communication equipment						
a. Active communication				P21, Rule 3	2. 13	
b. Frequency guard				P24	2. 63	
3. 8 Enroute ATC Communications	$T_{10.5}$	105. 5 min.	T_{117}			Note: Frequency guarding is constant over the entire 105. 5 minutes. Active communications of a routing nature are over 30 seconds of time approximately every 15 minutes or a total of ≈7-8 times during the 105. 5 minutes.
Means: Data link/standard communication equipment						
a. Active communication				P21, Rule 3	2. 13	
b. Frequency guard				P25, Rule 4	1. 47	
3. 9 Intercom Announcements						
(1)	$T_{10.5}$	30 secs.	T_{11}			
(2)	$T_{19.5}$	30 secs.	T_{20}			
(3)	$T_{47.5}$	30 secs.	T_{48}			
(4)	T_{91}	30 secs.	$T_{91.5}$			
(5)	$T_{114.5}$	30 secs.	T_{115}			
Means: Intercom system				P4	2. 72	
3. 10 Enroute Company Communications						
(1)	T_{66}	1 min.	T_{67}			
(2)	T_{134}	1 min.	T_{135}			
Means: Data link				P21 Rule 3	2. 13	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
3.11 ATC Communications for Deceleration/ Initial Descent	T_{117}	10.5 min.	$T_{126.5}$			
Means: Data link/standard communication equipment						
a. Active communication				P21, Rule 3	2.13	
b. Frequency guard				P25, Rule 4	1.47	
3.12 ATC Approach Control Communications	$T_{126.5}$	21.5 min.	T_{148}			
Means: Standard communication equipment						
a. Active communication				P3	3.17	
b. Frequency guard				P24, Rule 3	2.63	
3.13 Final Approach Communications	T_{148}	3 min.	T_{151}			
Means: Standard communication equipment				P3	3.17	
3.14 Destination Ground Handling Communications	T_{151}	3 min.	T_{154}			
Means: Standard communication equipment				P3	3.17	
3.15 Visual Traffic Vigilance (1)	T_0-5	25 min.	T_{21}			It is assumed that the standard procedure of maintaining visual traffic vigilance by all crew members not occupied with other performance tasks which would preclude their participation will be continued in the cockpit of the SST. It is not possible, therefore, to fix the restrictiveness value for this function since crew size is not fixed. The workload profile reflects a dotted line through the "take-off/climbout" and "deceleration/descent/landing" phases of the flight profile. This line is roughly equivalent to the average, overall, restrictiveness value. It connotes that workload in these phases is equal to performance required by other functions plus maximum assumed capability devoted to maintaining visual traffic vigilance.
(2)	T_{120}	33 min.	T_{153}			
Means: All crew members				Rule 2	(5.0xN)	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
4.1 Engine Start and Checkout	T_0-9	4 min.	T_0-5			
<u>Means</u>: Computer checkout				P17, P20	2.55	
4.2 Thrust Application = F (Surface Speed) - Taxi	T_0-5	5 min.	T_0			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.3 Thrust Application = F (Maximum Power) - Take-off Thrust	T_0	1 min.	T_2			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.4 Thrust Application = F (Surface Speed) - Thrust Reversal	T_0 + "n" seconds.	≈15-20 secs.	Prior to T_2			
<u>Means</u>: Manual throttling (thrust reverser levers activated)				P3, P16	3.19	
4.5 Thrust Application = F (Noise Abatement) (V_2, PNdb)	T_2	1 min.	T_3			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.6 Thrust Application = F (Optimum Maneuver Speed) - Initial Climb	T_3	1 min.	T_4			
<u>Means</u>: Auto-throttle				Rule 4, P25	1.47	
4.7 Thrust Application = F (Optimum Maneuver Speed) - Subsonic Climb	T_4	7 min.	T_{11}			
<u>Means</u>: Auto-throttle				Rule 4, P25	1.47	
4.8 Thrust Application = F (Sonic Barrier Penetration) - Transonic Acceleration	T_{11}	4 min.	T_{15}			
<u>Means</u>: Auto-throttle				Rule 4, P25	1.47	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
4.9 Thrust Application = F (Optimum Air Speed) Supersonic Climb Means: Auto-throttle	T_{15}	6 min.	T_{21}	P25, Rule 4	1.47	
4.10 Thrust Application = F (Transition to Cruise) Means: Auto-throttle	T_{21}	1 min.	T_{22}	P25, Rule 4	1.47	
4.11 Thrust Application = F (Constant Mach 3.0) - Cruise Means: Auto-throttle	T_{22}	98 min.	T_{120}	P25, Rule 4	1.47	
4.12 Thrust Application = F (Optimum Air Speed) - Deceleration/Descent Means: Auto-throttle	T_{120}	2 min.	T_{122}	P25, Rule 4	1.47	
4.13 Thrust Application = F (Sound Barrier Penetration) - Decelerating Means: Auto-throttle	T_{122}	30 secs.	$T_{122.5}$	P25, Rule 4	1.47	
4.14 Thrust Application = F (Optimum Maneuver Speed) - Subsonic Maneuvering Means: Auto-throttle	$T_{122.5}$	4 min.	$T_{126.5}$	P25, Rule 4	1.47	
4.15 Thrust Application = F (Optimum Maneuver Speed) - Let Down Means: Auto-throttle	$T_{126.5}$	21.5 min.	T_{148}	P25, Rule 4	1.47	
4.16 Thrust Application = F (Optimum Maneuver Speed) - Level Off Means: Auto-throttle	T_{148}	30 secs.	$T_{148.5}$	P25, Rule 4	1.47	

Table **A1** Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
4.17 Thrust Application = F (Optimum Maneuver Speed) - Initial Approach	$T_{148.5}$	30 secs.	T_{149}			
<u>Means</u>: Auto-throttle				P25, Rule 4	1.47	
4.18 Thrust Application = F (Optimum Maneuver Speed) - Final Approach	T_{149}	1 min.	T_{150}			
<u>Means</u>: Auto-throttle				P25, Rule 4	1.47	
4.19 Thrust Application = F (Maximum Power) - Missed Approach	T_{149} + "n" seconds	≈1 min.	T_{150} + "n" seconds			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.20 Thrust Application = F (Flare Execution)	T_{150}	30 secs.	$T_{150.5}$			
<u>Means</u>: Auto-throttle					5.0	
4.21 Thrust Application = F (Surface Speed) - Thrust Reversal for Braking	$T_{150.5}$	30 secs.	T_{151}			
<u>Means</u>: Manual throttling (thrust reverser levers activated)				P3, P16	3.19	
4.22 Thrust Application = F (Surface Speed) - Taxi to Line	T_{151}	2 min.	T_{153}			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.23 Accomplish Power Plant System Deactivation	T_{153}	1 min.	T_{154}	P17	2.27	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
5.1 Taxi from Line	T_0-5	5 min.	T_0			
Means: A. Nose-wheel steering				P27	2.91	
B. Differential braking				P16, P27	3.19	
5.2 Initial Roll Control - Take-off	T_0	< 1 min.	T_2			
Means: A. Nose-wheel steering, rudder/aileron system				P16	3.19	
B. Differential braking, rudder/aileron system				P16	3.19	
5.3 Take-off Abort Control	T_0+ "n" seconds	≈15-20 secs.	Prior to T_2			
Means: A. Nose-wheel steering, rudder/aileron system				P16	3.19	
B. Differential braking, rudder/aileron system				P16	3.19	
5.4 Take-off Control - Rotation, Configuration Change	$T_{0.5}$	1 min.	$T_{1.5}$			
Means: Elevator/rudder/aileron system				P18	2.23	
5.5 Initial Climb Control - Initial Portion of Standard Instrument Departure	T_2	2 min.	T_4			
Means: Elevator/rudder/aileron system				P10	2.84	
5.6 Subsonic Climb Maneuvering	T_4	7 min.	T_{11}			
Means: Auto-pilot (computer coupled)				P25, Rule 4	1.47	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
5.7 Transonic Acceleration Control	T_{11}	4 min.	T_{15}			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.8 Supersonic Climb Control	T_{15}	5.5 min.	$T_{20.5}$			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.9 Transition to Cruise Control	$T_{20.5}$	1 min.	$T_{21.5}$			
Means: Auto-pilot (computer-coupled)					5.0	
5.10 Cruise Control	$T_{21.5}$	98.5 min.	T_{120}			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.11 Supersonic Descent Control	T_{120}	2 min.	T_{122}			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.12 Transonic Descent Control	T_{122}	30 secs.	$T_{122.5}$			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.13 Subsonic Descent Control	$T_{122.5}$	4 min.	$T_{126.5}$			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.14 Let Down Control	$T_{126.5}$	21.5 min.	T_{148}			
Means: Auto-pilot (computer-coupled)				P25 Rule 4	1.47	

Table **A1** Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
5.15 Level Off Maneuver	T_{148}	30 secs.	$T_{148.5}$			
Means: Auto-pilot (computer-coupled)				P25, Rule 4	1.47	
5.16 Initial Approach Control	$T_{148.5}$	30 secs.	T_{149}			
Means: A. Basic control system				P14	3.59	
B. Auto-pilot system (manual mode)				P15	3.19	
5.17 Final Approach Control	T_{149}	1 min.	T_{150}			
Means: Auto-pilot/coupler (landing system)					10.0	**Rated high in restrictiveness due to pilot responsibility in the automatic landing scheme and due to the anxiety/stress components inherent in a "blind" landing.**
5.18 Missed Approach Execution Control Operations	T_{149}+ "n" seconds	≈ 1 min.	T_{150}+ "n" seconds			
Means: Basic control system				P14	10.0	Same as for 5.17
5.19 Flare Maneuver Execution	T_{150}	30 secs.	$T_{150.5}$			
Means: Auto-pilot/coupler (landing system)					10.0	Same as for 5.17
5.20 Rollout Control	$T_{150.5}$	30 secs.	T_{151}			
Means: Auto-pilot/coupler (landing system)				P14	3.59	
5.21 Taxi to Line	T_{151}	2 min.	T_{153}			
Means: A. Nose-wheel steering				P27	2.91	
B. Differential braking				P16, P27	3.19	

Table **A1** Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
6.1 Duct System Configuration for Supersonic Climb	$T_{11.5}$	3.5 min.	T_{15}			Two ratings are given. For the first 30 seconds following activation of the automatic control system, a high restrictiveness is visualized to determine that the control system is activated and operating in an appropriate manner.
<u>Means</u>: Automatic control system				P25, Rule 4	5.0 1.47	
6.2 Duct System Configuration for Transition to Cruise	T_{15}	6 min.	T_{21}			
<u>Means</u>: Automatic control system				P25, Rule 4	1.47	
6.3 Duct System Reconfigured as Required	T_{21}	99 min.	T_{120}			
<u>Means</u>: Automatic control system				P25, Rule 4	1.47	
6.4 Duct System Configuration for Supersonic Descent Operations	T_{120}	2 min.	T_{122}			
<u>Means</u>: Automatic control system				P25, Rule 4	1.47	
6.5 Duct System Configuration for Transonic Deceleration/Descent	T_{122}	30 secs.	$T_{122.5}$			
<u>Means</u>: Automatic control system				P25, Rule 4	1.47	
6.6 Duct System Reconfiguration for Subsonic Operations	$T_{122.5}$	30 secs.	T_{123}			
<u>Means</u>: Automatic control system				P25, Rule 4	1.47	
7.1 Maintain Take-off Flight Path	T_0	1 min.	T_2			
<u>Means</u>: Basic navigation sensors/displays				P16	3.19	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
7.2 Maintain Flight Path for SID	T_2	13 min.	T_{15}			
Means: Automated, integrated navigation system				N17	3.57	
7.3 Monitor Enroute Weather Conditions	T_4	118.5 min.	$T_{122.5}$			
Means: Automated navigation system				P25, Rule 4	1.47	
7.4 Monitor Destination and Alternate Weather						
(1)	T_{15}	1 min.	T_{16}			
(2)	T_{38}	1 min.	T_{39}			
(3)	T_{53}	1 min.	T_{54}			
(4)	T_{68}	1 min.	T_{69}			
(5)	T_{83}	1 min.	T_{84}			
(6)	T_{98}	1 min.	T_{99}			
(7)	T_{113}	1 min.	T_{114}			
(8)	$T_{126.5}$	1 min.	$T_{127.5}$			
(9)	T_{146}	1 min.	T_{147}			
Means: Automated navigation system/and data link				P22	2.19	
7.5 Provide Differential in Forecast/Actual Weather Conditions	T_4	118.5 min.	$T_{122.5}$			
Means: Computerized solutions				P25, Rule 4	1.47	
7.6 Calculation of Overpressure being Generated	T_{11}	111.5 min.	$T_{122.5}$			
Means: Computerized solutions				P25, Rule 4	1.47	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
7.7 Internal System Position Generation	T_{15}	107.5 min.	$T_{122.5}$			
Means: A. Duplex/triplex INS.				P25, Rule 4	1.47	
B. Duplex/triplex doppler				P25, Rule 4	1.47	
C. Hybrids				P25, Rule 4	1.47	
7.8 External System Position Generation	T_{15}	105 min.	T_{120}			Note: GO/NO-GO monitoring is constant over the entire 105 minutes. CREDIBILITY monitoring upon fix generation is over a 1 minute time period approximately every 10 minutes or a total of ≈11-12 times during the duration of the function. This function is seen as basically in two parts, i.e., a monitoring task, and an accuracy or credibility determination task. For monitoring, Rule 4 is applicable, and for accuracy checking Rule 5 is applicable. Accuracy checking is seen as occurring at somewhat regular intervals and is indicated thusly on the chart.
Means: A. Automated Hyperbolic system				Rule 5	5.0	
B. Automated bearing/triangulation system				Rule 5	5.0	
C. Ground-equipment-generated fix				P25, Rule 4	1.47	
7.9 Present Position Updating						
(1)	T_{17}	1 min.	T_{18}			
(2)	T_{27}	1 min.	T_{28}			
(3)	T_{37}	1 min.	T_{38}			
(4)	T_{47}	1 min.	T_{48}			
(5)	T_{57}	1 min.	T_{58}			
(6)	T_{67}	1 min.	T_{68}			
(7)	T_{77}	1 min.	T_{78}			
(8)	T_{87}	1 min.	T_{88}			
(9)	T_{97}	1 min.	T_{98}			
(10)	T_{107}	1 min.	T_{108}			
(11)	T_{117}	1 min.	T_{118}			
(12)	$T_{120.5}$	1 min.	$T_{121.5}$			
Means: Computerized updating				N17	3.57	

Table A1 Time and Restrictiveness Values for SST Functions (Automatic Feasibility). (Concluded)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
7.10 ETA Prediction	$T_{10.5}$	112 min.	$T_{122.5}$			
Means: Computerized solutions				P19, Rule 4	1.70	
7.11 Optimum Profile Generation	T_{15}	107.5 min.	$T_{122.5}$			Requirements for significant changes in route involve situation assessment, derivation and ranking of alternatives, choice of course of action, and implementing that action. Progress monitoring is the majority case and is the rating shown. When significant changes in route are required, the rating for this function is fixed at a minimum of 10.0 until appropriate action is initiated. The value (10.0) is based on the requirement for at least two crew members to be fully aware of the action to be taken and the justification therefore.
Means: Computerized solutions				P20, Rule 4	2.55	
7.12 Maintain Flight Path for SIA	$T_{122.5}$	25.5 min.	T_{148}			
Means: Automated navigation system				N17	3.57	
7.13 Maintain Flight Path for AWL	T_{148}	3 min.	T_{151}			
Means: Automated "all-weather" landing system				P15, P23	3.30	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility).

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
2.1 Pre-Start System Checkout	T_0-24	15 min.	T_0-9		25.0	This function is visualised as essentially equivalent in either automated or manual concepts. Therefore the rationale under the "Automated Feasibility" is also applicable here.
2.2 Post-Start System Checkout	T_0-9	1.5 min.	T_0-7.5		20.0	A total of 12 man-minutes is estimated for manual performance of this check. The selection of a 3-minute period is arbitrary, but with a view toward the desirability of take-off ASAP after engine start.
2.3 System Set-up for Take-off	T_0-5	5 min.	T_0		10.0 (1 min.) 5.0 (4 min.)	Same as 2.2 (Automated Feasibility)
2.4 Post-Take-off Check	T_2	1 min.	T_3		15.0 (30 sec.) 10.0 (30 sec.)	Same as 2.2 (Automated Feasibility)
2.5 Pre-Transition Phase System Checkout	T_{10}	1 min.	T_{11}		15.0 (30 sec.) 10.0 (60 sec.)	Same as 2.2 (Automated Feasibility)
2.6 Pre-Deceleration/ Descent Phase System	$T_{119.5}$	30 secs.	T_{120}		15.0 (30 sec.) 10.0 (30 sec.) 5.0 (60 sec.)	Same as 2.2 (Automated Feasibility)
2.7 Pre-Landing System Checkout	$T_{147.5}$	1 min.	$T_{148.5}$		20.0 (30 sec.) 5.0 (90 sec.)	Same as 2.2 (Automated Feasibility)
2.8 Accomplish System Deactivation Procedures	T_{152}	4 min.	T_{156}		20.0 (30 sec.) 10.0 (30 sec.)	Same as 2.1 and 2.2 (Automated Feasibility)
						The majority of the communications functions will indicate two entrys in restrictiveness when only one set of means is indicated. This is due to the visualization of the communication activity as a two-part activity, i.e., frequency guarding, and active communication.

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
3.1 Ground Handling Phase Communications	T_0-24	24 min.	T_0			
Means: Standard communication equipments						
a. Frequency guard					1.0	
b. Active communication				P3	3.17	
3.2 Cockpit Communications for Take-off	T_0	1 min.	T_2			
Means: A. Intercom system				P4, P7, P21	2.72	
B. Direct voice				P3, P7	3.17	
3.3 Departure Control Communications	T_0	4 min.	T_5			
Means: VHF/UHF communication equipment						
a. Active communication				P3	3.17	
b. Frequency guard				P24	2.63	
3.4 Activate/Deactivate "No Smoking" Signs						
(Activate)	$T_{119.5}$	30 secs.	T_{120}			
(Deactivate)	T_4	30 secs.	$T_{4.5}$			
Means: Console switch				Rule 3	1.0	
3.5 Activate/Deactivate "Fasten Seat Belt" Signs						
(Activate)	T_{119}	30 secs.	$T_{119.5}$			
(Deactivate)	T_{21}	30 secs.	$T_{21.5}$			
Means: Console switch				Rule 3	1.0	
3.6 Initial Position Report	T_5	4 min.	T_9			
Means: VHF/UHF (SELCAL) equipment				P3	3.17	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
3.7 ATC Communications Handoff	T_9	1.5 min.	$T_{10.5}$			
Means: VHF/UHF (SELCAL) equipment				P3	3.17	
3.8 Enroute ATC Communications	$T_{10.5}$	105.5 min.	T_{117}			
Means: A. VHF/UHF equipment						
1. (Active communication)				P21 P24	2.63	
2. (Frequency guard)				P19, Rule 4	1.70	
B. LF/HF equipment						
1. (Active communication)				P3	3.17	
2. (Frequency guard)				P19, Rule 4	1.70	
						Note: Frequency guarding is constant over the entire 105.5 minutes. Active communications of a routine nature are over 30 seconds of time approximately every 15 minutes or a total of ≈7-8 times during the 105.5 minutes.
3.9 Intercom Announcements						
(1)	$T_{10.5}$	30 secs.	T_{11}			
(2)	$T_{19.5}$	30 secs.	T_{20}			
(3)	$T_{47.5}$	30 secs.	T_{48}			
(4)	T_{91}	30 secs.	$T_{91.5}$			
(5)	$T_{114.5}$	30 secs.	T_{115}			
Means: Intercom system				P4	2.72	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
3.10 Enroute Company Communications						
(1)	T_{66}	1 min.	T_{67}			
(2)	T_{134}	1 min.	T_{135}			
Means: HF communication equipment				P3, P4, P24	3.17	
3.11 ATC Communications for Deceleration/Initial Descent	T_{117}	10.5 min.	$T_{126.5}$			
Means: A. VHF/UHF communication equipment						
1. (Active communication)				P3, P24	3.17	
2. (Frequency guard)				P24	2.63	
B. LF/HF communication equipment						
1. (Active communication)				P3	3.17	
2. (Frequency guard)				P3, P24	3.17	
3.12 ATC Approach Control Communications	$T_{126.5}$	21.5 min.	T_{148}			
Means: VHF/UHF communication equipment						
a. Active communication				P3	3.17	
b. Frequency guard				P3	3.17	
3.13 Final Approach Communications	T_{148}	3 min.	T_{151}			
Means: VHF/UHF communication equipment				P3	3.17	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
3.14 Destination Ground Handling Communications	T_{151}	3 min.	T_{154}			
Means: Standard communication equipment				P3	3.17	
3.15 Visual Traffic Vigilance (1) (2)	 T_0-5 T_{120}	 25 min. 33 min.	 T_{21} T_{153}			It is assumed that the standard procedure of maintaining visual traffic vigilance by all crew members not occupied with other performance tasks which would preclude their participation will be continued in the cockpit of the SST. It is not possible, therefore, to fix the restrictiveness value for this function since crew size is not fixed. The workload profile reflects a dotted line through the "take-off/climbout" and "deceleration/descent/landing" phases of the flight profile. This line is roughly equivalent to the average, overall, restrictiveness value. It connotes that workload in these phases is equal to performance required by other functions plus maximum assumed capability devoted to maintaining visual traffic vigilance.
Means: All crew members				Rule 2	(5.0xN)	
4.1 Engine Start and Checkout	T_0-9	4 min.	T_0-5			
Means: Checklist, manual throttling				P17, P20, Rule 1	5.0	
4.2 Thrust Application = Surface Speed - Taxi	T_0-5	5 min.	T_0			
Means: Manual throttling				P3, P16	3.19	
4.3 Thrust Application = Maximum Power - Take-off Thrust	T_0	1 min.	T_2			
Means: Manual throttling				P3, P16	3.19	
4.4 Thrust Application = F (Surface Speed) - Thrust Reversal	T_0+ "n" seconds	≈15-20 secs.	Prior to T_2			
Means: Manual throttling (thrust reverser levers activated)				P3, P16	3.19	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
4.5 Thrust Application = F (Noise Abatement) (V_2, PNdb) Means: Manual throttling	T_2	1 min.	T_3	P3, P16	3.19	
4.6 Thrust Application = F (Optimum Maneuver Speed) - Initial Climb Means: Manual throttling	T_3	1 min.	T_4	P3, P16	3.19	
4.7 Thrust Application = F (Optimum Maneuver Speed) - Subsonic Climb Means: Manual throttling	T_4	7 min.	T_{11}	P3, P16	3.19	
4.8 Thrust Application = F (Sonic Barrier Penetration) - Transonic Acceleration Means: Manual throttling	T_{11}	4 min.	T_{15}	P3, P16	3.19	
4.9 Thrust Application = F (Optimum Air Speed) Supersonic Climb Means: Manual fuel control	T_{15}	6 min.	T_{21}	Rule 6	5.0	
4.10 Thrust Application = F (Transition to Cruise) Means: Manual fuel control	T_{21}	1 min.	T_{22}	Rule 6	5.0	
4.11 Thrust Application = F (Constant Mach 3.0) - Cruise Means: Manual fuel control	T_{22}	98 min.	T_{120}	Rule 6	5.0	
4.12 Thrust Application = F (Optimum Air Speed) - Deceleration/Descent Means: Manual fuel control	T_{120}	2 min.	T_{122}	Rule 6	5.0	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
4.13 Thrust Application = F (Sound Barrier Penetration) - Decelerating	T_{122}	30 secs.	$T_{122.5}$			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.14 Thrust Application = F (Optimum Maneuver Speed) - Subsonic Maneuvering	$T_{122.5}$	4 min.	$T_{126.5}$			
<u>Means</u>: Manual Throttling				P3, P16	3.19	
4.15 Thrust Application = F (Optimum Maneuver Speed) - Let Down	$T_{126.5}$	21.5 min.	T_{148}			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.16 Thrust Application = F (Optimum Maneuver Speed) - Level Off	T_{148}	30 secs.	$T_{148.5}$			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.17 Thrust Application = F (Optimum Maneuver Speed) - Initial Approach	$T_{148.5}$	30 secs.	T_{149}			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.18 Thrust Application = F (Optimum Maneuver Speed) - Final Approach	T_{149}	1 min.	T_{150}			
<u>Means</u>: Manual throttling				P3, P16	3.19	
4.19 Thrust Application = F (Maximum Power) - Missed Approach	T_{149} + "n" seconds	≈1 min.	T_{150} + "n" seconds			
<u>Means</u>: Manual throttling				P3, P16	3.19	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
4.20 Thrust Application = F (Flare Execution)	T_{150}	30 secs.	$T_{150.5}$			
Means: Manual throttling				P3	5.0	
4.21 Thrust Application = F (Surface Speed) - Thrust Reversal for Braking	$T_{150.5}$	30 secs.	T_{151}			
Means: Manual throttling (thrust reverser levers activated)				P3, P16	3.19	
4.22 Thrust Application = F (Surface Speed) - Taxi to Line	T_{151}	2 min.	T_{153}			
Means: Manual throttling				P3, P16	3.19	
4.23 Accomplish Power Plant System Deactivation	T_{153}	1 min.	T_{154}			
Means: Manual throttling				P17	2.27	
5.1 Taxi from Line	T_0-5	5 min.	T_0			
Means: A. Nose-wheel steering				P27	2.91	
B. Differential braking				P27, P16	3.19	
5.2 Initial Roll Control - Take-off	T_0	<1 min.	T_2			
Means: A. Nose-wheel steering, rudder/aileron system				P16	3.19	
B. Differential braking, rudder/aileron system				P16	3.19	
5.3 Take-off Abort Control	T_0 + "n" seconds	≈15-20 secs.	Prior to T_2			
Means: A. Nose-wheel steering, rudder/aileron system				P16	3.19	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
B. Differential braking, rudder/ aileron system				P16	3.19	
5.4 Take-off Control - Rotation, Configuration Change	$T_{0\ 5}$	1 min.	$T_{1.5}$			
Means: Elevator/rudder/ aileron system				P18	2.23	
5.5 Initial Climb Control - Initial Portion of Standard Instrument Departure	T_2	2 min.	T_4			
Means: Elevator/rudder/ aileron system				P10	2.84	
5.6 Subsonic Climb Maneuvering	T_4	7 min.	T_{11}			
Means: A. Elevator/rudder aileron system				P10	2.84	
B. Autopilot (linkage only)				P11	2.52	
5.7 Transonic Acceleration Control	T_{11}	4 min.	T_{15}			
Means: A. Basic control system				P10	2.84	
B. Autopilot (linkage only)				P11	2.52	
5.8 Supersonic Climb Control	T_{15}	5.5 min.	$T_{20.5}$			
Means: A. Basic control system				P10	2.84	
B. Autopilot (linkage only)				P11	2.52	
5.9 Transition to Cruise Control	$T_{20.5}$	1 min.	$T_{21.5}$			
Means: A. Basic control system				P14, Rule 2	5.0	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
B. Autopilot (linkage only)				P13, Rule 2	5.0	
5.10 Cruise Control	$T_{21.5}$	98.5 min.	T_{120}			
Means: A. Basic control system				P8	2.81	
B. Autopilot (linkage only)				P9	2.25	
5.11 Supersonic Descent Control	T_{120}	2 min.	T_{122}			
Means: A. Basic control system				P12	3.44	
B. Autopilot (linkage only)				P13	3.06	
5.12 Transonic Descent Control	T_{122}	30 secs.	$T_{122.5}$			
Means: A. Basic control system				P12	3.44	
B. Autopilot (linkage only)				P13	3.06	
5.13 Subsonic Descent Control	$T_{122.5}$	4 min.	$T_{126.5}$			
Means: A. Basic control system				P12	3.44	
B. Autopilot (linkage only)				P13	3.06	
5.14 Let Down Control	$T_{126.5}$	21.5 min.	T_{148}			
Means: A. Basic control system, speed brakes/spoilers				P12	3.44	
B. Autopilot (linkage only), speed brakes/spoilers				P13	3.06	
5.15 Level Off Maneuver	T_{148}	30 secs.	$T_{148.5}$			
Means: A. Basic control system				P14	3.59	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
B. Autopilot (linkage only)				P15	3.19	
5.16 Initial Approach Control	$T_{148.5}$	30 secs.	T_{149}			
Means: A. Basic control system				P14	3.59	
B. Autopilot (linkage only)				P15	3.19	
5.17 Final Approach Control	T_{149}	1 min.	T_{150}			
Means: Basic control system				P14	3.59	
5.18 Missed Approach Execution Control Operations	T_{149} + "n" seconds	≈1 min.	T_{150} + "n" seconds			Rated high due to pilot responsibility and anxiety/stress components.
Means: Basic control system				P14	10.0	
5.19 Flare Maneuver Execution	T_{150}	30 secs.	$T_{150.5}$			Same as for 5.18.
Means: Basic control system				P14	10.0	
5.20 Rollout Control	$T_{150.5}$	30 secs.	T_{151}			
Means: A. Nose-wheel steering, rudder/aileron system				P14	3.59	
B. Differential braking, rudder/aileron system				P14	3.59	
5.21 Taxi to Line	T_{151}	2 min.	T_{153}			
Means: A. Nose-wheel steering				P27	2.91	
B. Differential braking				P16, P27	3.19	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
6.1 Duct System Configuration for Supersonic Climb	$T_{11.5}$	3.5 min.	T_{15}			Two ratings are given, for the first 30 seconds following activation of the automatic control system, a high restrictiveness is visualized to determine that the control system is activated and operating in an appropriate manner.
<u>Means</u>: Automatic control system				P19, Rule 4	5.0 1.70	
6.2 Duct System Configuration for Transition to Cruise	T_{15}	6 min.	T_{21}			
<u>Means</u>: Automatic control system				P19, Rule 4	1.70	
6.3 Duct System Reconfigured as Required	T_{21}	99 min.	T_{120}			
<u>Means</u>: Automatic control system				P19, Rule 4	1.70	
6.4 Duct System Configuration for Supersonic Descent Operations	T_{120}	2 min.	T_{122}			
<u>Means</u>: Automatic control system				P19, Rule 4	1.70	
6.5 Duct System Configuration for Transonic Deceleration/Descent	T_{122}	30 secs.	$T_{122.5}$			
<u>Means</u>: Automatic control system				P19, Rule 4	1.70	
6.6 Duct System Reconfiguration for Subsonic Operations	$T_{122.5}$	30 secs.	T_{123}			
<u>Means</u>: Automatic control system				P19, Rule 4	1.70	
7.1 Maintain Take-off Flight Path	T_0	1 min.	T_2			
<u>Means</u>: Basic navigation sensors/displays				P16	3.19	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
7.2 Maintain Flight Path for SID	T_2	13 min.	T_{15}			
<u>Means</u>: Conventional (Current Jet) techniques				Rule 2	5.0	
7.3 Monitor Enroute Weather Conditions	T_4	118.5 min.	$T_{122.5}$			
<u>Means</u>: Basic weather sensors				P24, Rule 4	2.55	
7.4 Monitor Destination and Alternate Weather (1)	T_{15}	1 min.	T_{16}			
(2)	T_{38}	1 min.	T_{39}			
(3)	T_{53}	1 min.	T_{54}			
(4)	T_{68}	1 min.	T_{69}			
(5)	T_{83}	1 min.	T_{84}			
(6)	T_{98}	1 min.	T_{99}			
(7)	T_{113}	1 min.	T_{114}			
(8)	$T_{126.5}$	1 min.	$T_{127.5}$			
(9)	T_{146}	1 min.	T_{147}			
<u>Means</u>: Manual receipt of updated forecasts				P3, P22	3.17	
7.5 Provide Differential in Forecast/Actual Weather Conditions	T_4	118.5 min.	$T_{122.5}$			
<u>Means</u>: Comparison of actual to forecast conditions by manual means (Lowered Standard)				N7, P3, P24	3.24	

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
7.6 Calculation of Overpressure Being Generated	T_{11}	111.5 min.	$T_{122.5}$			
<u>Means</u>: Computerized solutions (manual monitoring)				P19, Rule 4	1.70	
7.7 Internal System Position Generation	T_{15}	107.5 min.	$T_{122.5}$			
<u>Means</u>: Automated system (manual monitoring)				P19, Rule 4	1.70	
7.8 External System Position Generation	T_{15}	105 min.	T_{120}			Note: GO/NO-GO monitoring is constant over the entire 105 minutes. CREDIBILITY monitoring upon fix generation is over a 1 minute time period approximately every 10 minutes or a total of ≈11-12 times during the duration of the function.
<u>Means</u>: Automated system (manual monitoring)				Rule 5 P19, Rule 4	5.0 1.70	This function is seen as basically in two parts, i.e., a monitoring task, and an accuracy or credibility determination task. For monitoring, Rule 4 is applicable, and for accuracy checking Rule 5 is applicable. Accuracy checking is seen as occurring at somewhat regular intervals and is indicated thusly on the chart.
7.9 Present Position Updating						
(1)	T_{17}	1 min.	T_{18}			
(2)	T_{27}	1 min.	T_{28}			
(3)	T_{37}	1 min.	T_{38}			
(4)	T_{47}	1 min.	T_{48}			
(5)	T_{57}	1 min.	T_{58}			
(6)	T_{67}	1 min.	T_{68}			
(7)	T_{77}	1 min.	T_{78}			
(8)	T_{87}	1 min.	T_{88}			
(9)	T_{97}	1 min.	T_{98}			
(10)	T_{107}	1 min.	T_{108}			
(11)	T_{117}	1 min.	T_{118}			

Table A2 Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Continued)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
(12) __Means:__ Temporary storage and interrogation devices	$T_{120.5}$	1 min.	$T_{121.5}$	N2, Rule 5	5.0	
7.10 ETA Prediction __Means:__ Manually generated ETA's	$T_{10.5}$	112 min.	$T_{122.5}$	N6	3.16	
7.11 Optimum Profile Generation __Means:__ Crew-controlled profile optimization	T_{15}	107.5 min.	$T_{122.5}$			Considerably less sophisticated control, and deletion of certain requirements, e.g., real-time sonic boom control; are envisioned if manual concepts are employed. The actual process under manual control is envisioned to be highly similar to current jet activity. Performance requirements are sufficiently broad and inclusive such that manual implementation of this function generates a situation where this function and the basics of flight management function "data monitor and compare" are roughly synonomous as regards the crew workload, if we assume no radical change in crew size. If intolerable encroachment on crew time is to be avoided, it is clear that this function cannot exist as an entity under manual implementation concepts, but must be "piecemeal" distributed among the crew members, as well as undergo some severe "lowering of performance standards," and deletion of certain requirements. In summation, manually implementing this function such that all the requirements are met would appear to be: (1) impossible without an extremely radical increase in crew numbers, and change in composition; and (2) impose workload requirements essentially to the exclusion of practically all other crew performance requirements, or more simply stated, preclude any refinements made possible by implementing flight management techniques premised on workload easement. Note: It is the conclusion of this analysis that the restrictiveness rating for SST operations under a manual implementation concept is essentially 5.0 x N where 5.0 represents one crew member full time, and N = at least the present crew complement. (See Rationale) (For purposes of the workload analysis diagrams, a $\bar{R}$ value of 10.0 has been selected to indicate the __relative__ workload assuming that optimization is __not__ computer exercised. It must be recognized, however, that the rationale statement should be of paramount consideration since its impact is overriding in all the areas of Flight Management.)

Table **A2** Time and Restrictiveness Values for SST Functions (Manual Feasibility). (Concluded)

FUNCTION	TIME OF INITIATION	DURATION	TIME OF COMPLETION	RELATED TASK OR RULES	RESTRICTIVENESS VALUE ASSIGNED	RATIONALE/REMARKS
7. 12 **Maintain Flight Path for SIA**	$T_{122.5}$	25. 5 min.	T_{148}			
Means: Conventional (Current Jet) techniques				Rule 2	5. 0	
7. 13 **Maintain Flight Path for AWL**	T_{148}	3 min.	T_{151}			
Means: Visual inputs (contact flying conditions				Rule 2	5. 0	

APPENDIX II

DESCRIPTION OF MECHANICAL RELIABILITY REPORTS (MRR) AND MECHANICAL INTERRUPTION SUMMARY REPORTS (MIS)

The regulation governing MRR's is presented below:

121.703 Mechanical Reliability Reports.

(a) Each certificate holder shall report the occurrence or detection of each failure, malfunction, or defect concerning--

(1) Fires during flight and whether the related fire-warning system functioned properly;

(2) Fires during flight not protected by a related fire-warning system;

(3) False fire warning during flight;

(4) An engine exhaust system that causes damage during flight to the engine, adjacent structure, equipment, or components;

(5) An aircraft component that causes accumulation or circulation of smoke, vapor, or toxic or noxious fumes in the crew compartment or passenger cabin during flight;

(6) Engine shutdown during flight because of flameout;

(7) Engine shutdown during flight when external damage to the engine or airplane structure occurs;

(8) Engine shutdown during flight due to foreign object ingestion or icing;

(9) Engine shutdown during flight of more than one engine;

(10) A propeller feathering system or ability of the system to control overspeed during flight;

(11) A fuel or fuel-dumping system that affects fuel flow or causes hazardous leakage during flight;

(12) A landing gear extension or retraction or opening or closing of landing gear doors during flight;

(13) Brake system components that result in loss of brake actuating force when the airplane is in motion on the ground;

(14) Aircraft structure that requires major repair;

(15) Cracks, permanent deformation, or corrosion of aircraft structures, if more than the maximum acceptable to the manufacturer or the FAA; and

(16) Aircraft components or systems that result in taking emergency actions during flight (except action to shut down an engine).

(b) For the purpose of this section "during flight" means the period from the moment the aircraft leaves the surface of the earth on takeoff until it touches down on landing.

(c) In addition to the reports required by paragraph (a) of this section, each certificate holder shall report any other failure malfunction, or defect in an aircraft that occurs or is detected at any time if, in its opinion, that failure, malfunction, or defect has endangered or may endanger the safe operation of an aircraft used by it.

(d) Each certificate holder shall send each report required by this section, in writing, covering each 24-hour period beginning at 0900 hours local time of each day and ending at 0900 hours local time on the next day, to the FAA maintenance inspector assigned to its operations. The report must be delivered to him by 0900 hours local time on the following day. However, a report that is due on Saturday or Sunday may be delivered on the following Monday and one that is due on a holiday may be delivered on the next workday.

(e) The certificate holder shall transmit the reports required by this section in a manner and on a form that is convenient to its system of communication and procedure, and shall include in the first daily report as much of the following as is available:

(1) Type and identification number of the aircraft.

(2) The name of the operator.

(3) The date, flight number, and stage during which the incident occurred (e.g., preflight, takeoff, climb, cruise, descent, landing, and inspection).

(4) The emergency procedure effected (e.g., unscheduled landing and emergency descent).

(5) The nature of the failure, malfunction, or defect,

(6) Identification of the part and system involved, including available information pertaining to type designation of the major component and time since overhaul.

(7) Apparent cause of the failure, malfunction, or defect (e.g., wear, crack, design deficiency, or personnel error).

(8) Whether the part was repaired, replaced, sent to the manufacturer, or other action taken.

(9) Whether the aircraft was grounded.

(10) Other pertinent information necessary for more complete identification, determination of seriousness, or corrective action.

(f) Failures, malfunctions, or defects reported under the accident reporting provisions of Part 320 of the regulations of the Civil Aeronautics Board need not be reported under this section.

(g) No person may withhold a report required by this section even though all information required in this section is not available.

(h) When a certificate holder gets additional information, including information from the manufacturer or other agency, concerning a report required by this section, it shall expeditiously submit it as a supplement to the first report and reference the date and place of submission of the first report.

The Control System Division of FAA compiles these data and distributes quarterly MRR statistical summaries known as Paper No. 20. (The same types of statistical summaries are also prepared for the MIS's.) The MRR statistical summary is explained in Paper No. 20 as follows:

> The Mechanical Reliability Report (MRR) data are presented in the form of rates (MRR's/1000 aircraft flight hours) in order to provide a valid comparison of data by eliminating the influence of such factors as the number of aircraft and to some extent the operator involved. Figures are included, however, showing the fleet size, actual number of MRR's and hours flown. Fleet size is an average of the number of aircraft operated each month by the various operators over the three month period. Flight time is the total number of hours of aircraft operation for the time period considered.
>
> The MRR rates contained in this paper were derived by dividing the number of MRR's reported by the aircraft flight hours for the time period considered. Aircraft flight time is used as a basis in all cases including MRR rates for the engines, propellers, and other duplicate systems.

Paper No. 20 contains a section on"Data Review Highlights" and the bulk of the data is presented in tabular and chart form. The basic data (i.e., MRR's/1000 aircraft flight hours) is presented as shown in Table A3.

Table A3. Sample of Data Presented in MRR (Distribution by Aircraft Type and Aircraft System of MRR's per 1000 Hours Flight Time)

AIRCRAFT TYPE	AIRCRAFT SYSTEM						
	LANDING GEAR (3200)	ENGINE (7200)	FIRE PRO-TECTION (2600)	WINGS (5700)	FLIGHT CONTROL (2700)	HYDRAULIC POWER (2900)	FUSELAGE (5800)
AW-650	.78	.39	.20			.20	
B-707	.28	.10	.16	.09	.10	.06	.02
B-720	.24	.08	.16	.22	.09	.11	.10
B-727	.60	.20	.06	.06	.31	.11	.03
CL-44	.28	.06	.22		.11	.06	
CV-28	.94						
CV-240	.65	.86	.17	.09	.04	.17	.04
CV-340/440	.20	.51	.10	.01	.06	.06	.25
CV-340T							
CV-880	.50	.06	.26	.03	.15	.18	.03
CV-990	1.61	.35	.23		.12	.12	
CW-46	.42	.34	.11	.04	.15	.08	
DC-3	.30	.53	.06	.05		.02	.02
DC-4	.54		.40			.40	
DC-6	.17	.31	.03	.27	.02	.04	.15
DC-7	.21	.50	.17			.13	.02
DC-8	.37	.08	.14	.02	.06	.03	.01
F-27	1.03	.14	.03	.06	.25	.06	.06
F-C82		13.51					
G-SA16		2.55				2.55	
G-21							
L-049/149		.66					
L-188	.48	.18	.10	.20	.06	.01	.07
L-749	.06	.38	.06		.13		.06
L-1049	.25	.88	.03	.25	.10	.08	.03
L-1649	.90	2.40	1.20			.60	
M-202	1.08	.95	.14			.27	
M-404	.58	.75	.03	.03			
SE-210	.18	.09	.27			.18	
V-745	.46	.04	.19		.04	.04	
V-810/812	.46			.12		.12	.12
Jets	.36	.10	.16	.09	.11	.08	.04
T/Ps	.56	.13	.11	.11	.09	.04	.05
Piston	.28	.50	.08	.10	.03	.07	.09

which is an actual but incomplete sample. The basic "ATA Spec. 100 'Systems'" are used to code the aircraft systems. Table A4 presents the ATA Spec. 100 systems code. Figures A1 through A4 are samples of the data presented in chart form in each paper No. 20 and are generally self-explanatory.

DESCRIPTION OF MECHANICAL INTERRUPTION SUMMARY REPORTS (MIS)

The regulation covering MIS is presented below:

> 121.705 Mechanical interruption summary report.
>
> Each certificate holder shall regularly and promptly send a summary report on the following occurrences to the Administrator:
>
> (a) Each interruption to a scheduled flight, unscheduled change of aircraft en route, or unscheduled stop or diversion from a route, caused by known or suspected mechanical difficulties or malfunctions that are not required to be reported under Section 121.703.
>
> (b) The number of engines removed prematurely because of malfunction, failure or defect, listed by make and model and the aircraft type in which it was installed.
>
> (c) The number of propeller featherings in flight, listed by type of propeller and engine and airplane on which it was installed. Propeller featherings for training, demonstration, or flight check purposes need not be reported.

The MIS reports are very smiliar to the MRR in that they are also published as quarterly statistical summaries and are part of Paper No. 20. In addition, since May 1964, the Mechanical Interruption Statistical Summaries have been tabulated by the Data Services Division, FAA, in Oklahoma City on a monthly basis. Mechanical interruption frequencies are tabulated to produce a MIS breakdown with regard to specific aircraft type and specific subsystem within the major aircraft system category. Thus the MIS data is very similar to the MRR data shown in Figures A1 through A4,and in addition includes a monthly computer summary tabulation.

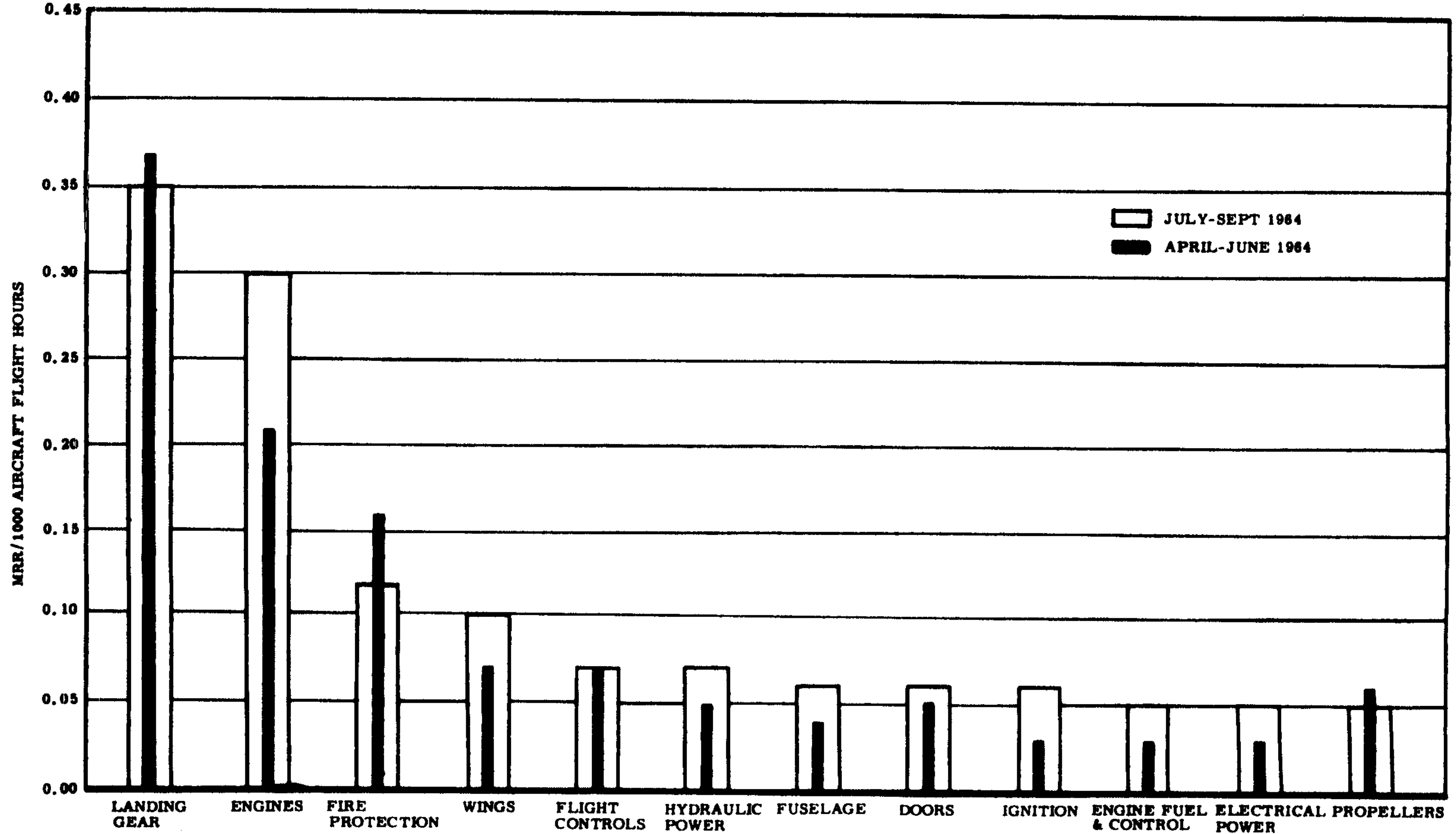
Table A4. ATA Spec. 100 Systems Code

C.A.R. ITEM	NATURE OF CONDITION	STAGE OF OPERATION	EMERGENCY PROCEDURE EFFECTED	SAFETY FACTOR
1. Fire with warning	FC - Controlability affected	AP - Approach	ED - Emergency descent	1. Little
2. Fire without warning	FF - Structural failure, etc.	CL - Climb	EL - Unscheduled landing	2. Moderate
3. Fire without warning system	FL - Fluid or gas loss	CR - Cruise	EX - Both above	3. Moderate, potentially substantial or severe
4. False fire warning	FS - Fire, smoke, etc.	DE - Descent	PD - Other	4. Substantial, potentially severe
5. Damage due exhaust system failure	FW - False warning	FC - Flight crew operation, etc.	UN - Undetermined	5. Severe
6. Smoke, vapor, etc.	OH - Over-temperature	GR - Maintenance, etc.	ZE - None	
Engine Shutdown:	OR - Other than above	HO - Hovering		
7. due flameout	UN - Undetermined	LD - Landing		
8. with external damage		TO - T. O.		
9. due foreign object ingestion		UN - Undetermined		
10. of more than one engine				
11. Propeller control				
12. Fuel leakage or fuel flow				
13. Landing gear operation				
14. Brakes				
15. Structural repair				
16. Cracks, deformation, etc.				
17. Emergency action				
18. Main rotor, etc.				
19. Other than above				
20. Undetermined				

ATA SPEC. 100 SYSTEMS

System	Sub	Title
21	00	AIR CONDITIONING
	10	Compression
	20	Distribution
	30	Pressurization Control
	40	Heating
	50	Cooling
	60	Temperature Control
	70	Humidity Regulation
22	00	AUTO PILOT -
	10	Amplification
	20	Actuation
	30	Controlling
	40	Indicating
	50	Sensing
	60	Coupling
23	00	COMMUNICATIONS
	10	HF
	20	VHF
	30	PA& Pass. Entertainment
	40	Interphone
	50	Audio Integrating
	60	Static Discharging
	70	Voice Recorders
24	00	ELECTRICAL POWER
	10	Generator Drive
	20	AC Generation
	30	DC Generation
	40	External Power
	50	Elect. Load Distribution
25	00	EQUIP. / FURNISHINGS
	10	Flight Compartment
	20	Pass. Compartment
	30	Buffet/Galley
	40	Lavatories
	50	Cargo & Accessory Comp'rt
	60	Emergency
26	00	FIRE PROTECTION
	10	Detection
	20	Extinguishing
27	00	FLIGHT CONTROLS
	10	Aileron & Tab
	20	Rudder & Tab
	30	Elevator & Tab
	40	Horiz. Stabilizer Control
	50	Flaps
	60	Spoiler & Drag
27		(continued)
	70	Gust Lock & Dampener
	80	Lift Augmenting
28	00	FUEL -
	10	Storage
	20	Distribution
	30	Dump
	40	Indicating
29	00	HYDRAULIC POWER
	10	Main
	20	Auxiliary
	30	Indicating
30	00	ICE & RAIN PROTECTION
	10	Airfoil
	20	Air Intakes
	30	Pitot and Static
	40	Windows & Windshields
	50	Antennas & Radomes
	60	Propellers/Rotors
	70	Water Lines
	80	Detection
31	00	INSTRUMENTS
	10	Panels
	20	Independent Instruments
32	00	LANDING GEAR
	10	Main & Doors
	20	Nose & Doors
	30	Extension & Retraction
	40	Wheels and Brakes
	50	Steering
	60	Position & Warning
	70	Supplementary Gear
33	00	LIGHTS
	10	Flight Compartment
	20	Passenger Compartment
	30	Cargo & Service Comp'ts
	40	Exterior
	50	Emergency Lighting
34	00	NAVIGATION
	10	Air Data Instrumentation
	20	Attitude & Direction Inst.
	30	Radio Navigation
	40	Radar Navigation
	50	Proximity Warning
	60	Position Computing
35	00	OXYGEN
	10	Crew
35		(continued)
	20	Passenger
	30	Portable
36	00	PNEUMATIC
	10	Distribution
	20	Indicating
37	00	VACUUM
	10	Distribution
	20	Indicating
38	00	WATER/WASTE
	10	Potable
	20	Wash
	30	Waste Disposal
	40	Air Supply
49	00	AIRBORNE AUX. POWER
	10	Power Plant
	20	Engine
	30	Engine Fuel & Control
	40	Ignition/Starting
	50	Air
	60	Engine Controls
	70	Indicating
	80	Exhaust
	90	Oil
51	00	STRUCTURES
52	00	DOORS
	10	Passenger/Crew
	20	Emergency Exit
	30	Cargo
	40	Service
	50	Fixed Interior
	60	Entrance Stairs
	70	Door Warning
	80	Landing Gear
53	00	FUSELAGE
	10	Main Frame
	20	Auxiliary Structure
	30	Plates, Skins
	40	Attach Fitting
	50	Cones & Fillets/Fairings
54	00	NACELLES/PYLONS
	10	Main Frame
	20	Auxiliary Structure
	30	Plates/Skin
	40	Attach Fittings
	50	Fillets/Fairings
55	00	STABILIZERS
	10	Horizontal
	20	Elevator
	30	Vertical
	40	Rudder
	50	Attach Fittings
56	00	WINDOWS
	10	Flight Compartment
	20	Cabin
	30	Door
	40	Inspection & Observation
57	00	WINGS
	10	Main Frame
	20	Auxiliary
	30	Plates/Skin
	40	Attach Fittings
	50	Flight Surfaces
61	00	PROPELLERS-general
	10	Propeller Assembly
	20	Controlling
	30	Braking
	40	Indicating
65	00	ROTORS
	10	Main Rotor
	20	Anti-Torque Rotor Assy.
	30	Accessory Driving
	40	Controlling
	50	Braking
	60	Indicating
71	00	POWER PLANT
	10	Cowling
	20	Mounts
	30	Fireseals
	40	Attach Fittings
	50	Electrical Harness
72	00	ENGINE TURBINE
	10	Reduction Gear & Shaft Sect.
	20	Air Inlet Section
	30	Compressor Section
	40	Combustion Section
	50	Turbine Section
	60	Accessory Drives
	70	By-pass Section
72	00	ENGINE RECIPROCATING
	10	Front Section
	20	Power Section
72		(continued)
	30	Cylinder Section
	40	Supercharger Section
	50	Lubrication
73	00	ENGINE FUEL & CONTROL
	10	Distribution
	20	Controlling
	30	Indicating
74	00	IGNITION
	10	Electrical Power Supply
	20	Distribution
	30	Switching
75	00	AIR
	10	Engine Anti-Icing
	20	Accessory Cooling
	30	Compressor Control
	40	Indication
76	00	ENGINE CONTROLS
	10	Power Control
	20	Emergency Shutdown
77	00	ENGINE INDICATING
	10	Power
	20	Temperature
	30	Analyzers
78	00	EXHAUST
	10	Collector
	20	Noise Suppressor
	30	Thrust Reverser
79	00	OIL
	10	Storage
	20	Distribution
	30	Indicating
80	00	STARTING
	10	Cranking
	20	Igniting
81	00	TURBINES
	10	Power Recovery
	20	Turbo-Supercharger
82	00	WATER INJECTION
	10	Storage
	20	Distribution
	30	Dumping & Purging
	40	Indicating
83	00	ACCESSORY GEAR BOXES
	10	Drive Shaft Section
	20	Gearbox Section

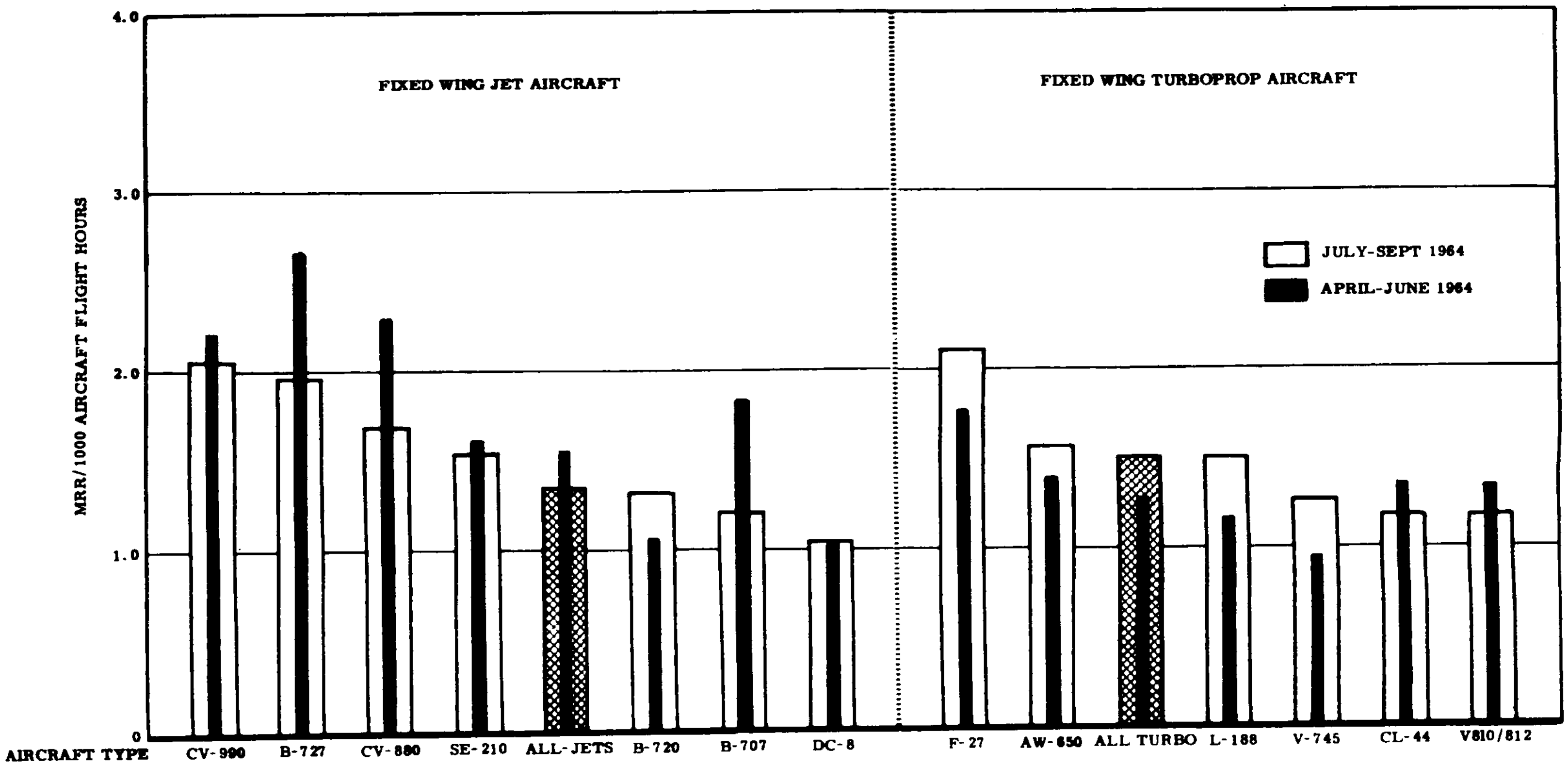
ATA Spec. 100 "Systems" are generally in alphabetical order starting with the low numbered "Systems"



	LANDING GEAR	ENGINES	FIRE PROTECTION	WINGS	FLIGHT CONTROLS	HYDRAULIC POWER	FUSELAGE	DOORS	IGNITION	ENGINE FUEL & CONTROL	ELECTRICAL POWER	PROPELLERS
MRR'S REPORTED	401	339	134	112	80	79	73	70	70	62	55	55
% OF TOTAL REPORTED	21.24	17.96	7.10	5.93	4.24	4.24	3.87	3.70	3.70	3.28	2.92	2.92

Note: The remaining 358 MRR's (18.96% of the total reported) are distributed among <u>28</u> aircraft systems.

Figure A1. Sample of distribution by aircraft system of the MRR's per 1000 hours of flight time.



AIRCRAFT TYPE	CV-990	B-727	CV-880	SE-210	ALL-JETS	B-720	B-707	DC-8	F-27	AW-650	ALL TURBO	L-188	V-745	CL-44	V810/812
FLEET SIZE	19	59	46	20	518	111	151	112	55	7	277	126	49	21	11
HOURS FLOWN	13, 143	35, 015	34, 081	10, 967	426, 194	91, 899	139, 914	101, 175	35, 976	5, 122	180, 752	83, 971	26, 176	18, 093	8, 609
MRR'S REPORTED	27	69	58	17	565	120	169	105	76	8	273	125	33	21	10

Note: The CV340T, G-159 and PC-6A accumulated 2805 Flight hours but no MRR's were reported.

Figure A2. Sample of distribution by aircraft type of the MRR's per 1000 hours of flight time.

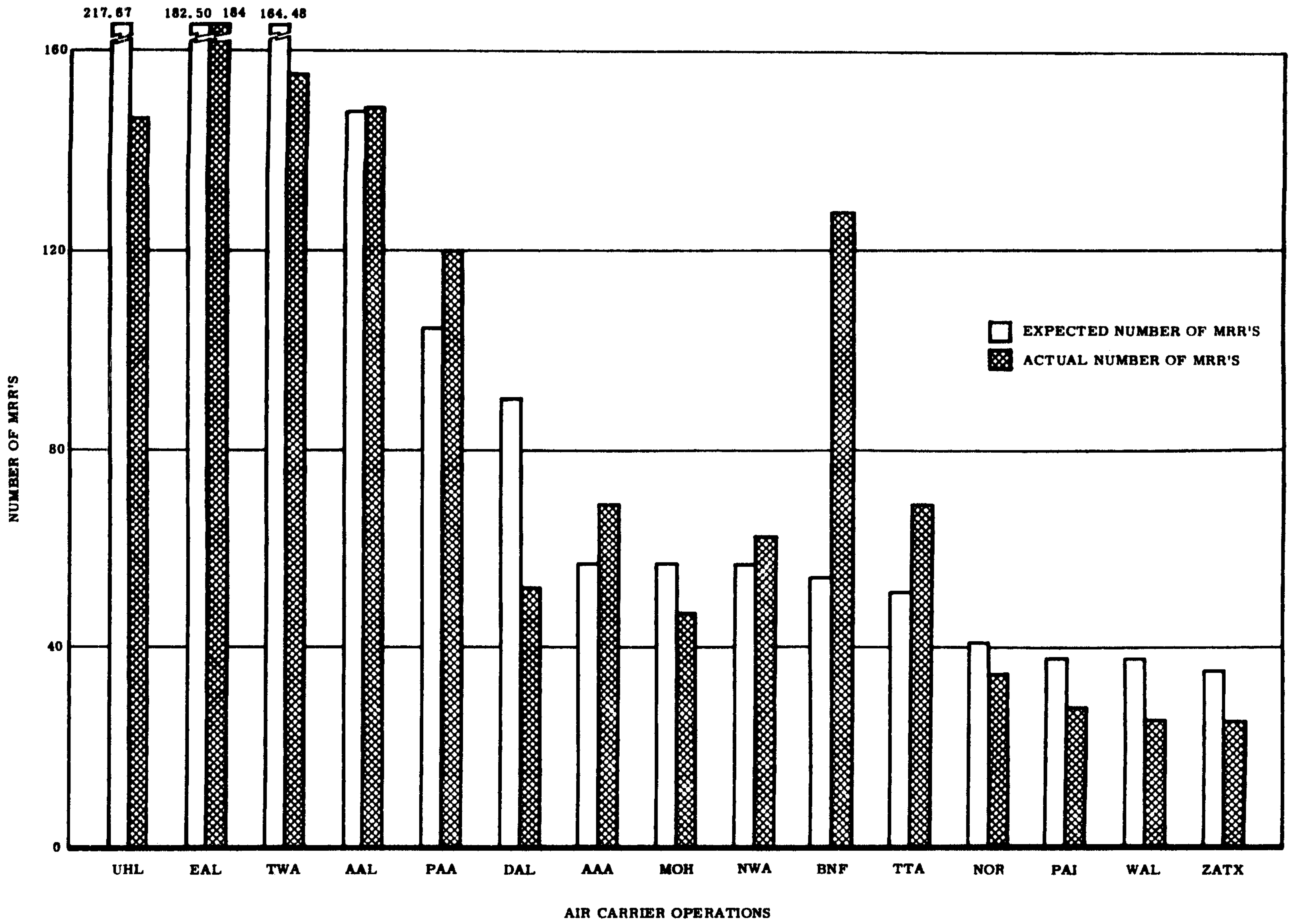


Figure A3. Sample of expected number vs. actual number of MRR's reported.

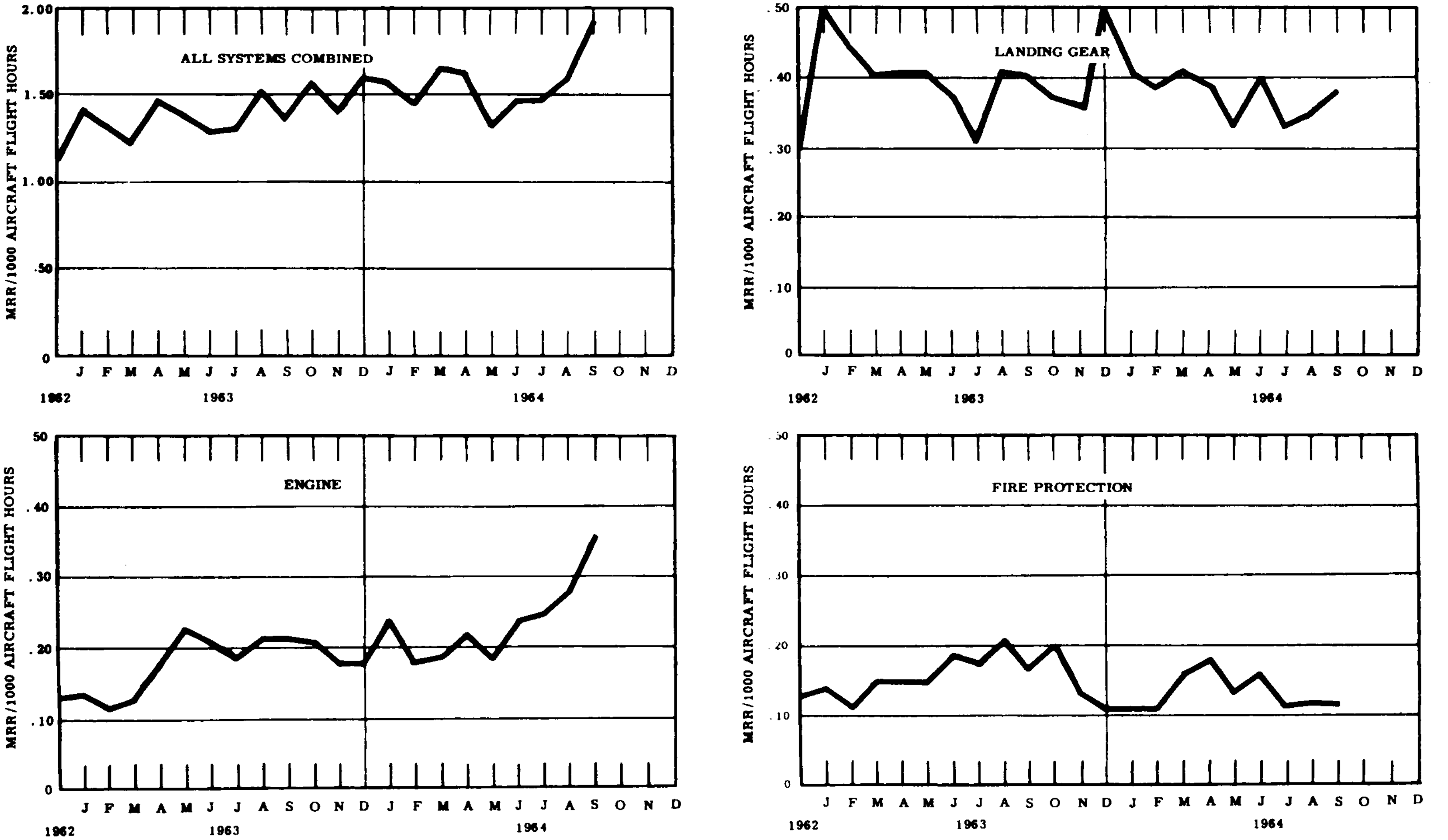


Figure A4. Sample of monthly distribution by aircraft system of the MRR's per 1000 hours of flight time.

APPENDIX III DEVELOPMENT OF CREW WORKLOAD MEASURES

In order to assess crew workload, some measure of crew participation was needed because (1) every operation in which a crew member participates may not require his total attention, and (2) each human being has only a given capacity which can be employed in a performance situation. Rather than using an arbitrary rating scale, it was decided that the opinions of current jet crew members concerning the workload associated with tasks they perform would have greater reliability and validity. Validity of these data was based on the supposition that if a man believed a certain type of task required all his attention or capacity, then for all practical purposes, he was completely loaded. A performance restrictiveness scale was developed as the measure of workload. Five degrees of restrictiveness were chosen as follows:

1. Non-restrictive
2. Lightly-restrictive
3. Moderately restrictive
4. Severely restrictive
5. Completely restrictive

Next, two questionnaires were prepared for pilots and navigators which itemized certain tasks performed in current jet operations. Recipients were asked to rate the restrictiveness of each task. Time-to-perform data were also requested where appropriate. Questionnaires were administered both by mail and in person. A sample cover letter, the two questionnaires and their accompanying instructions are presented on the following nine pages. Approximately 100 pilot questionnaires were distributed with a usable return of 32; approximately 70 navigation questionnaires were distributed with a usable return of 37.

serendipity associates
9760 COZYCROFT, CHATSWORTH, CALIFORNIA / 341-0033

Dear Pilot:

Serendipity Associates is under contract to the National Aeronautics and Space Administration to study the Operational Crew Task Requirements of Supersonic Transports (SST). At this time we are concerned with "workload" and interested in Pilot opinion as to the restrictiveness of some of the tasks found in today's commercial jet operations. This will assist us in evaluating potential crew workload in the SST.

Calling upon your experience, to obtain the necessary information, we have developed a short questionnaire to elicit the necessary information. We would appreciate very much your filling out the enclosed questionnaire and returning it in the self-addressed stamped envelope as soon as possible.

We have been working with the ALPA in the United States and the IFALPA also, as well as with many of the airlines. Their help and yours is very important to us as we are very concerned with the opinions of personnel who may ultimately fly the SST.

Thank you for your cooperation.

Sincerely,

Harold E. Price
Principal Investigator
SST Crew Requirements Program

HEP:dg

Encl.

Directions for filling out Questionnaire

Please fill out personal information at the top of page one. (Your name is for reference only and will not be used.)

Down the page at the left of the questionnaire is a partial list of tasks performed in the cockpit of the aircraft. To the right of these tasks are six columns. The first column reads "Task Performance not applicable (any reason)." If performance of the task is not your concern then put a check in that column and go on to the next task.

If you do perform the task we would simply like you to rate the task as to restrictiveness. By restrictiveness we mean the degree of attention the task requires of a pilot, thereby restricting his performing any other of his tasks at the same time. For example, pushing an ON-OFF switch to turn on some lights may not restrict you from monitoring a display and consequently would not be very restrictive. On the other hand, looking through the aircraft windscreen to try and locate the runway lights while breaking out at 200 feet may be considered very restrictive since your degree of attention may restrict you from performing any other task at the same time.

We have listed five degrees of restrictiveness. The choices (degrees) are: (1) non-restrictive, (2) lightly restrictive, (3) moderately restrictive, (4) severely restrictive and (5) completely restrictive. If the performance of the task you are rating does not preclude your performing other pilot tasks you would put a check in the "non-restrictive" column. If performing the task requires such a degree of attention on your part as to restrict you from performing any other task simultaneously then you would check the "completely restrictive" column. If a task doesn't fall into either of those categories but is somewhere in between you would check one of the three remaining restrictiveness columns.

Finally, when applicable we would like to know the *average* time it takes to perform the task one time under *normal* conditions. Note this time at the far right in the space provided.

We realize that there may still be questions in your mind as to filling out this questionnaire. It may help to follow these rules:

1. All the tasks are performed under *instrument conditions*.
2. When you rate task restrictiveness remember that we are not concerned with your ability to perform emergency or non-routine tasks but only other routine pilot tasks.
3. Where a task may vary in restrictiveness as to airport, aircraft, etc. take the average condition. For example, flying a standard instrument departure at a certain airport may be so complex because of the airport's peculiar procedures or locale, as to make the task much more restrictive than normally. We are not concerned with this unique situation but only the typical situation.

Name ____________________ Airline ____________

Equipment you are currently flying ____________________

Usual Flight Position: Captain ________ 1st Officer ________

Approximate Total Airline Hours ________ Jet Hours ________

Presently flying Domestic ________ International ________ route.

ALL THE FOLLOWING TASKS ARE <u>PERFORMED UNDER INSTRUMENT CONDITIONS</u>:

	Task Performance Not Applicable (Any reason)	TASK RESTRICTIVENESS					Time Estimated in Minutes and Seconds
		Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	
1. Predict fuel over destination.							
2. Verify ETA validity.							
3. Receive, copy and verify ATC clearances or revisions.							
4. Intercom announcement.							
5. Calculate wind velocity and relative bearing.							
6. Calculate drift and ground speed.							
7. Evaluate aircraft speed vs. runway remaining on take-off for take-off/abort decision.							
8. Fly one minute holding pattern without use of autopilot.							
9. Fly one minute holding pattern using autopilot COURSE-HOLD.							
10. Fly a standard instrument departure manually.							
11. Fly a standard instrument departure using autopilot COURSE-HOLD.							
12. Fly standard instrument approach manually.							
13. Fly standard instrument approach using autopilot COURSE-HOLD.							
14. Fly ILS final approach manually.							

ALL THE FOLLOWING TASKS ARE PERFORMED UNDER INSTRUMENT CONDITIONS:

		TASK RESTRICTIVENESS					
	Task Performance Not Applicable (Any reason)	Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	Time Estimate in Minutes and Seconds
15. Fly ILS Final approach using autopilot coupler.							
16. Maintain runway centerline and wings level attitude during take-off roll.							
17. Perform pre-descent check.							
18. Reconfigure aircraft for landing (flaps, spoilers, gear, etc.).							
19. Maintain constant MACH cruise speed.							
20. Monitor engine performance instruments during take-off.							
21. Verify VOR station identification.							
22. Maintain cognizance of enroute weather conditions via all cockpit instrumentation (radar, temperature gauges, etc.).							
23. Vectoring aircraft through storm, using airborne weather radar.							
24. Monitor communications to other aircraft in terminal area.							
25. Monitor autopilot operation at cruise.							
26. Maintain altitude control in moderate to severe turbulence.							
27. Maintain obstruction and other traffic clearance from parking area to operational runway.							

Directions For Filling Out Questionnaire

Please fill out personal information at the top of page one. (Your name is for reference only and will not be used.)

Down the page at the left of the questionnaire is a partial list of navigation type tasks performed on the flight deck of the aircraft. The first column across the top reads "Task Performance Not Applicable (any reason)." If performance of the task is not your concern then put a check in that column and go on to the next task.

If you do perform the task we would like you to name the general type of equipment which you are using in the performance of this task and check in the appropriate column whether your performance of that task is completely manual, partially automated, or performed completely automatically by the equipment.

Next we would like you to rate the task as to restrictiveness. By restrictiveness we mean the degree of attention the task requires, thereby restricting the operator from performing any other of his tasks at the same time. For example, pushing an ON-OFF switch to turn on some lights may not restrict you from monitoring a display and consequently would not be very restrictive. On the other hand, converting a plotted point representing a fix of the aircraft's position into exact geographical coordinates may be considered very restrictive since your degree of attention may restrict you from performing any other task at the same time.

We have listed five degrees of restrictiveness. The choices (degrees) are: (1) non-restrictive, (2) lightly restrictive, (3) moderately restrictive, (4) severely restrictive and (5) completely restrictive. If the performance of the task you are rating does not preclude your performing other routine tasks you would put a check in the "non-restrictive" column. If performing the task requires such a degree of attention on your part as to restrict you from performing any other task simultaneously then you would check the "completely restrictive" column. If a task doesn't fall into either of those categories but is somewhere in between you would check one of the three remaining restrictiveness columns.

Finally, when applicable we would like to know the average time it takes to perform the task one time under normal conditions. Note this time at the far right in the space provided.

We realize that there may still be questions in your mind as to filling out this questionnaire. It may help to follow these rules:

1. All the tasks are performed under instrument conditions.
2. When you rate task restrictiveness remember that we are not concerned with your ability to perform emergency or non-routine tasks but only other routine navigation tasks.
3. Where a task may vary in restrictiveness as to airport, ground aids, aircraft, etc. take the average condition. We are not concerned with the unique situation but only the typical situation.

Name ______________ Airline ______________

Equipment you are currently flying ______________

Approximate Total Airline Hours ________ Jet Hours ________

Presently flying Domestic ________ International ________ route.

Flight Position: Pilot Navigator ______ Specialist Navigator ______

ALL THE FOLLOWING TASKS ARE PERFORMED UNDER INSTRUMENT CONDITIONS:

	Task Performance Not Applicable (Any Reason)	MEANS FOR PERFORMING TASKS				TASK RESTRICTIVENESS					Time Estimate in Minutes and Seconds
		General Type of Equipment Provided	Completely Manual	Partly Automated	Completely Automated	Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	
1. Obtain position fix by means of standard hyperbolic system.											
2. Obtain position fix by means of celestial techniques.											
3. Perform airborne gyro compass alignment check via celestial techniques.											
4. Unslave gyro compass and align for "free gyro mode" operation.											
5. Obtain position fix by means of short range point-source system.											
6. Verify the validity of the destination ETA.											
7. Calculate wind velocity and relative bearing.											
8. Calculate drift and ground speed.											
9. Pre-set and reset destination coordinates in self-contained navigation system.											
10. Determine course to steer.											
11. Maintain geographic plot of navigational situation.											
12. Calculate initial point of turn to minimize cross track error following turn.											

ALL THE FOLLOWING TASKS ARE PERFORMED UNDER INSTRUMENT CONDITIONS:

		MEANS FOR PERFORMING TASKS				TASK RESTRICTIVENESS					
	Task Performance Not Applicable (Any Reason)	General Type of Equipment Provided	Completely Manual	Partly Automated	Completely Automated	Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	Time Estimate in Minutes and Seconds
13. Derive navigational data to modify flight plan for storm avoidance.											
14. Predict fuel over destination.											
15. Derive doppler bias error											
16. Maintain cognizance of enroute weather conditions via all cockpit instrumentation.											
17. Determine self-combined navigation system accuracy following a maneuver requiring "memory" operation.											

APPENDIX IV REVIEW OF INSTRUMENTATION CONCEPTS ASSOCIATED WITH COCKPIT DISPLAY PARAMETERS

This appendix is a review of state-of-the-art instrumentation concepts and display techniques for those cockpit display parameters identified in section 7. A brief discussion of current cockpit display provisions, the suitability of this instrumentation for SST requirements, and alternative display concepts is presented for each parameter.

Desired/Required Ground Track

In current operations crews will usually plan their flight to conform to standard routes of travel and will request ATC clearance accordingly. In the case of continental flights the airway charts, standard instrument departures charts, and the standard instrument approach charts will be used with the ATC clearance to provide an indication of the desired/required track. On oceanic flights the navigator will usually plot a line indicative of the desired track, and then will up-date this as the flight progresses.

For flying continental airways, the omnidirectional ground navigational aids provide 360 tracks (radials) which are usually indicated in the cockpit via the radio magnetic indicator. This indication, coupled with the airway charts, gives the crew adequate navigational information. That is to say, if the clearance specifies an airway, and the airway is defined by a specific radial, then the desired/required track is also defined.

Current state-of-the-art instrumentation, and current thinking on applications to the SST, are pointed towards a pictorial display of the aircraft's actual track over the ground in relation to the aircraft's desired track in the future and to special flight path requirements (e.g., holding patterns, climb-outs, etc.). The use of roller maps and map projection techniques are being advocated for the SST. Using this technique, desired tracks could be defined on the chart prior to the flight and certain required tracks could be a permanent feature of the chart. Projection techniques are being developed which will provide for changes in track definitions during flight to give an optimum profile.

Although it does not appear that the SST will be required to fly the VOR airways, the capability to ascertain the aircraft's present position during continental flights will continue to exist. During the landing phase of flight the radio magnetic indicator will provide a more precise indication of required track and can be cross-checked with the ILS course deviation indicator.

Thus the SST should have the desired/required ground track displayed via a moving map presentation. Although some concepts advocate such a display for both the pilot and copilot, it would appear that a display located on the forward panel between the two pilots would fulfill the informational requirements. It also appears that the SST will continue to utilize the radio magnetic indicator (RMI) during the landing approach in those instances when the aircraft is flying the VOR system.

Angle of Aircraft's Longitudinal Axis with North Reference

In current operations there are many methods for deriving the desired heading of the aircraft, and each must be utilized when flying in a particular region of the world. However, this concerns itself with the control panel which provides the source for the heading display. The actual display in current aircraft is via some type of integrated navigational instrumentation (e.g., the radio magnetic indicator). There is also usually the stand-by magnetic compass, which is only really used as a gross cross-check on the other compasses.

The instrument is usually a fixed pointer with a movable field, so that as the aircraft changes heading the field will rotate with reference to the fixed pointer. In most of the current instrumentation used in commercial aviation the rotating field is graduated in 5° increments, which usually means that the crew can select a heading to within about 2 1/2°.

For the SST it would appear that the major change will come in the selection of the source to furnish the heading of the aircraft. As far as the interface is concerned, there does not appear to be any revolutionary new concepts advocated. It does appear that the graduation of the movable field should be finer, so that the crew will be able to select headings to within one-half degree. It further appears that heading will be a required part of any projected or pictorial navigation display.

Since heading is one of the basic reference tools of the pilot, it is logical to assume that each of the two pilot positions will be furnished with a display of the heading. As stated previously, the utilization of one pictorial display should suffice, so that the display of heading information on such a display would be available to both pilot members of the crew. It is also logical to assume that since the reliability of such heading sources is still indeterminant, there will continue to be the requirement for the stand-by magnetic compass. In the event that a navigator's position is decided upon, a heading reference must be available to that position.

Aircraft Displacement from Track in Lateral Plane

In current operations the displacement from track is displayed or inferred in various manners. For continental flights using the VOR system this is usually presented via the course deviation indicator (CDI), which presents a left or right deviation from some selected course of reference. The crew may also use the radio magnetic indicator to determine the aircraft's relative position to some required track (i. e., by referring to the RMI the crew is able to ascertain their position on some specific radial, from which they can then infer a left or right deviation from some prescribed radial).

On oceanic flights the crew must obtain a position fix and then compare it with the preplotted desired track; the result is some deviation (left/right) of the track. Other than that, however, there is no display of track deviation in the cockpit of the aircraft.

It should be noted that during the landing portion of the flight, when the navigation receivers are tuned to the localizer frequency of the instrument landing system (ILS), the sensitivity of the instrument is increased. This means that smaller excursions from the desired path (centerline) are noted immediately.

For the SST it would appear that the course deviation indicator would continue to be utilized when flying VOR airways and structure. However, although it will probably continue to be coupled to the landing navigational aid, it is assumed that some other form of landing display will be utilized, and that the deviation from the track will be presented as an element of such a display. The discussion of the all-weather landing display in section 8 describes the required information elements in greater detail and defines the sensitivity requirements.

The major change in the SST will be the pictorial display of the navigational situation. If, as anticipated, the roller map display is premarked with the desired track of the flight, then the addition of the aircraft's position at any instant will immediately display any lateral deviations. Thus, in essence, the task of the crew will be primarily a tracking task (i.e., to maintain minimal excursions from the preplotted flight path). Because of the more stringent requirements for exact position during terminal operations, it is felt that the sensitivity of the display to lateral displacements should be greater in these areas. This can be accomplished by changing the scale of the map.

Aircraft Rate of Movement in the Vertical Plane (Vertical Vector)

In current operations, the vertical speed is displayed or inferred in various manners. Generally, the rate of ascent/descent indicator gives the direct indication of the vertical vector of the velocity. Currently, this instrument is of the dial type with a fixed field and a moveable pointer. The graduation of the instrument is usually in thousands of feet per minute, and can be read to about 250 feet per minute. The largest deficiency of the instrument is its lag with changes in the pitch attitude of the aircraft.

In the SST vertical velocity profiles will be flown and the scale of this instrument will need to be such that the crew will be able to select vertical speeds to within 100 feet per minute. This is especially true during the landing phase when in the execution of the "flare" maneuver the rate of descent will need to be decreased to about 1 to 2 feet per second (i.e., 60 to 120 feet per minute).

A vertical tape display will probably be required for the display of this parameter, since greater resolution than that obtainable with conventional circular dial instruments is necessary. This type of indicator provides a display of rate of climb over a range from 0 to ± 40,000 feet per minute and has an indicator accuracy of ± 250 feet per minute.

Aircraft Rate of Movement Along the Trajectory (Velocity Vector)

The airspeed of the aircraft is currently displayed in various ways (e.g., indicated airspeed, and true airspeed) to satisfy different uses. Generally, indicated airspeed is used primarily during the low speed regions and Mach number is used during the high speed, high altitude flight. True airspeed is used to derive time enroute estimates and ETA's for specific control points. In all instances, conventional instrumentation employed to display this parameter is a dial with a fixed field and moveable pointer.

In the SST airspeed display requirements are not expected to change, but a vertical tape indicator will probably be employed as the primary display technique. There are many other concepts advocated for the display of the airspeed, and these will be incorporated into the specific displays (e.g., the all-weather landing instrumentation utilizing a projected display requires a projected airspeed element). In those instances where a Doppler or inertial navigation system is utilized, there are provisions on the control panel for direct readout of an airspeed component. Thus, these auxiliary systems will employ specific airspeed displays.

Generally, the performance accuracy required will be about 1 knot (nautical mile per hour) during the takeoff and landing phases and about 5 knots during the remainder of the flight. For those areas where Mach speeds are utilized, a performance accuracy of about 0.01 Mach will be required. It would appear that instrumentation of the vertical scale type will provide the resolution and accuracy required of these parameters.

Aircraft Rate of Movement Along its Track

This parameter is more commonly referred to as "ground speed" and generally is not displayed in current aircraft. It can be calculated by various navigational techniques (e.g., timing the rate of change of the distance on the distance measuring equipment [DME] or comparing the distance travelled to the time between subsequent fixes).

In the SST, ground speed will be required to assist in providing accurate position reports and time estimates to Air Traffic Control. When some form of Doppler radar navigation is used, ground speed can be readily available to a direct readout instrument. It is anticipated that this parameter will be in a navigational instrument grouping rather than with the basic control instruments, because it is used primarily for secondary calculations (i.e., it is used to assist in making calculations and decisions).

Aircraft Location in the Vertical Plane

In current operations, the altitude is usually displayed on some type of barometric altimeter and is presented in the cockpit via a circular dial with fixed field and moveable pointer. Usually incorporated into the instrument is a digital readout in one thousand foot increments which extends the range of the instrument. This type of instrument is an outgrowth of the three-pointer instrument which was quite difficult to interpret. In most instances the accuracy of the instrument is dependent upon the accuracy of the barometric pressure set into the instrument. In an effort to control the consequences of this error, flight level flying above 24,000 feet is employed wherein all aircraft flying in this region are required to set their altimeters for an atmospheric pressure of 29.92 inches.

Military aircraft, and some of the current aircraft using the newer landing systems, employ the radar or radio altimeters which give an absolute value above the local terrain. Most of these readings are extremely accurate and can be read to the nearest foot. Although not practical for high level flying, the radar altimeter will definitely be part of any all-weather landing system which is being advocated.

The SST will probably employ a barometric altimeter similar to those found in current aircraft. However, the display technique will probably be of the vertical tape indicator type. It would appear that because of the greater vertical freedom which will be allowed the SST, the resolution of the instrumentation will need to be such that the crew will know altitude to within 100 feet. During the landing phase, provisions will probably be made to drive the all-weather landing display with the radar system so that accurate altitude information will be available.

Airway Marker Beacon Passage

While flying the airway structure in current operations, marker beacons are used to pinpoint aircraft location. These beacons are highly directional and passage over them is indicated in the cockpit by a light. It is anticipated that the same type of indicator will be provided in the SST.

Passenger "g" Loading

In current operations this parameter represents the acceleration forces imposed on the aircraft in performing maneuvers. It is usually indicated via a dial type instrument which employs a fixed field with a moveable pointer.

High performance military aircraft utilize a similar instrument, which incorporates provisions for displaying the maximum value achieved during any maneuver (i.e., if a 3 "g" maneuver were performed, the instrument would maintain a record of this maximum value and would continue to indicate instantaneous values).

In current operations, under normal conditions, this is not an important parameter, but in the SST "g" forces must be given more consideration. The higher speeds and the greater accelerations of the SST will have to be considered by the crew before initiating certain maneuvers. Because of its new importance, it would appear that the instrument will take a new position of prominence on the instrument panel. Instrumentation of the vertical scale type is currently available which provides coverage from 0 to 7g. These ranges can be changed to suit the situation.

Fuel Consumption Rate

In current aircraft, fuel consumption rate, or fuel flow, is expressed in terms of pounds of fuel consumed per hour. Usually a dial type instrument is used which employs a fixed field with a moveable pointer. Since this indicator is also an indicator of engine performance, each of the engines is monitored for its specific fuel consumption. As a result, the number of instruments required is equal to the number of engines on the aircraft.

In the SST, indications of the fuel system and its status will be extremely important. Also, since the control of the engines at supersonic speeds will be a function of fuel flow, the resolution of such instruments will need to be such to provide the crew adequate information in all speed regions. It would appear that the vertical scale indicators could again be utilized to provide the needed resolution. It has also been advocated that instead of one indicator per engine, a single indicator could be used which would display the value of the parameter which was most out of tolerance. For example, if four engines were utilized and all were set for about 8,000 pounds per hour ± 100 pounds, any value in excess of this would be indicated, as would the indication of which engine was suspect.

This is one of the areas of repetitive instrumentation which appears to be a suitable candidate for the shared space display technique. In this instance the space saved would be a function of the number of engines. This type of instrumentation concept would alleviate some of the lag associated with scanning a large number of instruments. If a "flight engineer's" position is utilized (i.e., a third crew member), the vertical scale instrument can be used which displays the parameter for each of the power plants. This provides an easy method for comparing the outputs of the systems.

Signal from Ground Navigational Aid Station (Signal Source)

In current operations this parameter is manually set into the equipment by the crew and is usually displayed on navigational equipment control panels. When utilizing the VOR airways, the crew will tune in the appropriate station using airway charts and other preflight data.

In the SST the same requirement will exist when the aircraft is operating within the VOR system. The only provisions for display which are being advocated are the same type of control panel. The military uses a "channelization" concept to some extent, wherein those frequencies which will be utilized are preset and the crew merely selects the appropriate channel.

On-line System Configuration of the Navigation Equipment

This parameter is generally represented by the position of the switches on the navigation system control panel. It is important for the crew to know exactly which navigation signal source is driving the navigational displays. In other words, if the equipment being utilized is the VOR/DME and the ADF the crew should know this so that they can make appropriate judgments.

In the SST, cognizance of the on-line configuration of the navigation system will be even more important. The control panel will continue to provide this information, but some provision for displaying the source of the navigation position fix, (e.g., VOR, LORAN, etc.) on map projection displays is being considered. Because of the inherent errors of the various navigation equipments (e.g., the Doppler radar or the inertial platforms), the crew will require this information in order to evaluate the performance of this equipment and the credibility of the position data it provides.

Indicated Position Fix

In current operations, this parameter is presented via instrumentation which indicates present position relative to some external navigation ground aid. Flying the VOR airways, aircraft are able to position themselves on some specific radial of a known navigation facility, and with the use of either distance measuring equipment (DME) or a bearing from another facility are able to determine a precise fix over the ground. Thus positions are described in terms of radial and distance, or the intersection of two radials when operating in the VOR system. When operating outside of the VOR range, other nativation techniques are utilized which will usually define a line of position (LOP). These lines are plotted on appropriate charts to define a position fix. The use of LORAN or any such hyperbolic navigation system with its corresponding charts provides the same capability.

In the SST, the requirement for more precise position fixing coupled with the time compression brought on by high speed flight generates the requirement for a new display technique of the position fix. For flights within the VOR structure, provisions will have to be made for displaying the same information as is currently available and the same type of instrumentation should be utilized. However, it is felt that such instrumentation should be located in some peripheral area rather than occupy an area of prime importance. It may be possible to incorporate the position fix as an element of the navigation situation display. As described above, the use of a pictorial navigation display will assist in alleviating the problems associated with time compression and the flying of "area navigation" rather than "airway" navigation. Using this display, the crew would require information concerning the aircraft's position relative to some specific coordinate system which is easily interpretable by the crew, e.g., if the aircraft is flying an oceanic flight and is using a standard longitude/latitude reference system, the navigational display should be oriented to correspond to the heading of the aircraft.

Pictorial situation displays are available which provide a permanent log by utilizing an ink plot of track. With this type of system, the crew's task becomes one of "flying" the tracing pen in an effort to minimize deviations from the preplanned track. Whatever system is adopted to display the position fix, provisions must be made for up-dating, e.g., if an internal navigation system is generating a position fix on the pictorial display, the crew should be able to enter an externally-generated fix which differs from that being displayed and be capable of selecting the position considered to be more accurate.

Signal from Ground Navigational Aid Station (Directional Vector)

As mentioned in the section on position fixing, provisions are currently available for displaying in the cockpit the position of the aircraft from a selected ground navigational facility. This display is an integrated one in that the signal from the station (directional vector) is being displayed and this, in turn, defines the position of the aircraft relative to the ground station. In current operations the radio magnetic indicator (RMI), or a similar instrument, provides the indication of the ground signal. In addition, the DME readout indicator provides slant range information when available.

When utilizing an external source, the SST will require provisions for displaying the position generated by the signals. It is likely that the RMI and the DME readout will continue to be the display technique utilized. The pictorial navigation display also will have provisions for displaying any position fix obtained from an external source and for indicating the type of ground source generating the signal (e.g., VOR/DME, ADF, etc.). As mentioned previously, this type of navigation will be of secondary importance and the location of such instrumentation should be selected with this in mind.

Aircraft Aerodynamic Center Relative to the Center of Gravity

In current operations, the consideration of the shift of the aerodynamic center is of small importance. Devices such as Mach trimmers compensate for the effect accompanying subsonic speeds. However, except for an indication that the Mach trimmer is functioning, no indication is provided to the crew on the position of the aerodynamic center relative to the center of gravity.

In the SST, the shift caused by high-speed flight will be of greater concern to the crew and will have to be displayed in the cockpit. The main disadvantage of such a shift is the requirement for changes in trim to compensate for the movement. This, in turn, causes a considerable increase in trim drag.

The Concorde will utilize a shift of the internal fuel to offset the change in the aerodynamic center, but this shifting technique is not being advocated by U.S. designers. However, some automatic system will be selected in the final design to compensate for this characteristic of high-speed flight and the crew will need a display of the location of the aerodynamic center relative to the center of gravity. This display will be used to monitor the automatic system and, in the event of malfunctions, to manually maintain the desired relationship.

Total Fuel Remaining

In current aircraft, the status of the fuel system is usually presented in terms of the specific amount of fuel in each of the individual fuel cells and summed readout of total fuel remaining. The instrument used is usually of the dial type with the fixed field and moveable pointer. The only change envisioned for the SST appears to be the proposed use of vertical scale indicators and, perhaps, a preprogrammed fuel schedule to compare with the actual fuel remaining. The fuel use schedule would allow the crew to compare the actual fuel remaining to the preplanned value at any time during the flight. The significance of this parameter may also be displayed. For example, with a given amount of fuel remaining, the remaining range of the aircraft or the alternate airfields within the range of the aircraft may be displayed. This additional display of the implications of this parameter is an example of the type of data which is amenable for presentation on a general purpose display.

Status of Fuel Reserves

This parameter is usually not displayed in current aircraft; it is inferred from the navigation calculations which are periodically made throughout the flight. In general, check points are used to determine a fuel "howgozit," and any fuel consumption over that which was planned is analyzed in terms of economics and safety. Many factors need to be considered when judging the status of the fuel reserves. Generally, required fuel reserves are computed during flight planning and represent that amount of fuel which is sufficient to comply with Federal regulations and to allow sufficient margin for safety.

The SST will be very fuel sensitive, and as a result, the crew will require continuous information on the fuel profile and the implications of any large deviations. It would appear that the use of some manually selected value in the total fuel indicator would provide this information. If the fuel utilization were to exceed some predetermined amount, the indicator would show the implications on the fuel reserves. On a pictorial navigation display such as the one proposed by the Hughes CEMS concept, a fuel range circle is utilized, with another circle indicating the additional capability provided by the fuel reserves.

Aircraft Fuel Storage Distribution

This parameter represents the fuel quantity stored in the various fuel cells which make up the fuel system. Since many of the current aircraft utilize a manual sequencing to maintain a specific center of gravity configuration, the crew requires information on the location of the fuel on board. The indicators generally used are dial types, indicating the amount of fuel remaining in each of the available fuel cells. At the present time, the fuel system status panel is positioned on the flight engineer's panel, and usually consists of individual indicators laid out in schematic form representing fuel flow through the system. Lights are used to indicate the status of sequencing valves and the various boost pumps utilized by the system.

The SST will utilize a completely automatic fuel sequencing system, and as such, the crew should not have to concern itself with the maintenance of any specific center of gravity configuration. It would appear, however, that information concerning the distribution of the fuel must be available so that the crew can adequately monitor the performance of the automatic system. In most cases, fuel systems attempt to keep the weight along the longitudinal axis of the aircraft i.e., fuel is used from the outboard tanks first and then moves consecutively inward. The use of vertical scale indicators, arranged to correspond to the location of fuel cells, would enable the crew to readily determine the fuel sequencing situation.

Aircraft Fuel Profile

This particular parameter is not displayed in the cockpit of current aircraft. During preflight planning, a fuel schedule is generated which is used throughout the flight to evaluate actual fuel consumption.

In the SST, it is anticipated that fuel consumption will be such an important factor in the economics and safety of the aircraft that an indication of this parameter should be continuously available. Preprogrammed, or instantaneously generated fuel profile data could be fed directly either to the fuel flow meters, or to the amount of fuel remaining indicator to provide the information concerning the fuel scheduling. It might be appropriate to make this parameter available on a "storage and retrieval" type of display wherein a computer would generate a display showing the implications of varying this particular parameter. This display would enable the crew to see the effect of altering the fuel schedule on such factors as the overall time of the flight, the economics involved, and fuel reserves on arrival at destinations.

Aircraft Velocity Schedule

Crews in current subsonic aircraft use aircraft performance tables and graphs to select an optimum velocity schedule for the type of flight that is being flown. This usually includes the airspeed for the climbout, for the cruise, and then for the descent. These will vary as a function of the length of the flight, atmospheric conditions, ATC restrictions, type aircraft, etc. In most cases the crew utilizes a very gross velocity schedule which they develop during preflight planning. The only display of this parameter in the cockpit is the notation made on the flight plan.

The navigation concept for the SST is such that an optimum velocity schedule will be generated continuously and this data will be fed into the autothrottle system to provide the optimum velocity. If the crew is inserted into the control loop, they would take the optimum velocity schedule provided by the profile generator and then manually insert this data into the autothrottle system, or they could manually fly such a velocity profile.

An additional display element on the airspeed (Mach) indicators, either driven by a computer or manually set by the crew, could be used to indicate the desired or commanded velocity. For example, a moveable pointer which would provide a delta velocity between actual and desired velocity might be used. If for any reason the optimum profile generator were to malfunction, a storage-retrieval display might be used to provide data similar to that utilized by the crew in current preflight planning.

Ambient Temperature

This parameter is displayed in current aircraft via a dial type instrument with a fixed field and a moveable pointer. In most cases the measurement dimension is degrees Centigrade, and covers a wide enough range to include the operating environment of the aircraft. It is used primarily for correcting airspeed calculations in certain navigation techniques. It is also used during the takeoff phase to ascertain that conditions have not varied appreciably from those used in calculating the takeoff roll and the various takeoff speeds.

In the SST, the main reason ambient temperature will be provided to the crew is to enable them to monitor the output credibility of the various automatic control systems which are influenced by deviations in temperature. The fuel system is an important example of this; if fuel flow rates appear higher than anticipated and a higher than anticipated ambient temperature is indicated, the crew could then accept the output of the automatic system as being reliable.

It would appear that the use of a dial type of instrument in the cockpit of the SST would fulfill the information requirements of the crew. Since this information parameter is used primarily to assist in making evaluations, the instrument can be in a secondary location, i.e., in a peripheral area. If the SST is equipped with a temperature-seeking sensor which provides information on temperature gradients well in advance of the aircraft so that the SST might be maneuvered to take advantage of such temperatures, then the crew must be provided with an indicator displaying the location and distance of such temperature gradients. If, because of the time compression of high speed flight, the crew is unable to utilize this data, it would appear that such information could be fed directly into the navigation equipment (e.g., the optimum profile generator) to assist in obtaining a truly optimum profile. The implications of such a capability would include savings in fuel due to optimizations of the acceleration schedule (e.g., if the temperature were more favorable at some distance along the profile but still within the acceleration corridor, then the decision might be made to delay the acceleration to take advantage of the fuel savings and the possible reduction in the sonic overpressures.

Turbulence

Instrumentation has not been perfected as yet which will predict the occurrence of turbulence. Research is continuing in an attempt to develop a sensor to provide this capability. However, the only method available to aircrews today is through association with certain types of weather phenomena. Crews flying in areas marked by certain weather conditions can predict with some accuracy the presence of turbulence; however, there is no way to pinpoint the turbulence. As a result, the crew is unable to take any precautionary steps until it is actually encountered.

When the SST is introducted into the commercial field, it is hoped that a suitable sensor will have been perfected which will provide the crew with sufficient information in sufficient time to maneuver around such turbulence. The development of such a sensor will then be coupled with a suitable display technique to provide this information to the crew. Generally, weather parameters sensed by internal sensors will be displayed on the weather radar or can be inferred from the information displayed on the scope. Turbulence will be associated with certain types of weather build-ups and with specific temperature and wind gradients.

Precipitation--Clouds--Weather Front Activity

Information on these three parameters is currently obtained by visual reference from weather briefing charts or cross-sectionals, and from the weather radar. In general, the weather situation is presented symbolically or as a radar return. The crew must interpret the situation, estimate the severity of the weather, make judgments as to the implications upon the flight, and finally make appropriate decisions as to any changes that must be made to the flight as planned and cleared.

The SST will be operating in an environment about which only sketchy meteorological data is available. This, coupled with the fact that the SST will be quite sensitive to many of the weather parameters, makes this an important area. The use of the weather radar will continue into the SST era with much the same interface that is utilized in today's aircraft. The range of the sensor will probably have to be extended in order to give the crew sufficient time to evaluate the weather situation. In this connection if data link is utilized to provide the latest weather information via ground stations, and if provisions are made for some type of hard-copy printout of this information, it would also appear feasible to provide for a printout of facsimile weather charts. It should be noted that the display of weather parameters is predicated upon their importance for any particular flight. It is assumed that during those periods of operation where the weather is marginal, more dependence will be placed upon the use of this information.

Radiation Level

At the altitudes flown by current aircraft, radiation levels do not represent a significant safety consideration. However, as the operating altitudes increase and the density of the air decreases, the hazards of radiation exposure begin to pose a threat to health and, therefore, must be monitored and given the same consideration as any other safety hazard. In scientific laboratories, various dosimetry methods are employed in the recording of exposures to radiation. Although available data indicate that the crews will not be exposed to excessive doses of radiation, it may be necessary to maintain a record of each crew member's total exposure. Standards can then be established which would limit the flight time of any crew member who has exceeded some cumulative value.

Generally speaking, flare-ups in the known radiation level can be predicted sufficiently in advance to enable the SST to descend to a lower and safer altitude. The main use of radiation level monitor will be to provide the crew with some indication in the event that the other means of ascertaining increases in radiation levels were to malfunction. The use of a vertical scale indicator would meet requirements for the display of this parameter. In most instances, monitoring will probably be automatic, and would indicate safe, marginal, and dangerous areas. If this is a completely automatic monitoring task, some type of alarm excitation should be provided to indicate that levels are reaching marginal values. If this alarm is provided, the instrument need not occupy a location of prominence.

Estimated Magnitude of Shock Wave at Points Directly Beneath the Aircraft and Along the Dispersion Pattern

This parameter is peculiar to supersonic flight and is not a consideration in subsonic aircraft. As yet, a method of calculating the exact magnitude of the sonic overpressure has not been perfected, but it is felt that by the time the SST is introduced into commercial aviation accurate means will be available for estimating this parameter. Because of the legal implications and the restrictions placed upon the SST by the FAA, all flight profiles must comply with the overpressure limitations.

The crew of the SST will have the capability of manually flying the SST, but in most instances will be monitoring the performance of the automatic systems. Since one of the constraints placed on the SST is the control of overpressure, it is necessary for the crew to know exactly what kind of overpressure envelope is being flown. The instrument might be graduated in pounds per square foot and could utilize a fixed field with a moveable pointer. It would seem that during the supersonic phase of the flight, the crew would require placement of the instrument in the basic grouping of the flight instruments. Since the overpressure or magnitude of the shock wave is, for the most part, a function of the velocity of the aircraft, it would appear that the instrument should be placed in the general area of the Mach indicators.

Predicted Magnitude of Shock Wave at Points Directly Beneath the Aircraft and Along the Dispersion Pattern, Over the Remainder of the Supersonic Flight Phases

This differs from the preceding parameter in that it is a predicted estimate rather than an instantaneous estimated value of the overpressure. This parameter stems from the type of navigation system being advocated for the SST and from the unusual characteristics of sonic overpressures. Generally, sonic overpressures are affected by the characteristics of the aircraft, the speed of the aircraft, the density of the surrounding air, the temperature, prevailing winds, etc. Since the navigation system will perform an automatic optimum profile generation function, it should also be able to ascertain the overpressure envelope which will be generated by flying such a profile. Since the various weather parameter sensors will be fed directly into the navigational computer and a commanded flight profile is being generated, this data can be utilized by the computer to provide estimates of the ground overpressures that would be generated. This parameter can be displayed qualitatively, e.g., ACCEPTABLE/ UNACCEPTABLE. It may be feasible to integrate this display with the previously discussed parameter as a display element representing acceptable and unacceptable ranges of values.

Operating Condition of Associated Navigation Equipment

Unless a major component of the navigation system fails, the only indication of an unacceptable system would be an evaluation by the crew. When an electronic device malfunctions, a warning device is typically used to warn the crew that the equipment is no longer furnishing credible information. For example, the distance measuring equipment indicator is usually shielded or the mileage will not lock at any particular value. The crew must then perform specified logical procedures to ascertain if the airborne equipment has failed or if the ground station is malfunctioning.

It is assumed that the SST will utilize the same type of warning devices as those currently used to warn the crew that the equipment driving the various navigation displays is outside predescribed tolerances. Such devices as warning flags, shields, unlocking of pointers, etc., are presently used, and will continue into SST instrumentation.

Source of External Signal

This parameter is similar to that described as the "signal from ground navigational aid stations" and is included because of its relationship to the new pictorial navigation techniques which are being advocated. In the SST, area navigation will be used and, for the most part, the position fix displayed on the pictorial charts will be generated by the internal navigation equipment. Because of the inherent errors in different types of navigation equipment, however, provisions to up-date this equipment are being provided. In the most automatic mode of operation, it appears that the navigation computer could be programmed to take an external fix when within range of a suitable site and then display this information on the pictorial display. The crew could then evaluate this externally generated position against the internally generated position to determine if any equipment up-dating were necessary. However, in order to make competent decisions, the crew requires information concerning the source of the external signal (e.g., the type of source, the location, etc.). This parameter can be displayed as an element of any pictorial display and would be in the form of a readout which would indicate LORAN, VOR, etc. It also seems that the position of the source would be indicated on the reference charts.

Externally Derived Position Fix

This parameter is also related to the concept of a pictorial navigation display and the concept of completely internal or self-conformed navigation systems. As has been mentioned many times previously, the navigation display will, for the most part, be driven by the internal navigation system. Thus, the position of the aircraft at any instant will be a function of the internal system generating that position. However, because of the inherent and sometimes insidious errors found in the different types of navigation equipments, provisions must be made to check the validity of the equipment output. This will be accomplished by obtaining an externally derived position fix, comparing it with the position derived by the internal system, and resolving any deviations.

When an external position fix is obtained, it can be projected on the pictorial display, or pen marked by the position indicator. When the sources to the pen are changed, the deviation (resultant) will be an indication of the amount of error which must be resolved. Since this is a periodic type of performance, it is logical to think in terms of sharing the position indicator pen or element. Of course when the pen is being driven by the external source, this mode of operation would be obvious to the crew by the readout of input source.

Updated Position Fix

This is another parameter which indicates,primarily, the operation of the pictorial display, e.g., if the display is being driven by an internal system and an external position is subsequently displayed and accepted as being the more accurate, there must be a visual indication that the internal system has received the data inserted by the crew and that the indicated position of the aircraft is the most accurate position to use as a basis for further position fixing. In terms of display techniques, this might be indicated by a shift of the indicator pen from the last internally generated fix to the position of the externally generated fix, and then a continuance of the flight record from that point.

Estimated Time of Arrival (ETA) at Destination Terminal and/or Any Way Point

Since Air Traffic Control procedures control traffic in all dimensions, time increments are used to provide sufficient longitudinal separation. Thus, in the filing of the flight plan, specific points are designated as reporting points and, in most instances, time estimates to these points are required. ATC will then add these times to the takeoff time in order to arrive at the time the aircraft should be at a specific location. In current operations the crew determines the estimated time enroute for each leg of a flight and is then able to determine the estimated time of arrival at the various reporting points. The crew may maintain these figures on their flight plan and up-date them as necessary during the flight. Deviations are determined by comparing actual time of arrival (ATA) to the ETA. In current operations if this deviation is expected to be more than 3 minutes, a revised clearance will have to be obtained from the controlling ATC facility.

In the SST, this function may be automated and the crew would then be provided with a continuous readout of ETA at any preselected point or set of coordinates. This indication can be in the form of either the actual time that the fix is anticipated (e.g., so many minutes past the hour) or in terms of minutes to go. It would appear that this particular indicator could occupy a location on the periphery of the instrument panel, probably near the clock.

Deviation of ETA's from Flight Plan Estimates

This parameter was partially described above as the deviation between the estimated time of arrival and the actual time of arrival. During preflight planning, the crew computes the estimated time enroute for the various legs and this is filed as a part of the flight plan which is authorized by Air Traffic Control. Once airborne, however, the crew recomputes ETA's on the basis of actual weather conditions and compares these to the precomputed values. If the resultant deviations are in excess of 3 minutes, the crew must notify the ATC facility controlling them. In current operations, neither the preflight generated time estimates nor the airborne computed values are displayed in the cockpit.

In the SST it is anticipated that the generation of ETA's will be an automatic function predicated upon the optimum profile generated. Therefore, it would appear that preflight computed values would be entered into the computer prior to the takeoff or into the ETA indicator to serve as a comparator to the automatically generated values. Thus a continuous display of the agreement of the two values is indicated, with the time differential being the important factor. In the SST this increment of time will probably have to be kept to within about 1 minute. Any larger deviation will probably require notification of the controlling ATC facility.

Optimum Flight Profile Based on Preflight Planning

In current operations this parameter is not displayed and usually is inferred from the flight plan. The crew will prepare the flight so as to comply with existing climb-out instructions and with local ATC restrictions and terrain obstructions. Generally, although climb speeds are developed, the crew is more concerned with concurrent horizontal navigation and altitude schedules. In some cases ATC will require that the aircraft be at a particular altitude prior to crossing some point, or that it remain below some altitude until reaching some point, but in general the climb schedule is predicated upon the capabilities of the aircraft.

In the SST, separation (and thus navigation) in the vertical plane will take on a new role. The crew will be required to meet ETA's in three-dimensional space. Thus, it would appear that the crew would require some commanded vertical scheduling, and that this can be either that which is generated prior to the flight, or that which is generated as a portion of the optimum profile.

The instrumentation required can be integrated into the vertical vector (rate of ascent/descent) display, and could be in the form of a commanded rate of climb or descent. Provisions would be provided for switching the source of the commanded signal from either the preflight computed values or from the optimum profile generator.

Optimum Flight Profile Generated During Flight

Current operations do not have provisions for automatically generating an optimum profile. Airborne navigation and recomputation of flight profiles is manually performed by the crew. This usually will occur if weather conditions are appreciably different from those which had been predicted.

In the SST, it is anticipated that an optimum profile will be automatically generated and drive other systems of the aircraft such as the flight control system and the autothrottle system, and the chief role of the crew will be to monitor the output of the system. As indicated previously, the preflight calculated track of the aircraft would be continuously displayed on the pictorial navigation display so as to present the horizontal navigation picture. The vertical component of the desired profile would be fed via a commanded altitude pointer to the altimeter and the rate-of-climb indicator. In most cases it would appear that the major changes to preflight planned profiles will be in the vertical profile, thus excursions from the preplanned track would be small. However, the crew will still require information on the intended track of the aircraft as generated by the optimum profile computation. It would seem logical to assume that some type of projection would be used which would present the desired track as generated by the navigation computer. In this way the crew would be aware of any large deviations from the original track, and could then decide if the equipment is correct. Without this provision, the crew would have to accept the output of the generator.

The display technique which probably will be utilized will have elements in both the vertical scheduling display and in the horizontal situation display. It would appear that a moveable pointer to indicate the commanded altitude could be used. As an alternative, the crew could be provided with controls for call-up of a projected trajectory on a storage and retrieval type of display. This call-up could be a dynamic projection which would change continuously to provide the optimum profile.

Situation Assessment Data

The data presented found in the aircraft operations manual and which is typically used during preflight will also be required in the cockpit of the SST to assist in making judgments and decisions. In current operations, the crew must refer to the manual and use a variety of charts optimized for particular parameters in order to make their decisions. This can be a time consuming task.

In the SST, the crew will require this information, but will not have time to make the same calculations. It appears, then, that a navigation computer or some sort of separate off-line computer will be necessary to provide the crew with a means for obtaining the required data. The display technique has been introduced previously as the storage and retrieval display. If the navigation computer cannot handle the data requirements of the system, the use of a small computer to assist in situation assessment should be seriously considered.

Aircraft Passage over ILS Marker Beacons

In current operations, provisions are made for displaying passage over the outer and middle markers on an instrument landing approach (ILS approach). These marker beacons are highly directional signal generators which trigger receivers in the aircraft and, in turn, illuminate indicator lights in the cockpit. In most cases the outer marker is indicated by the use of a blue light, and the middle marker by the use of an amber light. The only change envisioned for the SST will be the addition of a runway threshold marker beacon. An additional indicator will be necessary for passage over this beacon.

Aircraft Deviation from Glide Slope

This parameter is an extension of the parameter describing flight path deviations and excursions in the vertical plane. In this particular phase of the flight the aircraft is following an electronic beam rather than a predetermined vertical schedule or an automatically generated optimum profile. Deviations from the beam must be displayed so that the crew can make any appropriate corrections. In current operations, this parameter is displayed in several ways; e.g., flight director commands indicative of the position of the aircraft in three-dimensional space and a course deviation indicator which provides a dot deflection above or below the desired glide path angle.

The SST will probably utilize instrumentation similar to that found in current aircraft. In addition, the use of a projected landing display will assist the crew in keeping ahead of the all-weather landing system. A description of this display is provided in section 8.0. In general, it is assumed that the flight director and the horizontal situation indicator (HSI) will continue to incorporate the aircraft's position relative to the glide slope as one of their display elements.

Proximity of Aircraft to Flare Initiation Point

In current operations the crew initiates the flare by external visual reference and there is no need to display this parameter. If the weather is such that the runway cannot be acquired visually prior to reaching established minima, a missed approach must be executed.

In the SST, the flare and decrab maneuvers are expected to be automatic functions which will be monitored by the crew. Because of the criticality of this control function, the crew will require as much information as possible on its performance so that manual control can be assumed if necessary. All-weather landing systems for the SST are expected to be completely automatic and capable of controlling the landing through the rollout. The feasibility of the concept has been demonstrated, but acceptance of the system by the crew will be an important consideration in its effectiveness. To assist in establishing positive acceptance, it is logical to assume that the crew will be provided with new types of landing displays which will enable them to stay ahead of the automatic system and permit an easy transition to visual conditions. In almost all cases the display technique advocated is some form of heads-up display. Generally speaking, the proximity of the aircraft to the flare initiation point will be a part of the radar altimeter system. The command to flare will be in the form of a specified altitude or of time-to-go in seconds to initiate the flare maneuver. If the pilot is in the control loop during the all-weather landing, the flight director could be provided with signals from the glide slope receiver and the radar altimeter so that as a specified point in three-dimensional space is approached, changes in pitch attitude would be commanded which would correspond to the optimum flare maneuver.

Pitch Angle

The presentation of pitch angle will be presented in much the same way as it is displayed currently. The gyro system provides the necessary platform from which to obtain deviations around a three-coordinate system. The attitude gyro displays currently utilized have various modes of operation and usually incorporate a command element which is driven by the navigation computer. Thus, for the most part, the pitch is presented via an integrated type of instrument, i.e., it is combined with the other attitude parameters to provide a coordinated picture of the aircraft's attitude with reference to the stabilized platform.

There is no reason to suspect that this presentation will change in the SST. If such new presentation techniques as the contact analog display are adopted, a pitch angle element will be incorporated into the visual presentation employed. Pitch angle is expected to assume a more important role in the vertical navigation of the SST and provisions will have to be made for a more exact indication of this parameter. At Mach 3, flight path deviations for any angle of pitch will be four times as great as at Mach .8.

Roll Angle

In current aircraft roll angle is presented via the gyro-stabilized attitude instrument and this same type of instrumentation is expected to be used in the SST. With the advent of the SST, it is hoped that the necessity for large high-speed turns will be eliminated, both because of the airspace requirements and the comfort of the passengers.

Unless an entirely new concept of attitude presentation is accepted, the use of the conventional type of attitude indicator will fulfill the requirements of the crew. It is anticipated that the integration of new information elements into the attitude instrument will assist in alleviating the cluttered instrument panels. These elements will probably include rate-of-turn information, yaw information, and perhaps, directional information. In the event that a contact analog type of display is used, a display element for roll angle will be incorporated.

Yaw

In current aircraft, yaw is presented as an unbalanced situation rather than a specified number of degrees of deviation. In the SST the crew will require the same display of yaw deviation with reference to a null point. Although commercial instrumentation utilizes a separate indicator to present yaw and rate-of-turn, military instrumentation has integrated this indicator into the basic attitude instrument.

Position of Flaps and/or High Lift Devices

In current aircraft, flaps are used to increase the L/D ratio of the wing during specific phases of flight. These devices are usually preset during the design of the aircraft, and the crew merely selects one of several positions along the continuum. In most cases the controls consist of a control lever and several detents which correspond to specific angular deflections of the flaps from a reference position and a flap position indicator is provided on the panel.

In the SST it is anticipated that the same provisions will be available (although they are only used at subsonic speeds). In the case of the Boeing design, it is also anticipated that the position of the variable incident wing will be displayed in essentially the same manner as the position of the flaps is now displayed. The use of a dial type of instrument with a pointer appears to satisfy the requirements for the display of this parameter.

Elevator Control Tab Position

In current operations the pitch of the aircraft is controlled by the movement of the control column and the subsequent movement of the elevator control tabs. This movement of the control tabs results in the necessary pitch changes. Although the amount of actual pitch is a function of the speed of the aircraft, the amount of travel of the control tabs is a fixed value. However, at any specific speed some angular deflection of the control tabs will result in a specific amount of pitch. In current operations, the amount of movement of the control tab is expressed as degrees of travel in either the UP or DOWN position. This then allows the crew to monitor the present position of the control tab.

In SST operations, the same parameter is required and there seems to be no need to introduce new concepts of presentation for this particular parameter. The main reason for the display of this parameter is to monitor the operation of the flight control system, especially in the automatic mode of operation.

Aileron Control Tab Position

In current operations the wheel on the control column positions the aileron control tabs which in turn produces a specific amount of aileron deflection for turns. The crew uses another control to eliminate any unwanted roll in the aircraft and, in some instances, to maintain level flight in turns. This is usually accomplished via an aileron trim control wheel located on the center pedestal. Rotation of the wheel from its centered position results in some specific amount of RIGHT or LEFT trim and this is indicated in degrees.

In the SST, the same type of presentation should suffice for the manual mode of operation. During periods of automatic control, provisions will have to be made for displaying the trim condition or control tab position for all three major axes of the aircraft. This information is already available in current aircraft when the autopilot is engaged. The amount of aileron on control available to the crew is indicated by the stops on the control wheel.

Rudder Control Tab Position

Aircraft yaw is controlled partly by the use of the rudder controls to position the rudder control tabs which in turn displace the rudder. The amount of deflection of the rudder pedals dictates the amount of available control, i. e., full deflection of a rudder pedal represents the full control in that particular direction. The amount of control tab desired can be set manually via the rudder pedals and maintained by setting a rudder trim control which is usually situated on the center pedestal. This control is graduated in degrees of LEFT or RIGHT deflection. When the autopilot is engaged, the trim in this axis is also displayed so that when the crew overrides the system, they know the trim status of the aircraft.

The SST will utilize the same types of displays and controls as are currently used to maintain the directional control in the yaw axis. The display of rudder trim condition during automatic operation is a requirement, and it seems likely that the use of indicators similar to those currently found in subsonic aircraft will be sufficient.

The power plants of the SST will be located as close as possible to the longitudinal axis of the aircraft, so that in the event of an engine failure the amount of adverse yaw will be kept to a minimum. Provisions are being made for controlling large yawing forces automatically, but it will also be necessary to display some indication that an unusual yaw condition exists. This probably will be shown via the trim status indicator as an extreme rudder trim condition.

Position of Landing Gear

The position of the landing gear is currently represented by the position of the landing gear control lever and by indicator lights. In some aircraft there is also an alarm system built into the aircraft, so that if the aircraft is alowed to approach speeds and the landing gears are not in the correct position, an audible alarm will be sounded. The SST will incorporate similar systems to indicate the position of the landing gear. In most instances the gear handle and a series of lights will be used to show the status of the landing gear.

Brake System Hydraulic Pressure

In current aircraft, a separate indicator is used to indicate the pressure in the hydraulic reservoir connected to the braking system. This indicator is in addition to the normal indicators used to present information on the status of the entire hydraulic system. The actuators are usually coupled to the rudder pedals so that by depressing these levers and observing the indicator the crew can determine that pressure is available in the braking system. Prior to takeoff or landing the crew must know that the braking system is working properly. The SST will employ similar indicators in the display of this braking system information.

Autopilot Status

This parameter refers to the operating condition of the system. Preprogrammed tolerances set the limitations on the control movements of the autopilot and a command for performance outside this envelope would illuminate a malfunction light. In most current aircraft, this condition is indicated by a light.

The autopilot of the SST will be slightly more sophisticated than present day systems, but it is felt that the use of a single light to indicate the status of the system should be adequate. Once the crew is alerted to a possible out-of-tolerance condition, they can call upon additional information to fully evaluate the situation, and perhaps to isolate the malfunctioning axis of the system. Since the autopilot will be performing the majority of the flight control functions during the enroute portion of the flight, and because the crew's attention is centered primarily on the forward panel, it would seem logical to locate this indicator light on the forward panel. In most cases it has been found that the location of these warning lights should be along the rim of the instrument panel.

Autotrim System Status

The autotrim system can be considered a subsystem of the autopilot system, in that during the automatic mode of operation the required amount of trim will be set into the system. As stated before when discussing the trim systems, the crew requires information on the amount of control being applied, even in the automatic mode of operation. The indicators which show the relative position of the trim control tabs will satisfy this requirement. The SST will utilize the same type of indicators.

Autopilot Mode of Operation

Autopilot mode of operation is obtained in most cases by reference to the control panel for the autopilot. Since most autopilots incorporate the split axis control feature the crew can use either the entire system or a selected axis of operation.. Depending upon the design of the control panel, the position of switches on the control panel or controls on the control wheel will indicate mode of operation. In addition to these indications, "disengaged" warning lights are provided to give alarm in the event of a malfunction in the system.

The SST will require an even more sophisticated autopilot system, but the controls should be quite similar to those found in current aircraft. It would appear that the primary information required is that the system is operating normally, and that in the event of a malfunction the crew is alerted to the situation. At that point, additional information could be retrieved to identify the out-of-tolerance condition. The primary utilization of this information is to maintain cognizance of the system and the amount of control available.

Landing Gear Limits

Placards are used in current aircraft to present suitable information on the operating limitations of the landing gear system. These limitations are usually presented in terms of restricting airspeeds, and provide the crew with suitable guides to the operation of the landing gear. This particular information is used during very specific and discrete time periods and the nature of the information is such that no changes in format are foreseen for the SST. The preferred placement of this placard is in the immediate vicinity of the landing gear handle to assure consideration of established limits when the gear is operated.

Flap Operation Limits

As in the case of the landing gear, placards are currently used to display limitations on the operation of the flap system. In most cases these restrictions are dictated by structural limitations and are usually presented as some function of the aircraft's airspeed. The SST will utilize a flap system to assist in obtaining desired low-speed aerodynamic characteristics. Since the controls for the system will be similar to current aircraft, it is anticipated that the use of the flap operational limit placard also will be similar. In the event that a variable incidence wing design is selected, any limitations concerned with its operation should also be included on this placard since the varying of the wing sweep will have to be closely coordinated with the flap control. The placard should be placed in close proximity to the flap handle.

Status of the Automatic Inlet Duct Configuration System

This particular parameter is not displayed in current subsonic aircraft. Since it is a status indicator, it probably should be of the warning type used to indicate the status of such systems as the autopilot and the autothrottle. It is anticipated that the placement of these indicators will be along the upper edge of the forward panel where they are accessible to both the forward positions. Illumination of these indicators will signal that the positioning of the shock wave in the inlet duct with respect to the axial velocity of the airflow to the power plants is out-of-tolerance.

Status of the Automatic Fuel Control/Exhaust Nozzle System

This parameter is also one which is peculiar to supersonic flight and is not a current display requirement. A GO/NO GO type of indicator is considered adequate for this parameter. This indicator should be placed on the forward panel in the vicinity of the fuel indicators and the engine performance instrumentation. This placement is suggested because of the change in control envisioned for the supersonic power plant, i.e., by regulating the fuel and the area of the exhaust nozzle.

Axial Velocity of the Air Flow to the Power Plants

The supersonic transport will introduce a new concept of engine air flow control wherein the performance of the automatic inlet duct configuring system will be indicated by the axial velocity of the air flow at the lip of the power plant compressor. In order to obtain efficient operations, this air flow velocity must be subsonic. The use of a graduated indicator would appear to provide the optimum display of this parameter. Depending upon the design of the aircraft and the power plants and inlet duct reconfiguring system, the axial velocities could be specified. A range of values could then be designated as safe, marginal or dangerous regimes. If the velocity of the air flow varies from the optimum, the crew will require some estimate of its actual value so that the appropriate decisions and evaluations may be made.

The placement of this instrument probably should be adjacent to the indicator for the automatic inlet duct configuration system.

Exhaust Gas Velocity

The automatic reconfiguring of the exhaust nozzle provides the means for regulating the velocity of the exhaust gases. Since the uncontrolled expansion of the exhaust gases to ambient conditions results in additional drag and a reduction of the efficiency of the system, it is essential that the exhaust nozzle be optimized for the speed regime of the aircraft. Since this control function is expected to be automatic, the information required by the crew will be limited to an operating status indication. However, if a malfunction is indicated, then additional information would be required to fully assess the situation. In some cases where the performance of the automatic function may be outside the tolerance envelope programmed into the alarm system, the actual performance of the system may be tolerable when evaluated against all other alternatives. To determine this, quantitative information would be required. This type of information may be made available on a general-purpose type display when requested by the crew.

Automatic Throttle System Status

An automatic throttle system will be employed to maintain specific velocity schedules and, when integrated with the navigation system, will provide almost automatic flight. As a result, the crew will first require information on the operational status of the equipment (ENGAGED/ DISENGAGED), and then will monitor its performance credibility through other aircraft performance parameters. It is envisioned that the status indicator will be similar in design to that described for the autopilot, and that it will be placed in the same relative position on the forward panel.

Inlet Compressor Speed of Rotation (N_1)--Exhaust Compressor Speed of Rotation (N_2)

These two parameters may be combined when describing the display requirements since they utilize the same display techniques. They are also used together in obtaining a measure of the performance of the power plants. In current operations, the speed of the compressor is indicated in percentage of the optimum speed of rotation of the turbine shaft. Currently, these parameters are displayed via dial-type instruments which contain two pointers and two scales. The larger pointer gives the gross indication of the percentage, and the smaller pointer utilizes a units scale to give a more accurate indication of the systems output.

The SST will utilize a similar system to regulate the output of the power plants in the subsonic speed regime. However, during supersonic flight the engines will be operating at maximum RPM, and the output of the power plants will be regulated by contolling fuel flow to the engines. Even so, a display of these parameters is considered necessary since during the subsonic portions of the flight the crew will employ the same means currently in use to regulate the output of the power plants. Also, during the supersonic speed regime the crew will require information on the speed of rotation of the engines.

Although the normal type of dial instrumentation could be utilized, the use of the vertical scale indicators is recommended. The presentation is clearer, and the space requirements of the instrumentation would be less than that required for the conventional instrumentation. The position of this instrumentation should be on the forward panel, placed so it can be shared by both of the pilots. It would appear that the location of these instruments on the panel just forward of the power plant controls would be consistent with these requirements.

Engine Exhaust Temperature

In current operations, engine exhaust gas temperature (EGT) provides information on the performance of the power plants. The indicator used is a dial type which employs a pointer on a fixed field. During different phases of the aircraft's operation the crew must ascertain that specific temperatures are not exceeded. It is also possible to detect trends indicating that an out-of-tolerance condition is about to occur and thus enable the crew to anticipate a hazardous condition.

In the SST the same requirements will exist and, in addition, the control of the power plants in the supersonic speed regime will probably be based on obtaining some specific exhaust gas temperature. Since an indicator is required for each of the power plants, it is recommended that the vertical tape indicators be used to display this parameter. The space required would be less, and the reading of the parameter value would be more precise. Also, since a common line of reference can be used, an abnormal indication is readily detected.

Quantity of Lubricant for Power Plant System

Currently, the lubrication system for the power plants is considered an integral part of the power plant system. Parameters indicative of the status of this system are thus considered to be as important as engine performance parameters. The quantity of lubricant in the system, is currently displayed on a dial-type indicator with a fixed field and a moveable pointer. This parameter is displayed continuously and can be located either on the main panel with other lubrication system instruments and warning lights or on a flight engineer's panel.

Undoubtedly the information concerning the status of the lubrication system will continue in importance with the SST, however, continuous display may not be necessary. Other parameters indicative of the status of the lubrication system (e.g., pressure) are also available during the flight.

Temperature of the Lubricant

This parameter is also indicative of the status of the lubrication system and is presented in current aircraft on a dial type of instrument utilizing a moveable pointer and a fixed field. This instrument has been moved from the forward panel to the flight engineer's panel and is considered to provide secondary information on the status of the lubrication system.

In the SST, the need for this information will continue to exist. It will also continue to be of secondary importance and should be displayed only when demanded on the crew.

Pressure of the Lubrication System

This parameter is the most important indicator of the status of the lubrication system. In current aircraft, two indicators of the system's pressure are used. A warning light on the forward panel is used to indicate a low pressure condition and a dial type of indicator on the flight engineer's panel provides a quantitative readout. This method of display appears to be suitable for SST requirements. However, the quantitative readout could be available on a demand type of display. The low pressure warning lights will thus be used to alert the crew to a potential problem and call-up of the actual reading would be used to evaluate the condition.

Thrust Indication

Although they are not available in current commercial transports, thrust meters are being used in military aircraft. From the opinions expressed by commercial pilots, it would appear that a need exists for incorporating this instrument in the cockpit of future aircraft. In current operations, each pilot establishes his own guidelines for the amount of power that is required and uses available instrumentation to estimate thrust.

In the SST, a direct readout of this parameter should be provided. It is recommended that a vertical scale indicator be utilized and that it be located on the forward panel with the power plant performance instruments.

Engine Pressure Ratio

This parameter is currently used as an engine performance instrument. The value at any instance indicates the performance characteristics of the engines and gives a gross measure of the efficiency of the power plants. Current aircraft usually have one dial per engine on the forward panel.

If the thrust meter does not provide adequate information on the performance of the engines, and it is necessary to provide an indication of the pressure ratio, it is recommended that the vertical scale indicators be used, and that they be placed on the forward panel with the EGT, thrust meter, and % RPM.

Status of Thrust Reverser System

In current operations when the thrust reverser levers are actuated, a system of lights indicates that the system is operating normally. These lights are placed on the forward panel right in front of the thrust reverser lever pedestal.

In all likelihood the SST will also utilize a thrust reverser system and the use of the same light system will be adequate to indicate that the system is engaged or disengaged.

Operating Condition of the Communication Equipments

In most current aircraft the communication equipment is placed on a pedestal located between both the pilots and just behind the power control pedestal. Controls are provided for selecting the specific communication network, specific frequencies, and specific modes of operation. Thus, the only current indicator of the operating condition of the equipment is that the power switches are activated and no malfunction lights are on.

The SST will utilize new types of communication equipment, but the presentation of the information concerning the operating condition of the equipment will essentially remain the same. Although it may be feasible for some other system of the aircraft to provide for automatic frequency switching, or for the communication activity to be automatically performed, the crew still will be required to initially activate the system.

Communication Transceiver Channel

Most of the communication equipment in current aircraft employs a manual, dial-in type of frequency change capability. The crew is responsible for switching frequencies as necessary to comply with the ATC requirements. The desired frequency is identified by a visual indication on the dial which corresponds to the frequency selected. The accuracy of this indication is dependent upon the calibration of the equipment. On some equipment a digital readout system is provided which provides a more accurate indication of the frequency selected. These frequency indicators are usually a part of the communication control console equipment, and are located on the center pedestal. It should be noted that military aircraft utilize a channel selection system wherein certain frequencies are preset before the flight commences and are associated with specific channels. In flight the crew member can select these channels using simple push-buttton controls and have this displayed on his instrument panel. To obtain frequencies which were not preset, manual tuning is required.

In the SST some of the communications functions will differ from those currently performed. Many of them will be completely automatic and will even employ automatic switching of frequency. For the most part the role of the crew will be to monitor the operating condition of the equipment and determine that the system has switched to the appropriate frequency. A visual presentation of the selected channel would present the crew the necessary information for monitoring the performance of the automatic switching capability.

On Line Configuration of Communication System

As described above, the communication system is controlled by the equipment and controls on the communication control console. In most instances this panel is located directly behind the power control console, and is usually referred to as the communication pedestal. This control console provides for selecting the specific type of communication equipment necessary for the accomplishment of specific functions. The crew's role is to manually activate this equipment and then to decide which equipment is to be used. This selection establishes on-line configuration of the communication equipment and no special display is used to present this information to the crew.

The SST will utilize new types of communication equipment and automatic selection of operating methods. In consequence, some provision for keeping the crew aware of the on-line configuration of the system will be necessary.

Indication of SELCAL Usage

The communication systems in today's aircraft use SELCAL (selective calling) only for company communications. For the other ATC communication functions the crew is required to constantly monitor (or guard) the assigned frequencies.

The SST will utilize communications system which all have the selected calling feature, and will probably require both an aural and visual means of alerting the crew to an incoming message.

Indication that Data Link is Sending or Receiving

Current commercial aircraft are not provided with data link equipment. If this equipment is used in the SST, the crew will require an indication that the equipment is transmitting or receiving information. This indication can be provided by one or two indicator lights.

Operational Mode of the Transponder

As in current operations, the use of a beacon transponder will be an important piece of equipment in the ATC system. The operational mode is usually assigned by the ATC clearance and will be inserted manually into the equipment by the crew. Thus, this information is located on the control panel for the beacon transponder, and is usually in a digital form (i.e., a switch may have one, two, etc. positions which would correspond to the number of modes possessed by the system.)

The SST will utilize the same type of control panel and will have the same type of manual control switching, however the number of modes may be expanded to provide the system with a greater number of discrete identifications. Some authorities have advocated the concept of ground switching of the equipment. If this were ever implemented, provisions would have to be made for an indication of these changes as they occur.

This indication is also required if automatic equipment switching by airborne equipment is used.

Operational Code of the Transponder

The current beacon transponders use a variable mode and code to obtain the necessary identification channels to handle the increasing amount of air traffic. The operational code is usually assigned by ATC during the initial clearance, and is manually inserted into the equipment by the crew.

The SST is expected to use the same type of equipment and the control consoles are expected to be similar. Some consideration is being given to increasing the number of modes or codes to increase the identification channels available for use in traffic control and, if this is done, the control panel for the transponder would have to provide added digital controls.

Smoking Indicator

In current aircraft this parameter is displayed on an associated control panel located on an overhead panel. When the "no smoking" indicators are lighted in the passenger sections, this indicator illuminates. In the SST, it is anticipated that the same type of control panel and associated indicator light will be used.

Seat Belt Indicator

One of the minor display requirements in the cockpit is an indication of the functioning of the "fasten seat belts" indicators. A control panel and associated status light will be required in the SST and will probably be located on the forward overhead panel as in current aircraft.

Traffic Alert Display

In current commercial aircraft no provisions are made for indicating the presence of other air traffic in the vicinity of the aircraft. The crew is always alert for conflicting traffic and relies on the control procedures of the ATC to assure separation.

In the SST, some type of proximity warning system which would provide an alarm to the crew that there was a conflicting aircraft in the vicinity and, in addition, provide avoidance control instructions has been widely advocated. Some military aircraft are equipped with front and rear scanning radar systems to provide a warning of the approach of other aircraft. In these systems, however, the maneuvering decisions are relegated to the pilot. At the speeds associated with SST operations (e.g., aircraft on opposite courses could close at the rate of about 60 miles per minute). This type of warning may be inadequate. When a potential collision course has been detected, it may be necessary to provide for automatically controlled maneuvering to avoid the collision.

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ERRATA

NASA Contractor Report 561

By Harold E. Price, William D. Honsberger, and William J. Ereneta

An error made in assembly of this report resulted in placement of pages 159 to 162 out of correct sequence. Corrections to these page numbers, as follows, will provide proper sequence:

Page 162 should be page 159

Page 159 should be page 160

Page 160 should be page 161

Page 161 should be page 162

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