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Definition of the 2005 Flight Deck Environment

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1.0 SUMMARY

This contract provides a detailed description of the functional requirements necessary to complete any normal commercial flight or to handle any plausible abnormal situation. This analysis is enhanced with an examination of possible future developments and constraints in the areas of air traffic organization and flight deck technologies (including new devices and procedures) which may influence the design of 2005 flight decks. The contract includes a discussion on the importance of a systematic approach to identifying and solving flight deck information management issues, and a description of how the present work can be utilized as part of this approach.

While the intent of this contract is to investigate issues surrounding information management in 2005-era supersonic commercial transports, this document may be applicable to any research endeavor related to future flight deck system design in either supersonic or subsonic airplane development.

2.0 INTRODUCTION

The Boeing Company is investigating the technical feasibility of a Mach 2.0 - 2.5 airplane capable of carrying approximately 300 passengers over 5000 nautical miles on international routes in 2005 (fig. 2-1). Other airframe manufacturers worldwide are also actively interested in developing a second generation supersonic transport, and thus it is possible that by the middle to end of next decade a fleet of new supersonic aircraft will be in service worldwide. In order to design and evaluate the flight decks of these advanced aircraft properly, it is necessary to look into the future and make predictions.

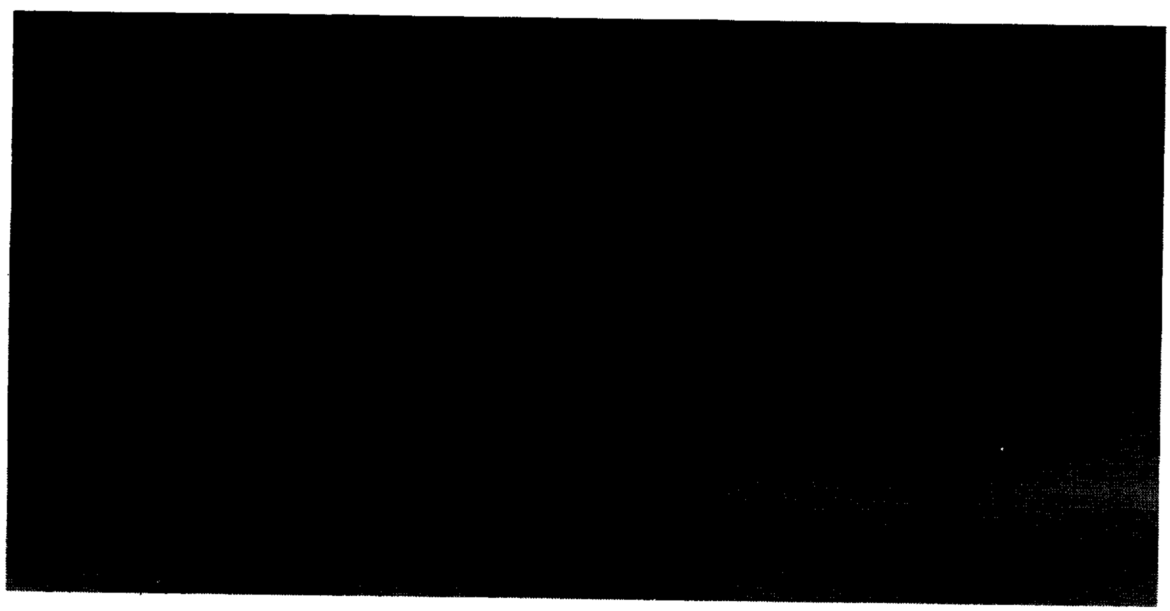


Figure 2-1. Boeing High Speed Civil Transport.

This document is primarily intended to provide a description of the 2005 flight deck information environment for researchers interested in identifying and solving flight deck information management problems. By examining the flight functions required to complete a supersonic commercial airline flight, and by determining the information transactions between the flight crew and the future onboard systems and Air Traffic Control (ATC) environment, researchers will have a comprehensive collection of the information that pilots will use in the 2005 flight environment. In addition, 2005-era subsonic transports will share most of the information management concerns of supersonic airplanes; thus, this report may prove useful for subsonic flight deck designers as well.

This document contains an examination of the 2005 airplane flight deck environment from the point of view of a supersonic transport design group. Irrespective of specific flight deck design, what are the flight functions necessary to accomplish a normal flight, and to handle non-normal situations? How will piloting a supersonic airplane be different from piloting a subsonic airplane from a functional standpoint? What will the 2005 worldwide air traffic management system look like, and how will this system affect the flight deck? What new flight deck technologies are under development today, and which are the most promising?

An approach to defining the information environment of the 2005 flight deck is to determine the information requirements for the flight crew. This can be done by conducting a top-down analysis and comprehensively organizing the aircraft mission into normal and non-normal components, then breaking down these components into their associated flight crew functions. These functions can be further broken down into the information required to complete each function. For this contract, function analyses for normal and non-normal commercial transport operations are accomplished. These are contained in section 5.0.

To complement this function analysis, it is helpful to examine present trends and proposals in flight deck and traffic management technologies, and project these into the future. This examination is useful because it represents current thinking on how some future flight deck information requirements might be met. Section 6.0 is a description of ATC and flight deck systems that could supply, receive, and manipulate information in the future.

3.0 RATIONALE

The goal of the air transport system is to move passengers and cargo from airport gate to airport gate efficiently and safely. The predicted increase in future aircraft traffic may place this goal in jeopardy, and to maintain, let alone improve, efficiency and safety, it is necessary to initiate action now. A major component of the required action will involve advanced flight deck design, and a primary component of successful flight deck design involves identifying and solving information management issues.

Efficiency and safety (including perceived safety) will suffer in the future if deliberate action is not taken. Delays caused by inadequate airport/airspace capacity and less than optimal management of traffic (particularly in areas of poor weather) result in inefficiency, which leads to canceled flights, greater fuel costs, and reduced passenger satisfaction. Current levels of traffic are already straining airspace and airport capacity. This congestion problem will only get worse, as traffic is predicted to increase 2 1/2 times worldwide by 2015.[1]

While the present aircraft accident rate (number of accidents per departure) is relatively low for scheduled air carriers when compared to other forms of transportation, it has remained relatively constant for the last twenty years.[2] The flying public, unfortunately, tends not to look at this rate, but rather at the absolute number of accidents per year. This means that as the number of departures increases, the total number of accidents per year will also increase. Some suggest that the projected increase in the absolute number of accidents will affect the public's willingness to fly. Further, as increased traffic results in denser airspace, the resulting formidable traffic management task could potentially compromise safety, unless it is accompanied by a comparable increase in air traffic management and/or aircraft capabilities. A final safety issue, although a subtle one, is the possible misuse of new technology.

Can flight deck design help alleviate these concerns? Consider that two thirds of aircraft accidents are attributed to pilot error.[3] If a majority of these errors can be overcome by the effective use of human factors principles in the design and operation of current and advanced flight deck technology, the accident rate may indeed drop significantly. The problem of maintaining or improving airport efficiency can also be addressed through the optimal use of technology, such as onboard navigation and surveillance equipment. Airport capacity could be increased by more precise control over aircraft spacing, and by an increased capability for low visibility operations.

These problems can be addressed because new technology has dramatically increased the potential of flight deck designs. The electromechanical flight instruments of older flight decks, consisting mainly of dials, pointers, and switches, posed substantial design limitations. New computer based instrumentation can take advantage of new sources of information (e.g. datalink, ELS, sensors), high-speed data processing capabilities and expert system algorithms, and new presentation approaches (e.g. computer-generated out-the-window type displays) for the production of powerful human/machine systems. The emergence of this new technology has significantly altered the nature of the flight deck design task. Instead of having a limited amount of information and very little flexibility in its presentation, flight deck developers now have an increased quantity of source information and numerous ways in which to display and interact with it. With graphics processor and video display terminal (VDT) technology advancing year by year, the capability to present almost any information in any way may soon exist. The new challenge becomes deciding which information is really needed, when that information needs to be displayed, what the best format for that information is, and how to call it up and interact with it. In this manner information can be tailored to best fit the situation.

To answer this challenge, flight deck designers must concentrate on the human side of the human-machine interface and design information systems which fully take advantage of the human's cognitive capability. For example, today's flight deck specialists need to know how the pilot's decision making process works to correctly decide how and when information is displayed during a particular event. The increased knowledge required of designers can be complex and extensive, as evidenced by the plethora of areas that contribute to this body of knowledge: visual and auditory perception, learning, memory, information processing, decision making, human error, workload, fatigue, stress, attention, and motivation. Thus, the optimal design of future flight decks will depend more on an in-depth understanding of the pilot's cognitive functioning.

New designs will take greater advantage of pilot's vast cognitive capabilities. Yet human cognition has its weaknesses, some obvious, others subtle, and while scientific understanding of cognitive functioning is significant, much remains which we do not fully comprehend. Engineers can create more powerful flight deck systems, but the danger of creating poor designs increases as we delve into the more technical, poorly understood areas of advanced flight crew interfaces. Clearly, this can be viewed as both an opportunity and a challenge. Success in this area depends heavily on recognizing and solving the problems of information management.

The danger of new technology being poorly implemented is very real. Experience indicates that it is not uncommon for engineering design groups to be unaware of the increased complexities of the human/aircraft interface described above. This may result in designs which do not consider or accommodate human factors phenomena, thus creating the potential for errors. To minimize the problems resulting from the haphazard introduction of new technology, it is important that human factors researchers and engineers identify pitfalls and suggest approaches that will set standards against which aircraft manufacturers and regulatory agencies can evaluate vendor designs. Much of this work will be in the area of information management.

To summarize, if we are to take advantage of the extended capabilities that new technology can contribute to efficiency and safety, it is critical that we overcome the difficulties inherent in successfully implementing this technology. An important step in this process is the identification and solution of problems relating to information management. In this contract we have completed the initial steps in a systematic approach aimed at identifying the nature and magnitude of the information management problems of the 2005 flight deck.

4.0 SYMBOLS AND ABBREVIATIONS

4-D	4 Dimensional (3-D positioning plus time)
ADS	Automatic Dependent Surveillance
AERA	Automated En Route ATC
ASDE	Airport Surface Detection Equipment
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATM	Air Traffic Management
CESS	Centralized Electronic Storage System
c.g.	center of gravity
CGI	Computer Generated Imagery
DGPS	Differential Global Positioning System
DH	Decision Height
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
ELS	Electronic Library System
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FMS	Flight Management System
GNSS	Global Navigation Source System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HEA	Human Engineering Analysis
HSCT	High Speed Civil Transport
HUD	Head-Up Display
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
kt., kts.	knot, knots
LRC	Long Range Cruise
MLS	Microwave Landing System
RTA	Required Time of Arrival
TCAS	Traffic alert and Collision Avoidance System
TECS	Total Energy Control System
TFM	Traffic Flow Management
VDT	Video Display Terminal
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range

5.0 FLIGHT DECK FUNCTION ANALYSES

This section contains a function analysis for a normal commercial transport flight, and an effects and high-level function analysis for non-normal flight situations. A "function" is defined as a goal which must be completed during the progression of a flight. In the case of function analysis for normal flight, functions are the set of goals required to safely complete a flight phase. In the case of the non-normal situations, functions are the set of goals required to properly respond to non-normal situations.

Function analyses are an intermediate segment of an entire Human Engineering Analysis (HEA) methodology. HEA, as the term pertains to the Boeing supersonic High Speed Civil Transport (HSCT), is a powerful top-down methodology for defining information requirements for the flight deck environment. These requirements can then be used to guide the design of flight deck displays and controls, the extent and type of automation, and the need for information management techniques. HEA develops these requirements using the step-by-step method described below and shown in fig. 5-1.

The first step in HEA is to create a list of the aircraft's missions that identify the high-level purpose(s) for the airplane's very existence. For example, a military airplane may be created to perform a variety of combat roles; the Department of Defense would clearly specify these roles. In the case of a commercial transport, such as the HSCT, the purpose of the airplane is to fly a payload (people and/or cargo) from one airport to another safely, efficiently, and comfortably. All civil airliners could be said to have two sets of "missions": the "normal" flight, which contains all standard phases of an error-free transport flight (for example, "missed approach", "divert", "hold", and, for supersonic airplanes, "supersonic cruise"); and the "non-normal" conditions, which includes unusual circumstances and malfunctions to which the flight crew might have to respond. Mission analysis also includes identifying technologies, airspace configurations, and regulations that would have an impact on any mission profile. The reason for this broad definition of the aircraft's mission is that it is necessary to be as comprehensive as possible in identifying conditions of flight that should be considered in designing the 2005 flight deck. The establishment of a comprehensive set of requirements before design begins will minimize the need for later re-work and the associated design compromises and expenses.

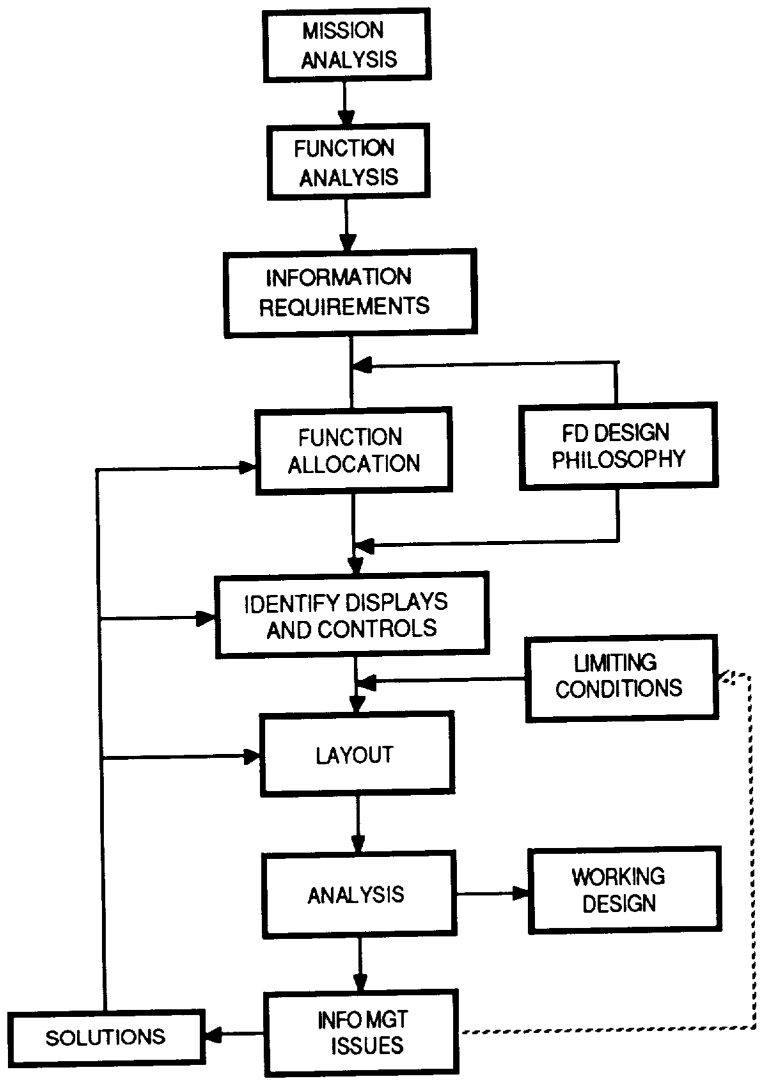


Figure 5-1. A Typical Human Engineering Analysis (HEA) Methodology.

To facilitate organization, the missions are broken down into a number of subsets. For normal flight, the mission is broken down into flight phases, such as taxi, takeoff, approach, etc. For non-normal flight, a list of non-normal situations is generated. This list includes conditions resulting from human limitations as well as system abnormalities, and is meant to be as comprehensive as possible.

Each mission phase is then separated into all the functions which need to be accomplished by the pilots or the onboard automation to complete the phase. These functions need not be listed temporally, but the function list should be comprehensive. A good strategy is to separate the larger functions into sub-functions (in a "tree"-type organization). For example, the phase "Descent" would include the function "Control Flight Path" which could be further broken down into "Follow lateral flight path," "Maintain appropriate longitudinal profile," "Meet airspeed/altitude restrictions," and "Modify route for weather/traffic." Each of these lower level functions would, in turn, be divided into its next lower level functions.

With a list of functions performed by the flight crew and flight systems, an examination of the information required by these functions can be made. For example, the high level function, "Identify collision hazards on or near flight path," suggests a need for some display which allows the crew to determine if the plane will pass too close to an obstacle in the future, and implies that enough advance warning be available to avoid an incident or accident. With lower level functions available, specific single pieces of information can be listed. The low level function "Monitor current fuel temperature" requires information on current fuel temperature in each tank, as well as predetermined comparison values to determine whether fuel temperatures are or will deviate out of the normal operating range.

Once the information requirements are available, a first cut can be made at allocating functions between the human flight crew and automation. This is followed by preliminary development of flight deck control, display, and pilot/machine interface designs, and an analysis of the tasks performed by the flight crew. This task analysis can be used to initiate studies in workload analysis and error analysis. The process leads to the identification and solution of information management issues. This process iterates, with the cockpit design becoming more refined with each iteration.

The benefit of using HEA over a bottom-up or derivative flight deck design methodology is that the resulting HEA flight deck is, comparatively, more comprehensive, integrated, and adaptive.

-- *Comprehensive design.* HEA can ideally assure that a flight deck design is comprehensive by first examining every mission that an airplane might fly. This includes any anticipated non-normal situation that could arise inflight that might affect design. Then, by working from the top down and being thorough at each level of analysis, HEA will ideally generate an information requirements list that contains appropriate information for every single function that the flight crew or flight deck automation performs regularly or may have to perform in an unusual situation.

-- *Integrated design.* HEA can assist in creating an improved flight deck by providing the flight deck designers with all the information flow requirements before they start developing displays and controls for the cockpit. By knowing all the requirements initially, the flight deck designers can optimize system integration and avoid the inefficiencies that can occur when the integration is done in a piecemeal fashion. Also, by starting the analysis with mission requirements and not preconceived solutions, flight deck designers can take a fresh look at how new computer-based technologies that provide expanded capabilities can be used in the modern flight deck. It may be found that previous solutions were based on technological constraints that existed at the time, but that these constraints no longer apply, and new designs may be developed to better meet the information requirements.

-- *Adaptive design.* HEA is an iterative process. As additional knowledge is gained at lower levels in the analysis, or as new functions or tasks are added to the missions (due to technology, airspace, regulation, or systems design changes), HEA can bring that information back up to the higher levels. If the total analysis is organized properly, the change should filter down through the levels of analysis resulting in new information requirements at the bottom.

5.1 Function Analysis for Normal Flight

The complete function analysis for normal flight is located in **APPENDIX A**. The "normal" air transport mission, for the purposes of this paper, assumes a standard flight with no abnormalities or emergencies, save the typical missed approach and divert from the destination airport with a hold en route. The fifteen phases of a normal flight are shown in fig. 5-2.

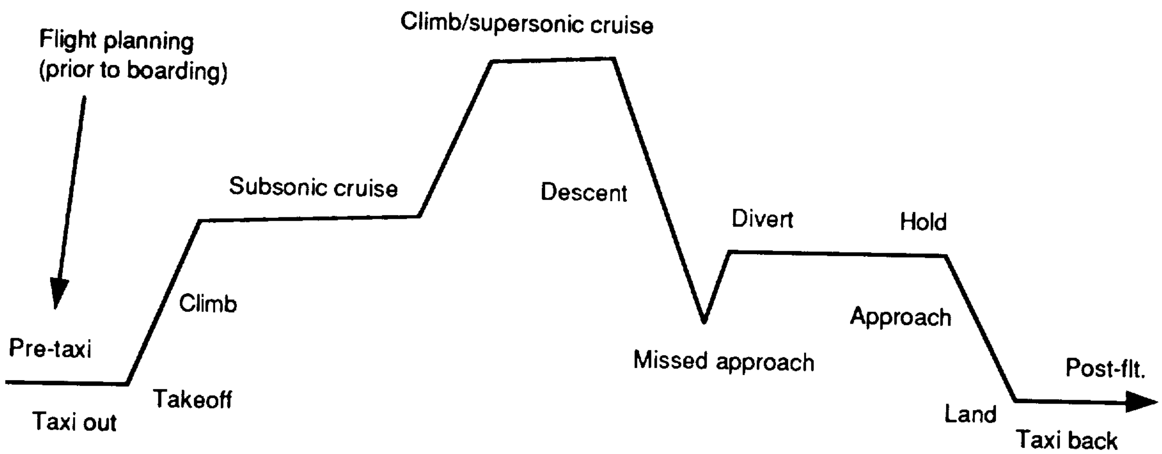


Figure 5-2. The Fifteen Phases of the "Normal" Flight.

The major functions for each flight phase are summarized as follows:

FLIGHT PLANNING (Before the flight crew arrives at the airplane)

PLAN 4-D ROUTE OF FLIGHT
ANALYZE WEATHER
DETERMINE ATC AND FACILITIES RESTRICTIONS
AIRPLANE CONDITION AND PERFORMANCE

PREFLIGHT DUTIES (From cockpit preparation to pushback/engine start)

INITIALIZE SYSTEMS
PROGRAM FLIGHT COMPUTERS
COMMUNICATE/ FOLLOW PROCEDURES
ENGINE START
MANAGE SYSTEMS
PUSHBACK

TAXI OUT (From the beginning of airplane movement under its own power to airplane line-up on departure runway)

PLAN TAXI PATH
CONTROL GROUND PATH
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
TAKEOFF BRIEFING

TAKEOFF (From application of takeoff power to airplane wheels off-ground)

CONTROL GROUND PATH
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS

CLIMB (From airplane airborne to top-of-climb)

CONTROL INITIAL FLIGHT PATH
CONTROL FLIGHT PATH DURING CLIMB
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS

SUBSONIC CRUISE (From top-of-climb to supersonic acceleration point)

CONTROL FLIGHT PATH
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
ATTEND TO PILOT NEEDS

SUPERSONIC CLIMB/ CRUISE (From application of power to accelerate through Mach 1 to top-of-descent)

CONTROL FLIGHT PATH
AVOID COLLISIONS
AVOID SONIC BOOM OVER NOISE SENSITIVE AREAS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
ATTEND TO PILOT NEEDS

DESCENT (From top-of-descent to Initial Approach Fix)

PLAN APPROACH
CONTROL FLIGHT PATH
AVOID COLLISIONS
AVOID SONIC BOOM OVER NOISE SENSITIVE AREAS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS

APPROACH (From Initial Approach Fix to just before the airplane flare)

CONTROL FLIGHT PATH
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS

MISSED APPROACH (From application of power for missed approach to approximately end of missed approach procedure)

CONTROL FLIGHT PATH
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
PLAN FUTURE ACTION

DIVERT (From end of missed approach procedure to Initial Approach Fix for alternate)

CONTROL FLIGHT PATH
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
PLAN FUTURE ACTION

HOLD (From beginning of leg/vector to holding fix to exit from hold)

CONTROL FLIGHT PATH
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
PLAN FUTURE ACTION

LANDING (From flare to turn off runway)

CONTROL FLIGHT PATH
GROUND ROLL
AVOID COLLISIONS
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS
PLAN FUTURE ACTION

TAXI BACK (From turn off runway to airplane stopped at gate)

PLAN TAXI PATH
CONTROL GROUND PATH
COMMUNICATE/ FOLLOW PROCEDURES
MANAGE SYSTEMS

POST FLIGHT DUTIES (From engine shutdown to end of cockpit procedures)

SHUT DOWN ENGINES
MANAGE SYSTEMS
COMPLETE PASSENGER-RELATED REQUIREMENTS
COMMUNICATE

The "tree"-type division of functions mentioned in section 5.0 is organized through the use of indentations. Functions that are the same tab indent are at the same functional level. Functions that are indented below any function are the subfunctions that comprehensively make up the "parent" function. Functions without any lower level functions are either not yet broken down or already in their simplest possible form. For example, refer to the following sample from the function analysis:

- Control taxi speed
    - Set breakaway thrust/ reduce thrust as airplane starts to move
    - Monitor ground speed
        Fast: decelerate (brake/ decrease thrust)
        Slow: accelerate (reduce brake/ increase thrust)
    - Stop as required
        Predict braking distance
        Reduce thrust to idle
        Brake as required
        Set parking brake if necessary

The highest level function, "Control taxi speed," is comprehensively divided into the three subfunctions "Set breakaway thrust/ reduce thrust as airplane starts to move," "Monitor ground speed," and "Stop as required." The subfunction "Stop as required" is itself comprehensively separated into its subfunctions "Predict braking distance," "Reduce thrust to idle," "Brake as required," and "Set parking brake if necessary."

Functions indicated in **boldface** type are specific to supersonic flight. By removing these functions, a fairly comprehensive list of normal subsonic functions remains.

Please note that the choice of specific functions included in any function analysis, and the detail of lower level functions, is somewhat subjective. Users who wish to utilize this function analysis should feel free to add or delete functions as required for their own purposes. Flight deck design engineers should periodically modify this function analysis as required to reflect the developing configuration of the aircraft.

5.2 Effects and Function Analysis for Non-Normal Flight

As a flight crew is expected to operate an airplane during non-normal events, it is important to examine these events as well as normal aircraft operations. An effects and function analysis for non-normal flight is located in **APPENDIX B**. No comprehensive method exists to analyze every possible abnormal or emergency situation that can occur on a commercial transport flight. However, this section contains an extensive list of possible non-normal occurrences, based on information from Aviation Safety Reporting System (ASRS) incident reports, Concorde incident reports, and the 747-400 Quick Reference Handbook. For the purposes of this paper, "non-normal" means any unusual or emergency situation, and includes events related to human limitations. The non-normal list has been broken into five categories of situations:

Airplane Systems--hardware/software malfunctions on board the airplane.

Engine Malfunction
Engine Fire
Engine Control System Problems
System Malfunction (Fail-operational)
System Malfunction (Fail-safe)
System Malfunction (Complete failure)
Cabin Depressurization
Thermal Problems
Structural Damage
Flight Control System/Surface Failure
Flight Management System Malfunction
Autoflight Malfunction
Vision System Problems
Instrument/Control Contamination

Environmental--weather or other natural phenomena.

Heavy Bird Activity
Icing Conditions
Windshear Conditions
Severe Turbulence
Volcanic Ash
Thunderstorms
Hail
Heavy Rain/Snow
Lightning Strike
Radiation Event
Low Visibility

Operational--flight situations or errors limited to the airplane itself.

- Unstabilized Approach
- Slow Acceleration on Takeoff
- Incorrect Configuration on Takeoff
- Aborted Takeoff
- No Braking Action during Landing
- High Rate of Descent during Landing
- Airplane Off End/Edge of Runway
- Fuel Mismanagement
- Unusual Attitude
- Stall
- Overspeed
- Structural Overstress
- Center of Gravity Mismanagement
- Off-Airport Landing
- Evacuation
- Inflight Medical Emergency
- Unruly Passengers

Traffic/ATC/Collision/Communications--flight situations or errors resulting from ATC/other aircraft interaction.

- Obstacle Conflict (Airborne or Air/Ground)
- Obstacle Conflict (Ground)
- ATC Provides Incorrect Information to Crew
- ATC Receives Incorrect Information
- ATC Fails to Control Airplane
- Busted Clearance
- Wake Turbulence/Jet Blast
- Controller Busy
- Other Aircraft in Distress

Crew Related--"pilot error" events related to human limitations.

- Pilot(s) Fatigued
- Lack of Crew Awareness of Attitude/Systems/Weather/Location
- Erroneous Information Output from Pilot
- Erroneous Information Input to Pilot
- Degraded Manual Flying Skills
- High Workload
- Low Workload
- Poor Intracrew Communication
- Low Experience in Aircraft Type
- Instrument Fixation
- Pilot Incapacitated

For each situation in the list, the effects and function analysis is formatted as follows:

SITUATION

- Immediate Effects: (If included) listing of immediate consequences following the onset of the situation.
- Subsequent Effects: (If included) listing of effects that must be addressed to successfully plan for the remainder of the flight
- Unaware: (If included) listing of particular consequences that may occur if the crew continues the flight unaware of the non-normal situation. It is assumed that the crew is more likely to encounter more severe "immediate" effects if it continues on without understanding the non-normal situation (e.g. a fuel leak is more likely to result in total loss of fuel the longer the crew remains unaware of the situation)

- Response:

High level functional response to the situation

Again, functional responses that are specific to supersonic operations are listed in **boldface**. In each situation, it is assumed that the flight crew communicates its situation to ATC, the company, the cabin crew, and the passengers as required, and an emergency is declared if necessary.

Please note that, as with the function analysis for normal flight, the choice of specific effects and functions included in this function analysis, and the detail of lower level functions, is subjective. Users who wish to utilize this function analysis should feel free to add or delete effects and functions as required for their own purposes. Flight deck design engineers should periodically modify this effects and function analysis as required to reflect the developing configuration of the aircraft, and should add new non-normal situations as necessary.

5.3 Usage of Function Analyses

These function analyses are the first step in the development of a requirements driven (top-down) approach to flight deck design of a 2005 aircraft. The next step in this process would be to break the function analysis down into the information requirements necessary to support each function. The individual functions would then be allocated to either the crew or automated systems. The information requirements allocated to the crew could be turned into a platform for the identification of information management issues, and would allow a systems-level evaluation of information management designs as well as new control and display concepts.

6.0 THE 2005 FLIGHT ENVIRONMENT

This section contains a summary of advances being made in the area of Air Traffic Management (ATM) (Section 6.1), and of new technologies being developed for the commercial airliner flight deck (Section 6.2). This summary is intended to provide insight on how the flight environment may develop over the next 10-15 years. In describing the future flight environment, predictions are based on:

-- The state of the current air transport environment

-- The current plans for development and expansion of airspace, facilities, and aircraft systems

-- The overall goals and philosophies driving the aviation environment (e.g. safety and efficiency)

-- Experts' perceptions of future capabilities of developing technologies

It is important to note that these predictions may not come to pass at all. The underlying policies, economic drivers, or technological directions could change. In addition, the functional requirements, when broken down into information requirements and then arranged in an appropriate control and display arrangement, may turn out to not require the use of these technologies. Further, few experts in the industry have long range (beyond the year 2000) development plans.

While the equipment and processes used in the air transport environment arguably have and will continue to improve, the ultimate goal of this system will remain the same: to transport passengers and cargo between airports safely and efficiently. The responsibility for the achievement of this goal is shared between aircraft flight crews and the ATC controllers. While air traffic controllers maintain a certain amount of control over all aircraft under their jurisdiction, currently, and for the foreseeable future, each flight crew must be ultimately responsible for the operation of its aircraft. Only the flight crew has a comprehensive awareness of the overall condition of its airplane, and is thus in the best position to make decisions that might affect the safety of the flight.

6.1 The 2005 Air Traffic Management System

In order to understand how the future commercial transport flight deck operates within its environment, it is necessary to first understand one of the primary components of this environment, the Air Traffic Management (ATM) system, and how this system directly influences flight deck information flow and management. According to the Federal Aviation Administration (FAA), the role of the ATM system is "to ensure the safe, efficient, and expeditious movement of aircraft during all phases of operation." ATM can be broken into two separate elements: Traffic Flow Management (TFM) and Air Traffic Control (ATC). TFM is responsible for promoting the efficient flow of aircraft into and out of high-demand environments (e.g. on and off runways), while ATC refers to the process of providing aircraft separation in order to prevent collisions.[4] Note that in the context of this paper, the term ATC also refers to the network of ground-based facilities which issue clearances to aircraft (i.e., in the same sense as it does today). Any future ATM system will retain TFM and ATC components, though these components may become more tightly integrated than they are today. The ATM system has and will always have to support a wide range of aircraft types with very different performance characteristics and onboard equipment.

While the role of the ATM system will not change over the next few decades, the actual method of aircraft management may undergo a significant revolution. The current airspace system was created to provide flow management and traffic separation through the establishment of fixed Victor airways and jet routes (configured around ground-based VHF Omnidirectional Range (VOR) stations), fixed en route flight levels, and altitude crossing restrictions. Many experts consider this system to be extremely limited and outdated. Severe weather near terminal areas can force arriving and departing aircraft off predetermined routes, and require controllers to reroute these aircraft to and from the airport while manually maintaining spacing between aircraft. As controllers can manually vector only a small number of flights around weather safely, arrival flow into the terminal area can drop by as much as 80%, inducing numerous inbound flights to hold, divert, or hold at their origination if they have not yet taken off. Flight crew requests for deviations in speed, altitude, or flight path may be denied due to the human controller's limited capacity to handle off-route aircraft. Rigid airport departure and arrival procedures can require restrictive numbers of aircraft to fly over specific fixes, forcing departure delays. These shortcomings will become even more of a problem as projected air traffic is expected to increase significantly over the next 25 years (see sec. 3.0). To adapt to this increase, the ATM system may change to take advantage of area navigation capabilities of future navigation systems (see sec. 6.2.2.1), surveillance systems that will very accurately locate airborne aircraft and allow for much tighter spacing, precise 4-D flight management systems which will place aircraft over fixes at precise required times of arrival (RTA's), high-speed computers which will be able to keep track of 4-D aircraft flight plans, and the sheer abundance of total airspace available for routing of flights.

A proposed future ATM concept replaces existing fixed airways, jet routes, and oceanic tracks with open airspace, except in high-density airspace around airports (fig. 6-1). In this environment, each individual flight could request a preferred routing. This strategy, when augmented with controller-assisting automation, is viable in light of the principle that if most aircraft were able to fly their preferred route, very few traffic conflicts would arise. Before departure, individual flights would preselect optimum lateral paths and vertical profiles (limited only by regions of restricted airspace), including great circle routes, wind-optimum routes, cruise climbs, and requested time of arrival at its destination (with an acceptable window around that arrival time). The ATM system would adjust preferred routes only if necessary, and then just enough to assure conflict free operation and good traffic flow management into and out of terminal areas. Either case involves a certain amount of negotiation between ATC and each individual flight to achieve a flight plan that is acceptable to both. En route, ATC is responsible for fine tuning these flight plans to account for unpredicted situations, such as emergencies, unanticipated weather, or flights which deviate from their original flight plan. This fine tuning includes slowing or speeding up traffic, turning aircraft, adjusting vertical profiles, moving route waypoints, or changing RTA's for en route aircraft. As each flight approaches its destination, the temporal window for arrival (the time between the earliest allowable arrival and the latest allowable arrival) at each successive approach fix and the arrival runway becomes increasingly narrow to assure that flights land as close as possible to their previously agreed-upon landing time.

To better understand this future ATM system, consider a scenario for a flight within this environment. A flight from Seattle to Hong Kong is cleared along its requested route, with

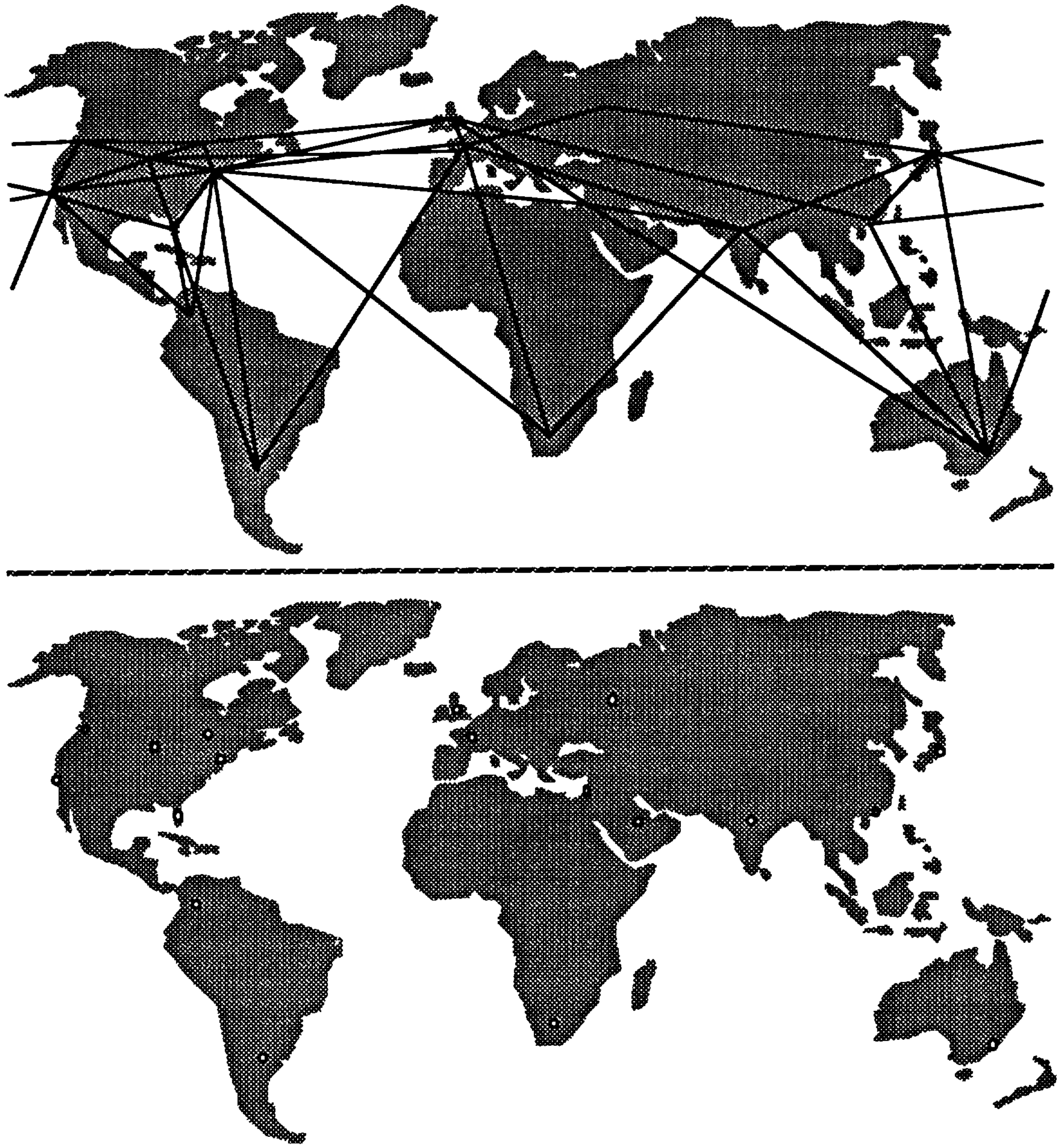


Figure 6-1. Top: Representation of Air Traffic Management of the past, with fixed route structures established around ground-based navigation sources. Bottom: Representation of Air Traffic Management of the future, with open airspace around relatively small areas of highly organized airspace reserved for takeoff and landing operations.

one departure waypoint adjusted one mile laterally to avoid an area of heavy traffic. The flight departs on schedule at 0205Z, climbs as cleared to the optimum altitude for its current weight, and begins an en route cruise climb at the aircraft's Long Range Cruise (LRC) speed (which is the selected best economy speed for this flight). While the flight is not yet 1000 nautical miles from Seattle, a line of heavy thunderstorms crosses directly over the airport at Hong Kong, causing unpredicted delays. The en route flight had scheduled an arrival time of 1445Z, but the destination airport now predicts that an arrival slot will not open until 1540Z. At 0400Z, ATC asks the flight to reduce its groundspeed by 38 kts. to meet this new arrival restriction. The flight is also asked to turn right 1° to avoid a future conflict with traffic at approximately the 10 o'clock position at 200 nautical miles, which would have passed behind the flight before the flight slowed, but is now on an intersecting course. Fifteen minutes later, it turns out the conflicting traffic's groundspeed is slower than predicted, and the flight is allowed to return to its original route. Later, after several more unexpected traffic conflicts, the off-path reroutes necessitate an speed increase of 3 kt. to assure an arrival time of 1610Z. While approaching the destination, the flight encounters another building line of thunderstorms, and asks to deviate from the planned route to maneuver between two cells. The deviation is approved provided the flight now passes a designated arrival fix 1000 ft. lower than previously planned to avoid another traffic conflict. Another slight speed increase to make up for the weather deviation assures that the flight arrives at the FAF right at 1540Z. Had this flight been operating in the current ATC environment, it likely would not have been told well in advance about the arrival delay. The flight would have continued en route at the LRC speed, arrived at the metering fix, and then been asked to hold for 55 minutes, burning fuel simply to stay aloft. Within the proposed ATM system, modifications would be made to provide continuous route optimization. In this scenario, because the flight was informed well in advance of arrival of the delay, it was able to cruise at a speed closer to its best endurance speed, efficiently incorporating the 55 minute delay into its flight plan. The flight thus realizes a significant total fuel savings over the routing which includes a holding pattern.

While the system described above is one solution, it should be noted that any future system must be versatile in real-time and responsive to unpredictable events, as it will remain an axiom that the flight environment contains a number of variables which cannot be predicted with certainty. Weather is probably the foremost of these somewhat random conditions. While weather prediction will continue to improve over the next 15 years (real-time automatic weather reporting should be available from most airborne aircraft and from many ground stations), unpredictable thunderstorms and other unforeseen severe weather events which disrupt traffic flow can be expected to occur occasionally. Aircraft may delay departure for any number of operational reasons, and, once en route, may ask to fly at a faster speed to make up for lost time on the ground. Airplanes executing missed approaches, airplanes flying off their planned profile, VFR traffic conflicts, and the occasional airplane needing priority handling are likely to have effects on other traffic. Finally, the "unknown unknowns" will require "on the spot" changes in terminal area and en route flow, and flexibility in the ATC system must remain to deal with these occurrences.

The current ATM system is limited by the human element involved in controlling aircraft. Like pilots, ATC controllers are subject to fatigue, stress, periods of high and low workload, and human error. To counter this, ATC controllers of the future are scheduled to receive advanced workstations which will contain improved displays, controls, and supporting automation with increased functionality. An example of this automation are advanced Automated En Route ATC (Advanced AERA) concepts. Advanced AERA concepts are functions that automate the en route ATC separation of aircraft by letting computers predict future conflicts and command appropriate resolution maneuvers for the aircraft involved. This leaves the human controller to the higher level task of managing traffic flows into, through, and out from his sector.[5] Better controller spatial awareness may come about through the introduction of the Global Navigation Source System (GNSS) and Automatic Dependent Surveillance (ADS), which provides air to ground datalink of the current aircraft position as determined by precise onboard navigation systems. This improved spatial awareness may allow for tighter separation between controlled aircraft in both terminal and en route environments. GNSS and ADS may also allow for homogeneous control and separation standards over most of the world, including in transoceanic airspace.

To operate within the future ATM environment described above, the aircraft of the future must provide ATC continuous aircraft altitude and position information (assuming onboard aircraft navigation systems can provide more accurate position information than ground based systems such as radar), as well as forecasted information on arrival times at fixes, anticipated crossing altitudes, requested future route modifications, and predictions related to the airplane's performance. In addition, aircraft may serve as airborne weather observation systems, automatically providing winds aloft, static air temperature, turbulence reports, and other information on weather phenomena. In return, ATC and other ground information sources may provide each airplane with real-time weather from other aircraft, as well as continuous weather information (including surface winds, visibility, runway conditions, and windshear and wake turbulence information) from ground sources during en route and terminal area operations.

In summary, advances in the ATM system may have the following influences on information flow into and out from the aircraft flight deck:

-- ATC may datalink routine commands into the flight deck to reduce communication errors. Workload may also be reduced as the electronic command can be formatted and incorporated into the FMS flight plan with a push of one button. However, the pilots must understand the content of each ATC clearance, and must manually accept or reject each clearance (see sec. 6.2.3).

-- Conversely, aircraft would downlink requests for route modifications, vertical profile changes, arrival windows at en route fixes, approach fixes, and their destinations, and other adjustments to ATC.

-- Aircraft will be expected to fly very precise 4-D paths and profiles to maintain conflict-free flight. To do this the flight crew must have the ability to maintain an assigned lateral path (e.g., a curved path), to fly specified, continuous vertical profiles (e.g., a cruise climb), and to cross a designated fix before an assigned time, at an assigned time, or after an assigned time as requested by ATC.

-- At different points in any flight, ATC may give the flight crew choices for future path and profile based on predicted traffic and the ATC computers' knowledge of the performance characteristics of their aircraft. Therefore, pilots must have the capability to weigh the given options to determine which is the most efficient and acceptable. For example, ATC may offer an airborne flight arrival slots 35 minutes earlier, 20 minutes earlier, or 10 minutes later than planned. The flight crew must decide which slot is best based on fuel economy, weather, scheduling, etc.

-- Aircraft must update ATC on their detailed future plans in a timely fashion. For instance, if a certain aircraft configuration requires the use of a particular runway at the destination airport, letting ATC know well in advance allows the ATC computers to properly sequence the flight's arrival. If, however, the same flight did not inform ATC of its situation until it was only 15 minutes out, the whole arrival flow could be disrupted as ATC attempted to accommodate the incoming flight. The sooner each individual aircraft predicts its own future flight states, the better the accuracy of the whole ATM picture, and the more efficiently the whole system will run.

Required information management includes systems to manage datalinked clearances and confirm that the existing onboard flight plan precisely matches the corresponding flight plan in the ATC computers. These information management systems also include flight management systems which analyze the current flight path with the constraints and options provided by ATC, and allow the flight crew to make decisions that optimize the efficiency of the flight.

6.2 2005 Flight Deck Systems

Many advanced flight deck systems, which include novel controls and displays as well as refined versions of current devices, are currently being researched and developed. Many of these are likely to be in use on commercial aircraft by 2005. This section contains an overview of the most consequential of these systems.

The likelihood of any system becoming fully integrated into future flight decks depends on its technical feasibility as well as its ability to satisfy operational requirements. In predicting the usefulness of any new system, one can ask two main questions:

-- Will the new system *improve airline economics* by

providing more overall savings (or additional revenue) than its cost?
providing expanded capabilities that increase fleet efficiency?
decreasing training requirements?
decreasing maintenance cost?
providing increased dispatchability?
reducing arrival delays?
increasing terminal and en route airspace capacity?
improving passenger comfort and service?

-- Will it create a *safer flight environment* by

lowering total crew workload in busy environments?
decreasing flight crew errors?
reducing the consequences of flight crew errors when they do occur?
increasing flight crew situational awareness?
contributing to effective cockpit resource management?
accounting for capabilities and past training of the entire pilot population?
working as part of an integrated system?

One can presume that a system that receives more positive answers to the questions above will be more likely to appear on next-generation aircraft.

New flight deck systems can be grouped into three categories. Advanced "control" systems, which control command flow from the flight crew to the aircraft systems, are discussed in section 6.2.1. Advanced "display" systems, which manage information flow to the flight crew, are presented in section 6.2.2. Advanced "information transfer" systems, which store and transfer information within, to, and from the aircraft, are discussed in section 6.2.3.

This list of potential new flight deck systems should provide researchers with a better understanding of the information that pilots will have to handle in the 2005 environment. This understanding may help with the identification of information management problems that need to be solved if future flight decks are to achieve their potential.

6.2.1 Advanced Control Systems

6.2.1.1 Flight Controls

Until recently, all airplanes were flown by a "direct" control law; that is, an input into the pilot's flight controls translated directly into motion of the control surfaces (elevators, ailerons, rudders, and spoilers). Most modern airplanes include features such as linear modification of the input command, as in a rudder ratio system, which changes the ratio of rudder movement to control pedal displacement depending on airspeed, or Mach trim, which automatically adjusts the airplane's horizontal stabilizer at high Mach number. Some of the newest airplanes are designed with more complex control laws (e.g. C* and Nzu) which are related to the vertical acceleration of the aircraft, and have flight control computers which control the aircraft control surfaces. Future aircraft may have flight control laws in which the pilot commands a flight path angle (e.g. gamma track). Airplanes may also have a control strategy known as a Total Energy Control System (TECS), which utilizes a composite control law that manages thrust to control total airplane energy, and airplane pitch to control the airplane's distribution of energy between kinetic and potential (airspeed and altitude). Another advancement under study is structural load alleviation, in which the flight control surfaces are continuously and automatically positioned to reduce gust-induced loads on the wings and other airplane structures. This results in a lighter airplane and a smoother ride for the passengers.

Modern airplanes already have autoflight systems with automatic landing capabilities which will continue to be used in the future. These systems allow the pilot to input a flight path goal, such as "hold a heading" or "descend and maintain a certain altitude," or even "fly this complex vertical profile, with the given altitude crossing restrictions" or "land the airplane." Future autopilots will allow progressively more complex flight paths and profiles to be flown automatically. Automatic takeoff (similar to autoland) will likely to be developed in the future, but not necessarily by 2005. These automatic flight systems must allow the pilot to quickly take over manual control of the airplane.

Flight controls transmit information to the pilot as well as from the pilot. With the direct control law, the experienced pilot can, to a certain extent, monitor the status of the airplane by comparing the control forces required to fly the airplane to the resulting dynamics of the airplane and noting any discrepancies (for example, pilots can be alerted to possible aircraft malfunctions if the airplane tends to roll or yaw with the controls neutral).[6] Even flight controls on a C* or TECS aircraft provide some information to the pilot by having stops which inform the pilot that he is commanding maximum pitch or roll rate. Feedback from the autopilot through the control yoke (or stick) and/or autothrottle movement may warn the pilot of an improperly configured autopilot control panel or a malfunctioning autoflight system. This monitoring feature of the flight controls must not be lost as newer flight control laws are developed. Potential monitoring features include synthetic feedback through the flight controls, feedback through display symbology, or more sophisticated automatic systems monitoring.

6.2.1.2 Systems Controls

Systems controls (fuel, hydraulic, external lights, etc.) are currently independent switches and knobs which are grouped by the system they control. As has happened in the past, it is probable that, in the future, the number of systems, or the complexity of systems, may increase to the point where not enough space exists on the flight deck to provide dedicated controls for each system, or the flight crew is seriously encumbered by the total number of dedicated controls and thus has difficulty in managing the entire suite. Information management techniques to handle this problem could include more intuitive methods for presenting information that will allow pilots to comfortably handle this information increase. "Smart" automatic systems managers (which leave the pilots in ultimate control) may alleviate some flight deck workload. Future developments may also include multifunction displays and controls, which have the capability of reducing overall flight deck clutter. These multifunction displays can use a cursor-control device for rapid selection or manipulation of data. In the more distant future flight decks may incorporate voice commands for systems control, but this application is heavily dependent on the capabilities of voice recognition technology, which may or may not be mature and reliable by 2005.

The quality of any particular arrangement of system controls is dependent on several attributes. Foremost, the most critical normal and non-normal controls (e.g. engine fire handles, landing gear lever) must remain readily accessible. Multifunction controls must be carefully designed so that they do not increase the likelihood of pilot error, especially when the consequences of an error is serious. Menu-driven options should be well organized in an appropriate hierarchical structure for inexperienced users, and accessible by abbreviated methods in minimum time for experienced users. As with flight controls, control switches also serve a "display" purpose, in that the physical position of a switch may alert the flight crew to an improperly configured system.

A supersonic transport, such as the HSCT, may have more complicated engine, fuel, and hydraulic systems than a subsonic airplane. However, it is likely these systems will be almost completely automated, and the controls required for these systems would simply engage normal or backup modes of automatic operation.

6.2.2 Advanced Display Systems

6.2.2.1 Navigation Systems

Airplanes are very rapidly moving away from their reliance on fixed, ground-based VOR stations which promote flight along predefined flight routes. Many modern airplanes are equipped with Inertial Navigation Systems (INS), updated by ground-based Distance Measuring Equipment (DME) and/or VOR input, which allows precise area navigation over certain areas of the world. With area navigation, airplanes can fly any chosen route, no longer being dependent on inflexible ground stations and airways.

The Global Navigation Source System (GNSS) is emerging as the probable worldwide area navigation system of the near future. GNSS relies on a chain of orbiting satellites which provides three-dimensional positioning to receiving aircraft. As of late 1990, 15 American Global Positioning System (GPS) satellites and 8 Commonwealth of Independent States' (formerly Soviet) "GLONASS" satellites were in orbit. The complete chain of 21 American satellites is planned to be operational by early 1993; 24 GLONASS satellites are planned operational by 1996 (this remains uncertain due to ongoing political situations). Current accuracy of GPS is approximately 100 meters (328 ft.). Higher accuracy is available through Differential GPS (DGPS), which utilizes a fixed ground-based GPS receiver to provide correction information to airborne traffic in the vicinity.[7] Accuracies are as precise as 5.18 meters (17.0 ft.) laterally and 9.1 meters (30 ft.) vertically (using a DGPS/INS hybrid navigation system), and have been demonstrated in some cases to be as precise as 0.3 to 3 meters (1 to 10 ft.) laterally.[8] Note that vertically accuracy improves significantly when supplemented with radar altitude. By comparison, Category II approaches require lateral accuracies of 5.15 meters (16.9 ft.). Some suggest DGPS may, in the future, be capable of providing guidance for Category III approaches.

The conventional Instrument Landing System (ILS) will continue to provide straight-in landing guidance for landing aircraft until the more advanced Microwave Landing System (MLS) is phased in between 1994 and approximately 2000.[9] Some experts argue, however, that MLS is an unnecessary system, and assure skeptics that DGPS will soon have the same or better accuracy at a lower cost. Regardless of which system (MLS or DGPS) provides precise area navigation during approach, by 2005 simple and complex curved instrument approaches should be common at major airports around the world.

Area navigation information will be provided to several display systems, as well as some other systems. "Map"-type displays will use precise position information for airborne plan view displays and taxi displays (fig. 6-2). Precise area navigation information would be used for CGI-type synthetic vision displays, ADS (which would provide current aircraft location and velocity to ATC via datalink), TCAS, takeoff monitor, and decisions aids.

6.2.2.2 Enhanced and Synthetic Vision

While normal flight deck windows supply the flight crew with a great deal of information for all phases of flight during daytime Visual Meteorological Conditions (VMC), they are limited in nighttime VMC and day and night Instrument Meteorological Conditions (IMC). Furthermore, certain airplane configurations, such as the extended, pointed forebody of a supersonic transport, significantly restrict forward vision. Vision systems are displays, usable in all-weather conditions, which provide flyable out-the-window type scenes. Information which is, for the most part, invisible to the unaided eye (e.g., clear air turbulence, windshear, wake vortices, volcanic ash) may be integrated into these displays. In the short term, these displays will likely consist of a raster display projected onto a HUD

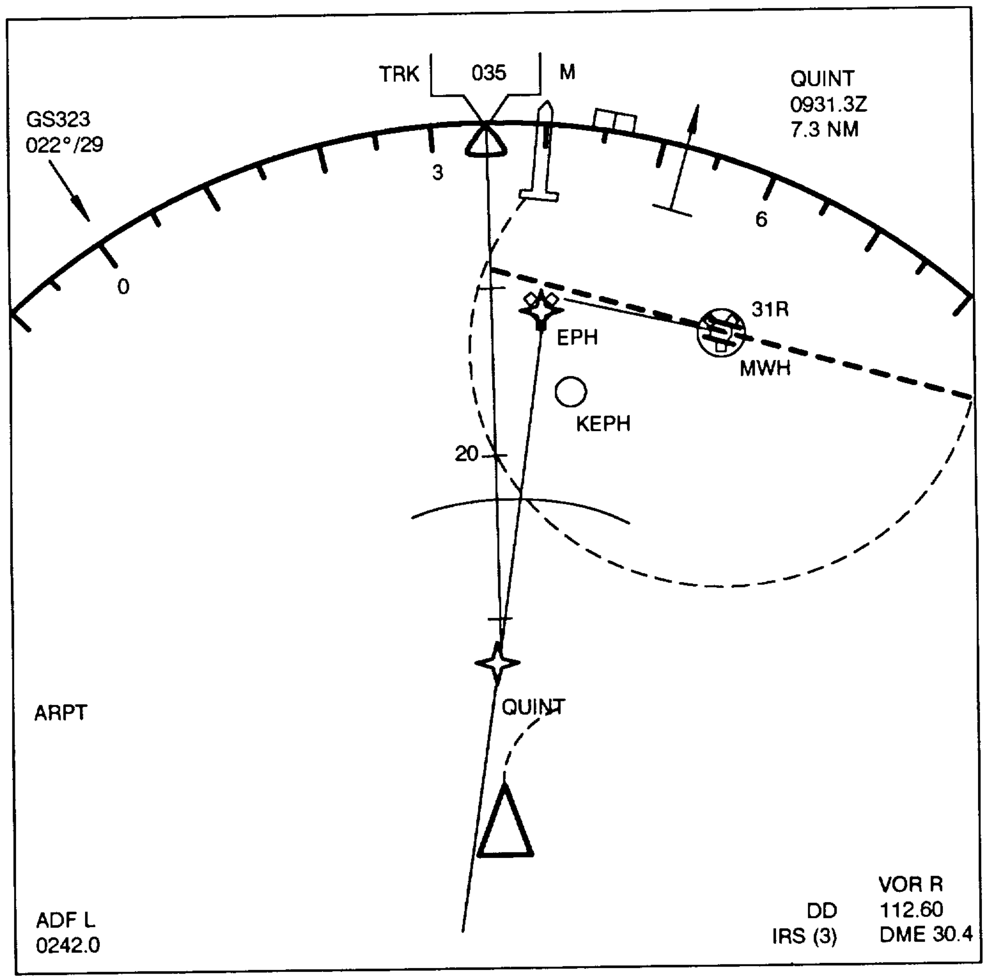


Figure 6-2. A Current-Generation Map Display.

("enhanced vision"). For the long term, head-down displays, fully independent from any windows, are possible ("synthetic vision").

Vision displays may be driven from one or both of two information sources. The first source is sensor information (e.g., electro-optic, infrared, millimeter wave radar, LIDAR, etc.). While sensors provide real-time imagery of objects and air mass movement in front of the airplane, they are limited by poor resolution and quality that can vary substantially with environmental conditions. The second source is Computer Generated Imagery (CGI). In this case, a high-resolution graphics computer, knowing the aircraft's precise position and attitude, uses a digitized terrain, obstacle, and surface features database to display a forward-looking scene (fig. 6-3). The main drawback of the CGI system is that it does not depict transient objects which are not contained in the database. It is very likely that future enhanced vision systems will combine both sensor and CGI information in a single display, taking advantage of the strengths of each approach.

Near-term enhanced vision research is centered on the specific purpose of allowing aircraft on a Category I ILS to descend below the Decision Height (DH) in Category III weather conditions by projecting forward-looking sensor information onto a Head-Up Display (HUD), which would provide guidance and obstacle avoidance from the DH to the runway. The synthetic vision system under consideration for the HSCT will probably use a combination of sensor and computer generated imagery.

6.2.2.3 Terrain and Stationary Obstacle Avoidance

At present, terrain avoidance during IMC is theoretically assured by aircraft following published procedures and maintaining at least a specific minimum altitude along a particular route or within a certain area. Should modern airplanes accidently or purposefully deviate off published routes or below the applicable minimum altitude, they may receive some protection from onboard Ground Proximity Warning Systems (GPWS), if installed. GPWS, which primarily uses radar altitude, alerts the flight crew if actual height above terrain decreases below a certain limit while the airplane is not in a landing configuration, or if terrain closure rate becomes excessive. Unfortunately, GPWS is a poor predictor tool as radar altimeters sense altitude directly below the airplane, not ahead of the airplane. Further, it does not warn the flight crew until the airplane is already dangerously close to and/or rapidly approaching terrain, and it tends to create nuisance alerts when pilots intentionally fly below a preset absolute altitude.

Terrain and obstacle avoidance in the future can be divided into two parts: terrain/obstacle awareness and terrain/obstacle conflict resolution. Advanced displays could provide assistance with both parts by providing the pilots with better situational awareness. Enhanced vision forward-looking sensor systems (see section 6.2.2.3) may provide some terrain information in IMC during departures and en route, as well as during approaches.

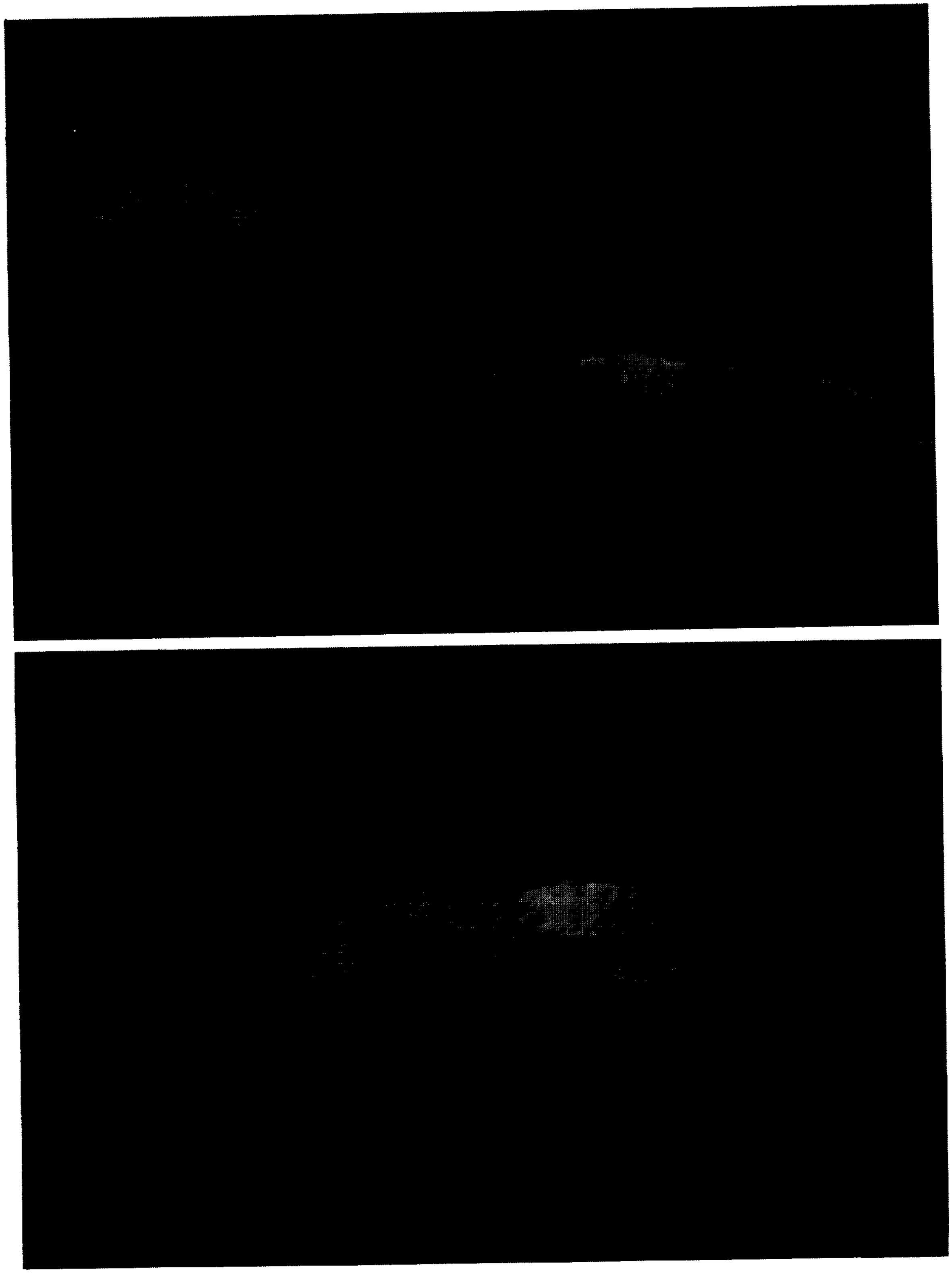


Figure 6-3. Examples of Computer Generated Imagery.

This information could be added to a forward looking perspective display, a HUD, or possibly to a map-type display. Another method is to provide a database that contains relevant terrain height, along with location and size of man-made flight obstacles (towers, buildings, power lines, etc.), in areas of aircraft operation. The Defense Mapping Agency (DMA) already produces electronic data which contain terrain elevation for much of the world's terrain, as well as limited height information on manmade features. Assuming aircraft onboard data storage capacities increase in the future, this or similar data could be carried aboard aircraft and used to alert the flight crew to a terrain conflict ahead, to the side, or below. Terrain awareness could be supplied by a plan or perspective view display which shows conflicting terrain and obstacle position relative to the airplane. Immediate conflict resolution could occur with a simple "pull up," or "turn right (or left)" alert and command, similar in concept to the current GPWS system. An advanced predictor system combined with a terrain database could keep the flight crew apprised of the terrain situation along the flight path and profile programmed into the FMS. Further, such a predictor system could be programmed with information on the airplane's dynamics, and thus could give some indication of the time left to maneuver before a terrain conflict becomes imminent, or guidance for the type and aggressiveness of the avoidance maneuver required.

6.2.2.4 Traffic alert and Collision Avoidance System (TCAS)

TCAS is a relatively new system that provides pilots with a plan view of other transponder equipped aircraft and relative altitude of Mode C (altitude encoding) equipped aircraft in their vicinity. If a potential collision situation exists, the current-generation TCAS system (called TCAS II) will issue an aural and visual vertical speed command, such as "climb" or "descend," as a recommendation for such a maneuver to prevent the collision. TCAS II also contains logic which allows two conflicting aircraft which are both equipped with TCAS II to electronically communicate and "negotiate" their intentions with each other. Consider, for example, two airplanes approaching head on at the same altitude. If the airplanes were to both climb to avoid each other, the result could be catastrophic. By having the TCAS II logic "agree" on recommending one airplane climb while the other airplane descend, the conflict is resolved. The next generation TCAS system (called TCAS III) will include lateral as well as vertical collision avoidance maneuver commands.

Future generation TCAS will likely provide collision avoidance through both the display of the relative positions of conflicting traffic and the generation of resolution advisories. Advanced systems should generate targets on airport surfaces to prevent air-ground and ground-ground collisions. Ground traffic may include ground vehicles, and possibly pedestrians, as well as stationary and taxiing aircraft (see sec. 6.2.2.5). Airplanes taking off or landing may be alerted if other airplanes encroach on the active runway. Location of other aircraft will likely continue to be displayed in plan view, which has the benefit of being able to be combined with other plan view navigation information. Spatial awareness of other traffic may be increased by also providing traffic information in a different format, such as adding traffic to forward-looking perspective displays (see sec. 6.2.2.2), presenting traffic in a 3-D format other than the conventional plan view, or possibly using 3-D sound to alert pilots to the location as well as the existence of threatening traffic.

Several questions regarding airborne conflict resolutions remain open-ended. If an aircraft such as a supersonic transport is designed with no forward-looking windows, and it relies solely on an advanced TCAS to avoid other aircraft, serious difficulties may arise should this transport be operated in the vicinity of non-transponder equipped aircraft. With advanced ATC automation monitoring for potential airborne conflicts, two sources (TCAS and ATC) for providing conflict resolution advisories will exist. While this situation may be safer (by having isolated and redundant systems to protect aircraft from midair collisions), the possibility could exist for the onboard TCAS system to command a specific resolution advisory while the automated ATC system simultaneously requests an incompatible vector for traffic. Thus, the hierarchy of conflict resolution authority must be established along with the implementation of advanced systems such as AERA 3 (see sec. 6.1).

6.2.2.5 Taxi Displays

Many next-generation commercial aircraft will have the capability to takeoff and land in limited to no visibility weather conditions; however, low visibility guidance during taxi on airport surfaces is currently limited or nonexistent. This generates problems for all taxiing airplanes, which may have difficultly seeing other ground traffic and may become unsure of their own locations. Flight crews unfamiliar with a particularly complex taxiway layout may become confused, and could make wrong turns, resulting in ground delays or, even worse, incursions onto an active runway. Ground system capacity may become the limiting factor in aircraft movement, causing significant pushback and taxi delays should ground control continue to utilize the relatively inefficient separation procedures it uses today.

Currently Airport Surface Detection Equipment (ASDE), which uses radar to detect traffic on the airport surface, is installed at selected major airports. However, many of these current systems provide ground controllers with only approximate locations of unlabeled moving "blips" overlaid on an airport diagram. Yet even the more advanced ASDE would, in certain situations, be reactive rather than proactive in avoiding hazardous situations. For example, a ground controller watching an ASDE display probably would not notice an aircraft inadvertently crossing an active runway until the airplane was actually on the runway, though certain systems under development will have the capability of alerting ground controllers to runway incursions.

To improve prevention of unsafe situations on the ground, taxi displays are being developed to increase both flight crews' and ground controllers' spatial awareness. A basic taxi display could show a taxiway and runway diagram of the airport, and, using INS, GNSS and/or other navigational equipment, could present the approximate location of the airplane on the airport diagram (fig. 6-4). This improves the flight crew's awareness of its position, especially in low visibility, but will not necessarily aid the pilot in steering the airplane on taxiways and avoiding other vehicles and objects on the ground. Millimeter-wave radar and/or infrared sensors onboard the airplane may be available to supplement GNSS data, as well as to provide obstacle detection. Assuming that DGPS, advanced ASDE, or some other system can provide an extremely accurate location of aircraft on the airport surface, a more advanced display could be developed to show the position of the aircraft relative to taxiways, runways, other moving and parked ground traffic, and fixed and temporary obstacles on a plan view or perspective display. To prevent air-ground conflicts, the display should also show departing aircraft and airplanes on final approach. A 2-D display could scale down to a taxi route planning view, with which a flight crew could project the airplane path from gate to runway or vice versa, or scale up to an

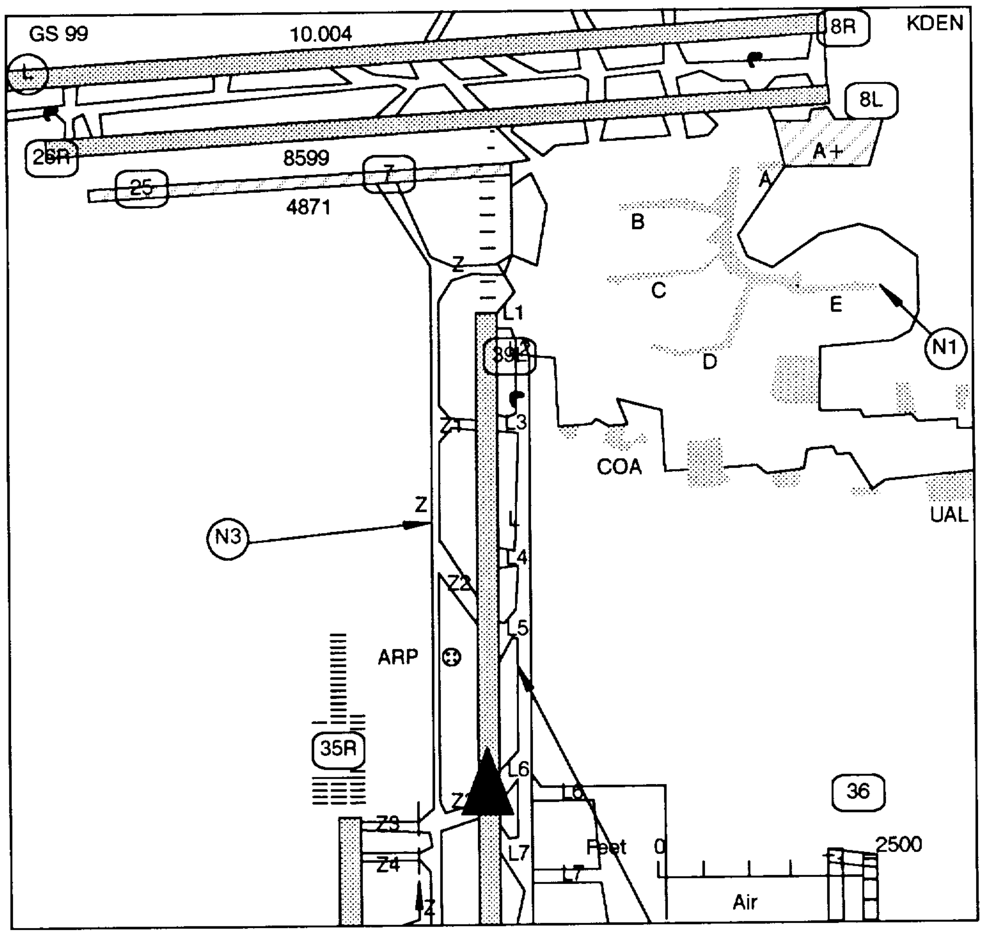


Figure 6-4. A Rudimentary Taxi Display showing aircraft position on the airport surface.

operational view, with which the pilot could steer the airplane and avoid obstructions. Advanced versions of this system may have prediction capabilities to alert the pilot of a potential collision with some object, or to warn the pilot that the aircraft is about to cross over a hold line onto an active runway.

6.2.2.6 Flight Path Management

The Flight Management System (FMS), which manages airplane flight path and profile, predicts fuel consumption and time en route, and determines key performance parameters, has become fairly commonplace on modern flight decks. These systems already allow aircraft to fly fairly complex area navigation arrivals, routes, and departures, as well as 4-D flight plans in which ATC requests the aircraft arrive at a given fix at a precise time. As ATC datalink capabilities increase, FMS's will likely receive clearances in electronic format directly from ATC, whereupon the flight crew can accept these clearances and incorporate them into the FMS flight plan with the push of a button. Conversely, the flight crew could select a proposed route modification on the FMS (to go around a thunderstorm, for example), then electronically downlink the modification to ATC as a request. In addition, the FMS might provide ground based computers with performance information to assist ATC in developing realistic profile climbs and descents. The FMS may also provide alerts and/or suggest corrective action to the crew. For example, if the airplane is about to pass through an altitude restriction or is about to "bust" any other clearance, the FMS may alert the flight crew and suggest corrective action.

Within the terminal environment, a developing technology known as pathway-in-the-sky may provide precise flight guidance during noise abatement departures and curved approach arrivals. Pathway-in-the-sky creates a 3-D pathway or "tunnel," which represents the planned flight route and profile and may be added to a forward-looking perspective display (fig. 6-5). This pathway should allow the pilot to very accurately fly (or monitor) a complex flight path while maintaining a high level of spatial awareness. The pathway generator would have logic to confirm that the programmed pathway remain clear of terrain and other obstacles.

A flight path management system that is specific to supersonic transports is a sonic boom footprint predictor. Any supersonic aircraft creates a huge cone-shaped shock wave behind itself. The curved intersection of the surface of this cone and the ground is known as the sonic boom footprint, and it is along this curve that bystanders hear the characteristic loud clap of a sonic boom. For environmental reasons, this sonic boom is not and will not be allowed to occur over populated areas. As the existing Concorde fleet is extremely small (approximately 14 airplanes), Concordes can avoid creating sonic boom by flying special departure and arrival routes which have been set up to assure the footprint will fall over unpopulated areas. Assuming a future fleet of hundreds of supersonic transports, it is probable that special priorities similar to those for the Concorde will not be allowed. These

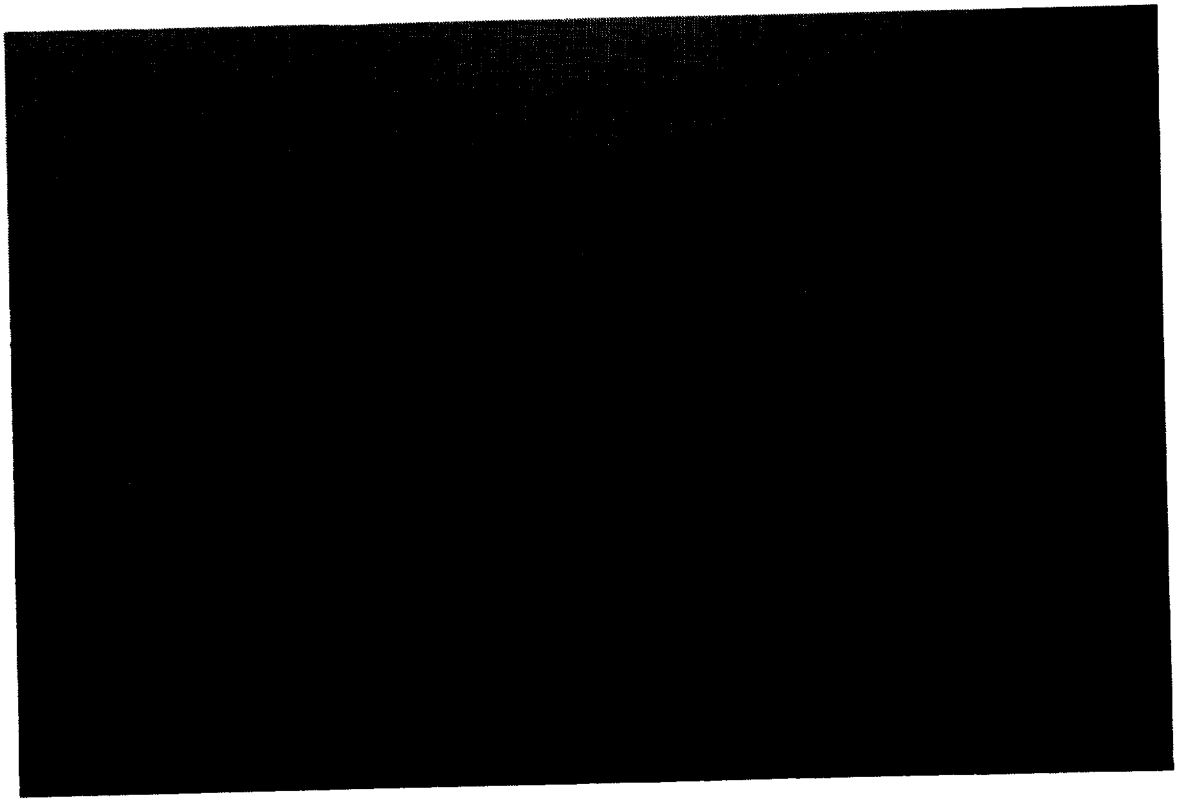


Figure 6-5. Pathway In The Sky.

future supersonic aircraft will be expected to occasionally fly off a planned path due to traffic or weather, and it then becomes the responsibility of the supersonic airplane flight crew to avoid "booming" populated areas. A plan view display that shows the calculated position of the current footprint and has the capability of predicting by which point the airplane must begin to decelerate to be below Mach 1 over populated areas would be valuable for future supersonic airplanes. The system must contain a database of the populated worldwide areas which need to be avoided.

6.2.2.7 Decision Aids

Researchers are investigating the possibility of adding expert systems to assist the human flight crew in making high level decisions during flight operations. Some of these include systems which could continuously monitor hundreds or thousands of parameters from hydraulic, electrical, powerplant, and other systems. This computer monitoring may predict failures well before the human crew, which visually monitors system indications. These systems could recommend system reconfigurations, power setting changes, flight profile or speed adjustments, or flight diversions. Diversion decision aids could assist the flight crew in choosing an alternate airport, given the current weather, airplane, and airport situations, and help the pilots plan the flight to the alternate airport. A takeoff decision aid could compare actual airplane acceleration, airspeed, and distance along the runway with calculated performance figures and recommend an abort, if necessary; while a landing decision aid could monitor airplane dynamics during approach and landing and recommend a go around, should the situation warrant. Certainly this is not a complete list of possible decision aids, and one should expect that as expert system capabilities improve in the future, electronic decision aids will assist the flight crew in many, if not all, of its decision-making tasks.

6.2.3 Advanced Information Transfer Systems

Until recently, all air/ground information transfer between commercial airplanes and ATC, the company, and other ground stations were conducted by voice. Onboard an aircraft, systems that needed to transfer information to another system were hardwired with an isolated connection. General information about airports (elevation, runway lengths, approaches, etc.), radio navigation equipment (frequencies, airway courses, etc.), was stored on paper, and read and memorized or manually input into the appropriate system by the flight crew as required. Now, with the advent of high-speed networks, lightweight and inexpensive computers, and reliable video display units, the aerospace industry has seen a rapid growth of electronic information being transferred between airplane systems and displayed to the flight crew.

Currently in use (and under development) is datalink, which refers to electronic air-air and air-ground communication. At present, datalink is limited to transfer of operations information, such as "out", "off", "on", and "in" times, en route weather, and maintenance reports, between aircraft and their respective airline company. A small number of airport clearance deliveries have the capability to transmit flight clearances via datalink. Air-air datalink is also used by TCAS systems.

In order to reduce the amount of paper carried aboard airplane flight decks, and to improve organization of large amounts of stored flight information, avionics designers are developing Electronic Library Systems (ELS). ELS has the capability of storing mass data and providing information not only directly to the flight crew but also to other systems across a data bus. Designers are hoping to provide airplane flight manuals, approach plates, and possibly taxi diagrams in electronic formats for introduction on 1995-era airplanes.

While short-term efforts in information transfer systems are limited to specialized projects, the longer-term development of these systems should take a much larger view. Computer processing speed and storage capacity have both increased radically over the past 30 years, and ongoing research suggests this growth will continue in the future. The result will be vastly increased storage capacity for mass data and significantly more processing power on next generation aircraft. Whereas ELS is a dedicated system for storing specific flight information, Centralized Electronic Storage Systems (CESS) would contain mass data accessible by the pilots and most of the aircraft systems. Datalink and gatelink (a future system which allows rapid transfer of mass storage while the aircraft is parked) would handle most information transactions to and from the aircraft.

One could compare the future flight deck environment with computer terminals on a network. Each computer can process and display information while running several applications at once. All of these applications can store and retrieve data from the computer's hard disk drive, which is analogous to a CESS. Information can be sent to and retrieved from other terminals and mainframe systems via the network. Similarly, information can be sent to and retrieved from ATC, other aircraft, and the company via datalink. Just as a computer in Los Angeles must send data through one or more gateways to transfer information to Tokyo, so must airplanes transmit information through satellite networks and ground stations from remote areas to the controlling ATC facility or the central company dispatch and management system. The end result will be a massive information network capable of moving, verifying, and recording sizable data transactions between aircraft and relevant institutions (fig. 6-6). Note that CESS may be a single storage device with appropriate backup, or it may involve several distributed units.

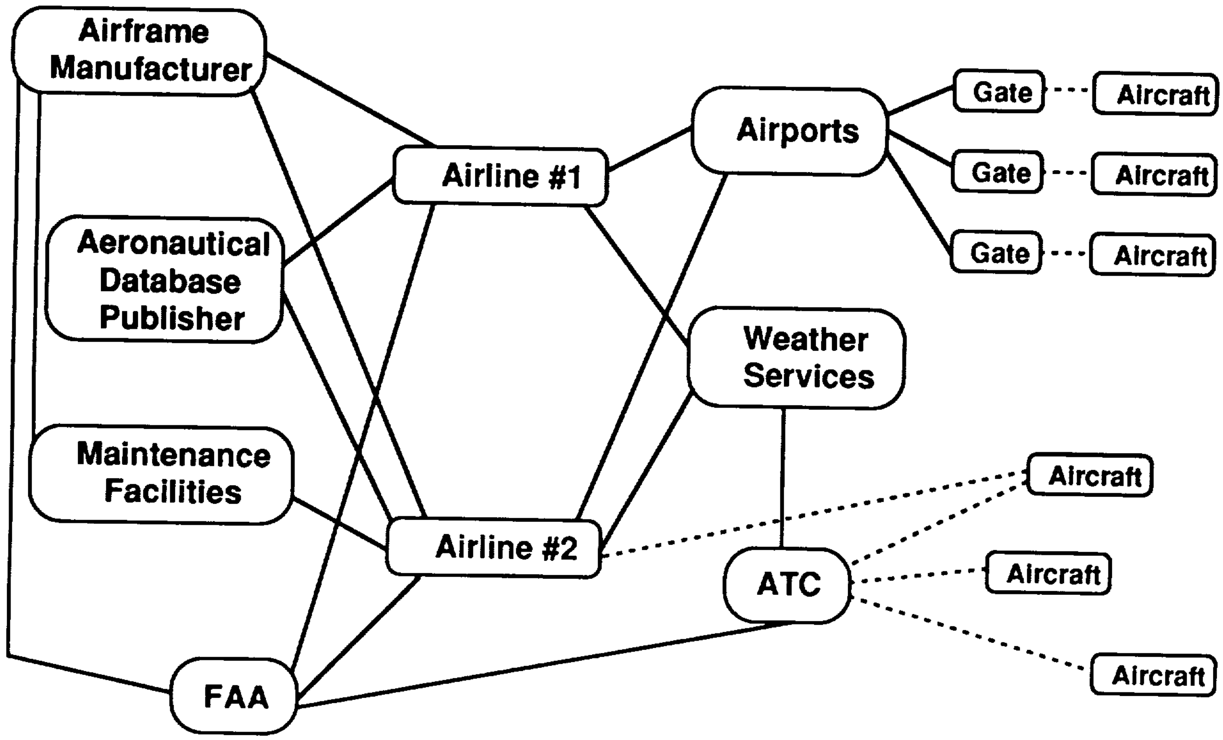


Figure 6-6. A Flight Environment Information Network. Ground-based electronic communication lines are solid, airborne datalinks and gatelink are dashed.

Advanced applications for a CESS include storage of airplane flight operations information; company procedures; relevant FAA regulations; electronic checklists; electronic maps; terrain databases; ground obstacles and features databases; airport data including airport surface information (taxiways, obstacles, hold lines, etc.) and approach and departure procedures; worldwide communications frequencies; flight logs; and all applicable maintenance information. Information in CESS could be tailored as required for the requesting system or individual human user. Passenger entertainment and cabin management information would likely be stored within a separate system.

Datalink and gatelink could be used to update and transfer information listed above, and may provide airborne transfer of ATC clearances; weather reports and forecasts (including real-time windshear and thunderstorm activity); company dispatch, maintenance, and other operational information; and personal passenger communications.

7.0 CONCLUSION

This contract is meant to be the first step in a systematic, requirements-driven approach to the design of a 2005 commercial flight deck, and especially in identifying the difficult design issues involved in this development. The first part provides an analysis of the functions that must be accomplished to complete the aircraft's normal mission and deal with non-standard situations that might arise (section 5.0).

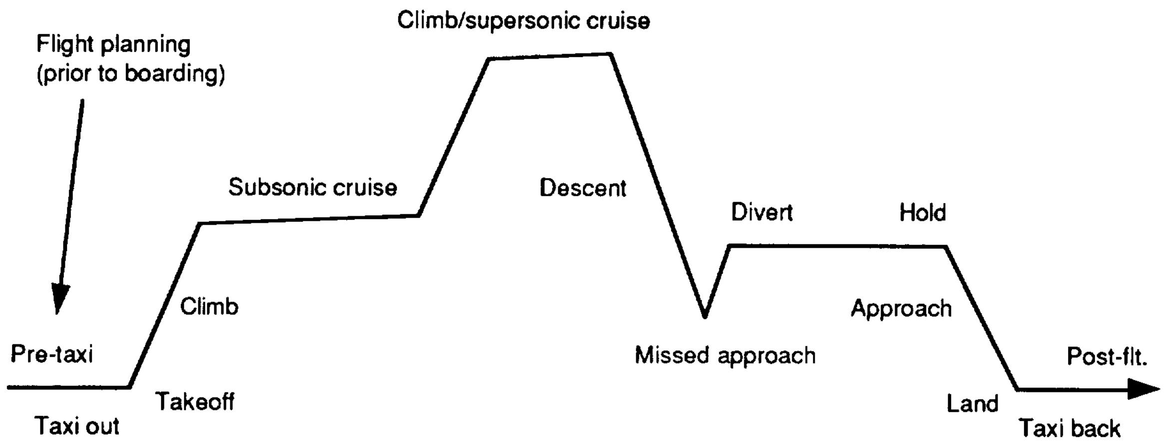
While a top-down approach to future flight deck design is highly favored, one must realize that this process is not completely independent of the existing (or forecast) technology base. That is, the procedures for accomplishing a mission, perhaps even elements of the mission itself, can be dependent on available technology. In this regard, the second part of the contract provides a description of predicted flight deck and ATC technology and procedures for the year 2005 (section 6.0).

Future steps in this design process would include breaking the identified functions down into their information requirements, allocating functions to the human flight crew or to automated systems, and then using the crew-allocated information requirements to develop a baseline flight deck design. This baseline flight deck would serve as a basis for identifying information management issues and evaluating display and control design concepts.

APPENDIX A -- FUNCTION ANALYSIS FOR NORMAL FLIGHT

See section 5.1 for details. Functions indicated in **boldface** type are specific to supersonic flight.

The function analysis is organized by flight phase. These phases are from a representative flight profile shown below.



Responsibility for functions may be allocated to either the human flight crew or automation.

FLIGHT PHASE: FLIGHT PLANNING

Note: This flight phase has not been broken down to the same level of detail as the other flight phases.

PLAN 4-D ROUTE OF FLIGHT
- Create lateral flight path
- Choose vertical flight profile
- **Differentiate subsonic/ supersonic route segments**
- Estimate time en route
- Examine alternate destination options
- Datalink requested 4-D flight plan/ temporal restrictions ("not earlier" and "not later" times) to ATC

ANALYZE WEATHER
- Forecast weather en route (includes **high-alt. winds/ radiation levels**)
- Forecast weather at destination
- Determine potential effects on flight/ hazards

DETERMINE ATC AND FACILITIES RESTRICTIONS
- Determine any deficiencies at departure/ arrival airports or en route
- Obtain any special ATC procedures required

AIRPLANE CONDITION AND PERFORMANCE
- Investigate any airplane system/ avionics problems
- MEL requirements
- Acquire estimated airplane weight
- Determine airplane performance
    - Take-off performance
    - Landing performance
    - Other
- Determine fuel requirements

FLIGHT PHASE: PREFLIGHT DUTIES

INITIALIZE SYSTEMS

- Turn on ground electrical power/ cabin recirculation as required
    - Determine ground services available (air/ electrical)
    - Engage available auxiliary power/ air as required
    - Coordinate with ground crew
- Configure systems
    - Set systems for flight
        Fuel
        Electrical
        Hydraulic
        Pneumatics
        Flight controls
        Autoflight
        Lights
        Emergency/ Fire suppression
        IRS/ Nav systems
        Displays
    - Adjust equipment settings for appropriate conditions
        Airport
        Pilot preferences
        Weather conditions
    - Confirm cargo loaded/ systems set as required/ cabin crew and passengers ready for pushback

PROGRAM FLIGHT COMPUTERS

- Enter proposed route (4-D profile)
- Enter performance
    - Airplane/ fuel/ cargo weights
    - Thrust derates
- Input weather
- Update maps/ charts/ taxi diagrams

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (departure ATIS/ clearance delivery/ ground)
    - Taxi clearance
    - Flight clearance
    - Weather updates
    - Ground holds/ other pre-taxi information
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
    - Revise clearance and resubmit to ATC if necessary
- Uplink/ downlink information as required
- Ground crew: Airplane secure and fueled/ equipment cleared
- Company: Maintenance issues/ schedule issues
- Confirm weather above minimums as required for dispatch

- Cabin crew as required
- Passengers as required

ENGINE START
- Clear ahead/ behind engines
- Initiate start procedure for each engine
- Monitor start for abnormalities
- Abort start if necessary

MANAGE SYSTEMS
- Reconfigure systems after engine start as required
- Monitor systems

PUSHBACK
- Confirm airplane ready for departure
    - Cargo loaded/ doors closed
    - Jetway retracted
    - Ground equipment clear
- Monitor pushback
    - Brakes released
    - Nosegear free
    - Airplane turned in correct direction
    - Airplane clear of obstructions

FLIGHT PHASE: TAXI OUT

PLAN TAXI PATH
- Optimize ground route to runway
  - Accept standard routing if adequate
  - Avoid areas of heavy ground traffic if possible
  - Request special routing if applicable
  - Request different runway if applicable
- Reference taxiway maps
  - Consider airplane size/ weight limitations
  - Identify relevant amendments (e.g. construction)
- Monitor taxiway conditions
  - Identify closed taxiways

CONTROL GROUND PATH
- Follow ground track laterally
  - Follow taxi centerline
    - Err right: steer left to intercept proper path
    - Err left: steer right to intercept proper path
  - Use differential thrust/ braking as required
- Avoid obstacles
  - Identify obstacle/ airplane conflicts
    - Airplane nose
    - Landing gear
    - Wing tips
    - Nacelles
    - Tail
  - Maneuver to avoid obstacle
    - Remain within taxiway boundaries
- Avoid foreign object ingestion
  - Identify foreign substances on taxiway
  - Determine if substance is ingestible
    - Not ingestible: avoid substance
- Avoid upsetting other obstacles with jet exhaust
  - Identify objects behind and near airplane
    - Ground equipment
    - Other airplanes
    - Buildings/ facilities
    - Large amounts of snow/ ice/ standing water
  - Determine if conflict exists
    - Conflict exists: turn airplane to new heading/ limit thrust/ have ground crew clear area behind airplane
- Control speed
  - Set breakaway thrust/ reduce thrust as airplane starts to move
  - Monitor ground speed
    - Fast: decelerate (brake/ decrease thrust)
    - Slow: accelerate (reduce brake/ increase thrust)

- Stop as required
    - Predict braking distance
    - Reduce thrust to idle
    - Brake as required
    - Set parking brake if necessary
- Avoid runway incursions/ stop at hold lines as required
  - Identify hold lines/ runway intersections
  - Confirm cleared to cross
    - By ground control
    - Visually
- Taxi into position on runway
  - Confirm runway/ approach path clear of other traffic
  - Release brakes
  - Add power/ reduce power as airplane starts to roll
  - Steer airplane over curved path (into position)
    - Err inside: decrease rate of turn
    - Err outside: increase rate of turn
  - Align airplane with runway centerline
  - Confirm airplane is not displaced too far from runway threshold
  - Use brakes as necessary to slow/ stop/ steer
  - Set parking brake if required
  - Check instruments
    - Runway guidance
    - Heading
    - Nosegear/ flight controls neutral

COMMUNICATE/ FOLLOW PROCEDURES
- Receive pertinent information/ clearances/ requests from ATC/ company (ground/ ramp control/ dispatch)
  - Cleared for pushback
  - Taxi clearances
  - Weather updates
  - Amendments to flight plan
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Confirm weather above minimums for takeoff
- De-ice aircraft if necessary
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS
- Monitor brakes/ engines/ steering
  - Unusual indications
    - As shown on displays
    - Sound
    - Feel
    - Sight (uncontrolled turning, etc.)
- Set takeoff configuration
  - Primary and secondary flight control surfaces
  - Autobrakes

- Autopilot
- Noise abatement system

TAKEOFF BRIEFING

FLIGHT PHASE: TAKEOFF

CONTROL GROUND PATH

- Set takeoff thrust/ verify engines producing correct and symmetric thrust
  - Increase thrust to takeoff setting
    - Check thrust increasing smoothly
    - Check all engines increasing symmetrically
    - Confirm all engines at takeoff thrust within proper time period
- Track centerline
  - Steer airplane along straight path
    - Err right: Steer left to intercept
    - Err left: Steer right to intercept
  - Monitor steering authority
  - Offset ground track from centerline if necessary
- Modify technique for crosswind/ gusts/ heavy rain/ standing water/ icy runway/ weight and C.G.
  - Monitor crosswind/ gusts
  - Monitor airplane pitch/ roll/ yaw dynamics
  - Control flight control surfaces to counter undesired motion
  - Identify extreme levels of undesired motion (wheel scrubbing/ aquaplaning/ runaway flight control surfaces)
- Identify abnormalities/ obstacles/ markers on ground path ahead of airplane
  - Other airplanes
  - Surface vehicles
  - Runway damage/ potholes
  - Baggage/ boxes/ loose equipment
  - Ice/ oil/ standing water
  - Lights/ edge lines/ centerline/ distance markings
- Abort takeoff if necessary
- Commit to takeoff at decision point (e.g., airspeed reaches V_1)
  - Identify airplane at decision point
  - Change abort procedure
- Rotate to liftoff attitude at V_R
  - Identify airplane at rotation speed
  - Rotate airplane to correct pitch attitude
  - Monitor pitch rate
  - Avoid tailstrike
  - Identify rotation abnormalities (sluggish or no rotation/ no liftoff)

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (tower)
  - Confirm cleared for takeoff
  - Confirm runway is correct runway
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Wheels-up within allotted time window

- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS

- Reconfirm systems set for takeoff
  - Release brakes
- Monitor status
  - Airspeed
    - Increasing steadily/ identify windshear
    - Compare to set values (e.g., V_1/ V_R/ V_2)
    - Matches visual scene
  - Acceleration
    - Proper positive level
    - Enough for runway length/ conditions
  - Engines
    - Developing proper thrust
    - No fires/ malfunctions
  - Flight Controls
  - Abnormal vibrations
    - Compare vibration to normal dynamics
    - Identify sources of unknown vibrations

FLIGHT PHASE: CLIMB

FLIGHT CONTROL MODES:

Note: Whether the human flight crew or automation is controlling flight guidance, during flight the airplane is always in some guidance mode; that is, the pilot or autopilot is always trying to accomplish a particular goal in both lateral and longitudinal control. Some example modes are listed here.

<u>Lateral</u>

Heading/ track hold
Turn to a heading (choose turn rate)
Intercept track
Sidestep from one track to a parallel track
Continuous turn (select bank angle)
Wings level
Complex
Limiting: bank angle

<u>Longitudinal</u>

Pitch:

Vertical speed
Altitude hold
Maximum climb/ descent angle/ rate
Intercept vertical path
As required for fixed thrust and speed
Complex
Limiting: pitch rate (wing loading)

Speed:

IAS hold
Mach hold
Speed change (acceleration/ deceleration rate)
As required for fixed thrust and pitch
Complex
Limiting: stall/ overspeed

CONTROL INITIAL FLIGHT PATH

- Confirm positive rate of climb
  - Identify altitude increasing
  - Feel/ hear liftoff
- Maintain initial climbout speed
  - If airspeed low increase thrust and/ or decrease pitch

- If airspeed high decrease thrust and/ or increase pitch

- Control airplane attitude/ windshear avoidance
  - Maintain control of airplane
    - Hold wings level as required (avoid rolling toward extreme bank angles/ wingtip scrape)
    - Hold precise pitch control (avoid stall/ descent into terrain)
  - Optimize energy management (engine out/ windshear)
- Avoid obstacles
  - Identify obstacles in flight path or potential flight path
  - Monitor time to maneuver
    - Determine obstacle clearance requirements
    - Modify path if necessary
  - Maneuver abruptly if required

CONTROL FLIGHT PATH DURING CLIMB

- Follow lateral flight path
  - Determine mode of lateral navigation
    - Optimize efficiency (Minimize time/ Minimize fuel burn/ Maximize safety/ Minimize passenger discomfort/ Maximize precision/ Reduce traffic delays)
    - Linked to longitudinal control
  - Track this path (control roll rate/ bank angle/ heading as required)
    - Small errors: correct error
    - Large errors: select new mode
- Maintain appropriate climb profile (speed/ altitude)
  - Determine mode of longitudinal navigation
    - Optimize efficiency (Minimize time to climb/ descend? Maximize fuel efficiency? Minimize imprecision?)
    - Linked to lateral control
  - Track this profile (control pitch rate/ pitch/ altitude/ thrust as required)
    - Small errors: correct error
    - Large errors: select new mode
- Maintain temporal profile
  - Maintain awareness of future time-related restrictions
  - Monitor closure rate to next fix with a time restriction
    - Adjust groundspeed as necessary to cross fix before/ at/ after time restriction as requested by ATC
    - If groundspeed adjustment is impractical, inform ATC of inability to meet time restriction
- Airspeed/ altitude restrictions
  - Identify restriction (e.g. IAS < 250 kts. below 10,000 ft. in U.S./alt. restriction at fix)
  - Monitor rate of closure to restriction (e.g. vertical speed vs. altitude to go)
    - Too fast: decrease rate of closure
  - Maintain restriction
    - Change longitudinal mode as required

- Modify route for weather/ traffic
  - Determine if weather/ traffic reduces efficiency of flight
    - Current weather en route
    - Forecast weather en route/ at alternate(s)
    - Efficiency reduced: change control mode/ routing to re-optimize efficiency

AVOID COLLISIONS

- Avoid stationary hazards (terrain/ obstructions)
  - Identify potential/ actual obstacles
    - Visually
    - Below minimum safe altitude for sector
    - Below assigned/ procedure altitude
    - Off procedure course
    - Radar
    - Ground proximity system
    - Advanced terrain avoidance system
    - ATC calls you below minimum vectoring altitude
  - Avoid potential obstacles
    - Maintain separation from obstacle
    - Be alert to deviations from planned flight path
  - Avoid actual obstacles
    - Plan avoidance maneuver if time permits
    - Change control mode to track avoidance maneuver
    - Evasive if required
      - Increase/ decrease thrust
      - Bank hard left/ right
      - Pitch up/ down
      - Exceed speed/ load limitations as required
- Avoid moving hazards [other airplane/ temporary (cranes/ balloons)]
  - Identify potential/ actual obstacles
    - Visually
    - ATC calls traffic
    - Other airplane/ ATC communications ("party line")
    - TCAS
    - NOTAMs
  - Avoid potential obstacles
    - Maintain separation from obstacle
    - Be alert to deviations from planned flight path
    - Be alert to changes in obstacles path/ location
  - Avoid actual obstacles
    - Plan avoidance maneuver if time permits
      - Predict future movement of obstacle
    - Change control mode to track avoidance maneuver
    - Evasive if required
      - Increase/ decrease thrust
      - Bank hard left/ right
      - Pitch up/ down
      - Exceed speed/ load limitations as required

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (departure control/ center)
  - Follow SID/ vectors
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required

MANAGE SYSTEMS

- Retract gear
  - Identify gear retraction point
  - If safe at this point retract gear
- Retract flaps/ other secondary flight control surfaces on schedule
- Modify thrust as required
  - Confirm thrust at proper level for given flight segment
  - Change thrust to match situation (e.g. extra climb power/ stop climb immediately)
- Engage autoflight systems as required
  - Determine point to engage autoflight systems
  - Confirm flight modes set correctly
  - If safe engage autoflight
    - Monitor autopilot takeover
    - Disconnect autopilot if system not working properly
- Monitor systems
  - Scan system parameters with priority to more important systems
  - System value out of proper parameters
    - Identify problem
    - Confirm problem if possible
    - Determine corrective measure
    - Take corrective action if required
- Set systems as required
  - Reset to more efficient configuration
  - Reset barometric altimeter
  - Set nav radios and other position info source equipment as required

FLIGHT PHASE: SUBSONIC CRUISE

CONTROL FLIGHT PATH (See CLIMB for details and flight control modes)

- Follow lateral flight path
  - Determine mode of lateral navigation
    - Optimize efficiency
    - Linked to longitudinal control
  - Track this path
    - Small errors: correct error
    - Large errors: select new mode
- Maintain appropriate longitudinal profile (speed/ alt.)
  - Determine mode of longitudinal navigation
    - Optimize efficiency
      - Determine speed for cruise
    - Linked to lateral control
  - Track this profile
    - Small errors: correct error
    - Large errors: select new mode
- Maintain temporal profile
  - Maintain awareness of future time-related restrictions
  - Monitor closure rate to next fix with a time restriction
    - Adjust groundspeed as necessary to cross fix before/ at/ after time restriction as requested by ATC
    - If groundspeed adjustment is impractical, inform ATC of inability to meet time restriction
- Airspeed/ altitude restrictions
  - Identify restriction
  - Monitor rate of closure to restriction
    - Too fast: decrease rate of closure
  - Maintain restriction
    - Change longitudinal mode as required
- Modify route for weather/ traffic
  - Determine if weather/ traffic reduces efficiency of flight
    - Current weather en route
    - Forecast weather en route/ at alternate(s)
    - Efficiency reduced: change control mode/ routing to re-optimize efficiency

AVOID COLLISIONS (SAME AS CLIMB-see CLIMB for detailed subfunctions)

- Avoid stationary hazards (terrain/ obstructions)
- Avoid moving hazards [other airplane/ temporary (cranes/ balloons)]

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (center)
  - Route updates
  - Weather reports
    - Receive updated weather
    - Examine weather with respect to future flight path/ destination/ alternate(s)
    - Modify flight path as necessary
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Set nav radios and other position info source equipment
- Change between ARTCC sectors
- Communicate with company
  - Maintenance
  - Flight schedule
  - Passenger requirements
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS

- Monitor systems (See CLIMB for details)
- Set systems as required
  - Reconfigure fuel
  - Anti-Ice
  - Exterior lights
  - Update flight computers

ATTEND TO PILOT NEEDS

- Eat/ drink/ smoke
- Go to lavatory

FLIGHT PHASE: SUPERSONIC CLIMB/ CRUISE

CONTROL FLIGHT PATH (See CLIMB for details and flight control modes)

- Follow lateral flight path
  - Determine mode of lateral navigation
    - Optimize efficiency
    - Determine limitations due to speed (e.g. turn radius)
    - Linked to longitudinal control
  - Track this path
    - Small errors: correct error
    - Large errors: select new mode
    - Limit bank angle to avoid boom focusing
- Maintain appropriate longitudinal profile (speed/ alt.)
  - Determine mode of longitudinal navigation
    - Optimize efficiency
      - Determine speed for supersonic cruise
      - Control speed to limit nose temperature
    - Linked to lateral control
  - Track this profile
    - Small errors: correct error
    - Large errors: select new mode
- Maintain temporal profile
  - Maintain awareness of future time-related restrictions
  - Monitor closure rate to next fix with a time restriction
    - Adjust groundspeed as necessary to cross fix before/ at/ after time restriction as requested by ATC
    - If groundspeed adjustment is impractical, inform ATC of inability to meet time restriction
- Airspeed/ altitude restrictions
  - Identify restriction
  - Monitor rate of closure to restriction
    - Too fast: decrease rate of closure
  - Maintain restriction
    - Change longitudinal mode as required
- Modify route for weather/ traffic
  - Determine if weather/ traffic reduces efficiency of flight
    - Current weather en route
    - Forecast weather en route/ at alternate(s)
    - Efficiency reduced: change control mode/ routing to re-optimize efficiency

AVOID COLLISIONS

- Avoid moving hazards (SAME AS CLIMB)

AVOID SONIC BOOM OVER NOISE SENSITIVE AREAS

- Monitor boom track
  - Monitor location of boom track intersecting with Earth's surface

- Determine areas of potential focusing
- Receive real time information from ground, if available
- Predict future boom profile
  - Actual flight path
  - Planned flight path
- Avoid allowing boom to enter noise sensitive areas
  - Define noise sensitive areas/ points on surface
  - Determine whether boom track will cross sensitive areas
  - Boom track crosses sensitive areas:
    - Replan route laterally
    - Replan route vertically if applicable
    - Slow to subsonic speed
    - Obtain clearance to cross area

COMMUNICATE/ FOLLOW PROCEDURES (SAME AS SUBSONIC CRUISE)

MANAGE SYSTEMS
- Monitor
  - Radiation
    - Determine current radiation level
    - Determine trend
    - Monitor forecast activity
- Set as required
  - Configure for supersonic flight at Mach 1/ accelerating
  - Reconfigure fuel
    - Predict fuel burn effect on airplane center of gravity
    - Reconfigure to keep center of gravity within limits
  - Update flight computers
- Thermal management
  - Structure temperature
    - Monitor current temperature
    - Determine rising/ falling trend
  - Fuel temperature
    - Monitor current temperature
    - Determine rising/ falling trend

ATTEND TO PILOT NEEDS
(SEE SUBSONIC CRUISE)

FLIGHT PHASE: DESCENT

PLAN APPROACH
- Determine arrival airport conditions/ procedures/ effects on flight
  - Weather
  - Traffic
  - Airport/ terminal area conditions
  - Arrivals and approaches
    - Altitude restrictions
    - High terrain
  - Noise abatement procedures
- Preview critical areas of arrival
- **Determine supersonic to subsonic transition point**
  - **Determine predicted point of boom degeneration**
  - **If problem:**
    - **Recompute top of descent**
    - **Adjust arrival route**
      - **High terrain**
      - **Heavy traffic**
      - **Weather**

CONTROL FLIGHT PATH (See CLIMB for details and flight control modes)
- Follow lateral flight path
  - Determine mode of lateral navigation
    - Optimize efficiency
    - **Determine limitations due to speed (e.g. turn radius)**
    - Linked to longitudinal control
  - Track this path
    - Small errors: correct error
    - Large errors: select new mode
    - **Limit bank angle to avoid boom focusing**
    - **Mach number < 1 before boom track enters noise sensitive areas**
- Maintain appropriate longitudinal profile (speed/ alt.)
  - Determine mode of longitudinal navigation
    - Optimize efficiency
      - **Limit nose temperature**
    - Linked to lateral control
  - Track this profile
    - Set thrust for proper deceleration/ descent
    - Small errors: correct error
    - Large errors: select new mode
- Maintain temporal profile
  - Maintain awareness of future time-related restrictions

- Monitor closure rate to next fix with a time restriction
  - Adjust groundspeed as necessary to cross fix before/ at/ after time restriction as requested by ATC
  - If groundspeed adjustment is impractical, inform ATC of inability to meet time restriction
- Airspeed/ altitude restrictions
  - Identify restriction
  - Monitor rate of closure to restriction
    - Too fast: decrease rate of closure
  - Maintain restriction
    - Change longitudinal mode as required
- Modify route for weather/ traffic
  - Determine if weather/ traffic reduces efficiency of flight
    - Current weather en route
    - Forecast weather en route/ at alternate(s)
    - Efficiency reduced: change control mode/ routing to re-optimize efficiency

AVOID COLLISIONS (SAME AS CLIMB-see CLIMB for detailed subfunctions)
- Avoid fixed hazards
- Avoid moving hazards

AVOID SONIC BOOM OVER NOISE SENSITIVE AREAS (SAME AS SUPERSONIC CRUISE)
- **Monitor boom track**
- **Predict future boom profile**
- **Avoid allowing boom to enter noise sensitive areas**

COMMUNICATE/ FOLLOW PROCEDURES
- Receive pertinent information/ clearances/ requests from ATC (center/ approach/ arrival ATIS)
  - Route updates
  - Weather reports
    - Receive updated weather
    - Weather/ arrival information at destination
    - Modify flight path/ systems (e.g. anti-ice) as necessary
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Set nav radios and other position info source equipment
- Communicate with company
  - Maintenance
  - Flight schedule
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS

- Monitor
- Set as required
  - **Configure for subsonic flight at Mach 1/ decelerating**
  - Exterior lights
  - Update flight computers for approach (STAR/ approach proc.)
  - Reset barometric altimeter
- **Thermal management**
  - **Structure temperature**
    - **Monitor current temperature**
    - **Determine rising/ falling trend**
  - **Fuel temperature**
    - **Monitor current temperature**
    - **Determine rising/ falling trend**

FLIGHT PHASE: APPROACH

CONTROL FLIGHT PATH

- Follow arrival procedures/ vectors to final approach
    - Continuously determine safety/ efficiency of clearances
    - Request deviation if necessary
- Slow to approach speed as per flight plan/ ATC clearance
    - Plan deceleration to arrive at final approach fix at approach speed/ configuration/ required time of arrival
        - Deceleration too high: Increase thrust/ retract spoilers
        - Deceleration too low: Reduce thrust/ extend spoilers/ reroute if necessary
    - Limit airspeed as required
        - Overspeed
        - Stall speeds
        - As per ATC request
- Intercept final approach path
    - Anticipate interception
        - Determine lead point
        - Determine predicted turn radius (rate)
    - Execute turn
        - Err inside: decrease rate of turn
        - Err outside: increase rate of turn
        - Limit bank angle as necessary
        - Large error: determine new intercept course/ request new clearance (e.g. 360° turn)
- Track final approach path
    - Small errors: correct error
    - Large errors: select new mode
- Follow appropriate glideslope
    - Small errors: correct error
    - Large errors: select new mode
- Maintain approach speed
    - If airspeed low increase thrust and/ or decrease pitch
    - If airspeed high decrease thrust and/ or increase pitch
- Control airplane attitude/ windshear avoidance
    - Maintain control of airplane
        - Hold wings level as required (Avoid rolling toward extreme bank angles/ wingtip scrape)
        - Hold precise pitch control (Avoid stall/ descent into terrain)
        - Optimize energy management (Engine out/ windshear)

AVOID COLLISIONS

- Avoid obstacles
    - Identify obstacles in flight path or potential flight path (including obstacles on runway)
        - Monitor time to maneuver
        - Determine obstacle clearance requirements

- Modify path if necessary
- Maneuver abruptly if required

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (approach/ tower)
  - Approach clearance
  - Landing clearance
  - Windshear alert
  - Runway condition
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Tune landing navigation equipment (ILS/ MLS) as required
  - Confirm receiving/ correct station for approach
- Determine whether weather conditions are above minimums at appropriate points in approach (e.g., FAF/ MDA/ DH)
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS

- Configure for approach
  - Extend flaps/ other secondary flight control surfaces to approach position
  - Extend landing gear
    Identify gear extension point
    If safe at this point extend gear
  - Arm autobrakes/ ground spoilers/ other automatic braking systems
  - Configure external lights as required

FLIGHT PHASE: MISSED APPROACH

CONTROL FLIGHT PATH

- Set go around thrust (and verify)
    - Command go around engine power
    - Verify engines promptly increasing thrust
    - Thrust insufficient: Set maximum thrust
- Accelerate/ decelerate to go around airspeed
    - Set pitch to go around attitude
    - Verify speed changing to go around speed
- Attain/ verify positive rate of climb
    - Verify vertical speed increasing through zero
    - Vertical speed remains negative:
        - Increase pitch if available
        - Increase thrust
- Follow flight path/ vectors
    - Published missed approach procedure or as assigned
- Accelerate/ climb on profile
    - Maintain initial climbout speed
        - If airspeed low increase thrust and/ or decrease pitch
        - If airspeed high decrease thrust and/ or increase pitch
    - Control airplane attitude/ windshear avoidance
        - Maintain control of airplane
            - Hold wings level as required (Avoid rolling toward extreme bank angles/ wingtip scrape)
            - Hold precise pitch control (Avoid stall/ descent into terrain)
        - Optimize energy management (Engine out/ windshear)

AVOID COLLISIONS

- Avoid obstacles
    - Identify obstacles in flight path or potential flight path (including obstacles on runway)
        - Monitor time to maneuver
        - Determine obstacle clearance requirements
    - Modify path if necessary
    - Maneuver abruptly if required

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (tower/ departure)
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
    - Advise tower of missed approach
- Uplink/ downlink information as required
- Company
    - Schedule
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS

- Retract gear
  - Identify gear retraction point
  - If safe at this point retract gear
- Retract flaps on schedule
- Modify thrust as required
  - Confirm thrust at proper level for given flight segment
  - Change thrust to match situation (e.g. extra climb power/ stop climb immediately)
- Engage autoflight systems as required
  - Determine point to engage autoflight systems
  - Confirm flight modes set correctly
  - If safe engage autoflight
    - Monitor autopilot takeover
    - Disconnect autopilot if system not working properly

PLAN FUTURE ACTION

- Select alternate airport if necessary
  - Determine whether to stay at intended destination or to divert to an alternate
    - Weather concerns
    - Traffic
    - Airport status
  - Remain here:
    - State intentions to ATC for vectors for another approach
    - Request priority if necessary
  - Divert:
    - Choose alternate
- Plan route to alternate
  - Optimize route to alternate
    - Lateral course
    - Choose en route altitude
      - Determine top of climb/ top of descent points
      - Meet crossing restrictions
    - Fuel constraints
      - Determine if fuel predictions meet company/ regulatory requirements
      - Insufficient fuel: modify route/ change alternate/ declare emergency if necessary
    - Weather constraints
      - Determine weather en route
      - Weather at alternate
      - Modify route as required due to weather
      - Change alternate if necessary
  - Review route to alternate with flight crew
    - Terrain
      - Examine en route terrain features
      - Identify areas of high terrain/ peaks near en route course
      - Minimum safe altitudes/ minimum en route altitudes

NOTAMs

- En route facilities
- Navigation stations
- Alternate airport NOTAMs

Approaches

- Preview possible approaches to be used at destination

Navigation and communication frequencies to be used

FLIGHT PHASE: DIVERT

CONTROL FLIGHT PATH
(SEE CLIMB/ SUBSONIC CRUISE)

AVOID COLLISIONS
(SEE CLIMB/ SUBSONIC CRUISE)

COMMUNICATE/ FOLLOW PROCEDURES
(SEE CLIMB/ SUBSONIC CRUISE)

MANAGE SYSTEMS
(SEE CLIMB/ SUBSONIC CRUISE)

PLAN FUTURE ACTION
- Revise flight plan as necessary

FLIGHT PHASE: HOLD

CONTROL FLIGHT PATH
- Define hold parameters
  - Location/ altitude of hold
  - Direction of turns/ leg lengths
    - As published
    - As requested by ATC
  - Expect Further Clearance time
  - Entry
  - Holding airspeed
    - Airspeed set to optimize efficiency (minimum fuel burn over time)
- Follow flight path to holding pattern
- Follow hold laterally/ maintain altitude/ speed
- Exit hold and proceed en route when cleared
  - Resume normal en route airspeed

AVOID COLLISIONS (SAME AS CLIMB)
- Avoid fixed hazards
- Avoid moving hazards

COMMUNICATE/ FOLLOW PROCEDURES
- Receive pertinent information/ clearances/ requests from ATC (center/ approach)
  - Acknowledge receipt of holding instructions
  - Route updates
  - Weather reports
    - Receive updated weather
    - Examine weather with respect to future flight path/ destination/ alternate(s)
    - Modify flight path/ systems (e.g. anti-ice) as necessary
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Communicate with company
  - Flight schedule
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS
- Monitor systems
- Set systems as required for hold

PLAN FUTURE ACTION
- Revise flight plan/ ETA and fuel at destination
- Examine fuel/ weather constraints
  - Determine if predicted fuel at destination is above requirements
  - Fuel quantity not enough: Request priority handling/ divert/ declare emergency if necessary
  - Receive new weather forecasts for revised arrival time

FLIGHT PHASE: LANDING

CONTROL FLIGHT PATH
- Confirm runway clear of obstacles
- Control rate of descent for touchdown at desired point along runway
    - Determine proper aim point on runway
    - Maintain precise flight path angle control
        - Touchdown point short of desired aim point: increase flight path angle to re-intercept proper glidepath
        - Touchdown point long of desired aim point: decrease flight path angle to re-intercept proper glidepath
        - Avoid high rate of descent near ground
    - Control speed
        - Maintain selected approach speed
        - Avoid extremely low thrust settings (in case of go around)
- Align airplane with runway centerline
    - Set lateral track along runway centerline or desired touchdown lane
        - Left of desired track: turn right to re-intercept extended centerline
        - Right of desired track: turn left to re-intercept extended centerline
- Correct for crosswind
    - Monitor crosswind/ crab angle
    - Determine decrab point
    - Decrab at appropriate point
        - Adjust airplane heading to align main landing gear to runway heading/ hold heading
        - Bank to keep track aligned with runway
- Flare
    - Determine flare point (or altitude)
    - Flare at appropriate point
        - Adjust pitch to touchdown attitude
        - Control pitch rate as required
        - Reduce thrust as required
        - Control vertical speed to achieve shallow rate of descent at touchdown

GROUND ROLL
- Derotate
    - Pitch down to level attitude
    - Control pitch rate as required
- Track guidance along centerline
    - Steer airplane along straight path
        - Err right: Steer left to intercept
        - Err left: Steer right to intercept
    - Use differential braking/ reversers as necessary
    - Monitor steering authority
    - Offset ground track from centerline if necessary
- Correct for crosswind/ gusts/ weight and C.G.
    - Monitor crosswind
    - Monitor airplane pitch/ roll/ yaw/ dynamics

- Control flight control surfaces to counter undesired motion
- Identify extreme levels of undesired motion (wheel scrubbing/ aquaplaning/ runaway flight control surfaces)
- Use control surfaces to keep weight on wheels

• Decelerate as required
  - Determine braking required based on
    - Field length
    - Airplane performance
    - Runway condition
    - Actual touchdown point/ speed
  - Operate braking devices
    - Wheel brakes
    - Spoilers
    - Thrust reversers
  - Monitor actual deceleration/ actual runway remaining ahead
    - Deceleration too high: decrease braking
    - Deceleration too low: increase braking

• Identify abnormalities/ obstacles/ markings on ground path ahead of airplane
  - Other airplanes
  - Surface vehicles
  - Runway damage/ potholes
  - Baggage/ boxes/ loose equipment
  - Ice/ oil/ standing water
  - Lights/ edge lines/ centerline/ distance markings

AVOID COLLISIONS
• Avoid fixed hazards
• Avoid moving hazards

COMMUNICATE/ FOLLOW PROCEDURES
• Communicate with tower
• Uplink/ downlink information as required

MANAGE SYSTEMS
• After touchdown
  - Confirm activation of automatic braking systems
  - If automatic systems fail, activate braking systems manually

PLAN FUTURE ACTION
• Execute go around if necessary

FLIGHT PHASE: TAXI BACK

PLAN TAXI PATH

- Exit runway
  - Verify airplane has completely crossed hold line
- Optimize ground route to gate
  - Determine gate assignment
  - Avoid areas of heavy ground traffic if possible
  - Request special routing if applicable
  - Request different gate if required
- Reference taxiway maps
  - Identify airplane size/ weight limitations
  - Identify relevant amendments (e.g. construction, etc.)
- Monitor taxiway conditions
  - Identify closed taxiways

CONTROL GROUND PATH

- Follow ground track laterally
  - Follow taxi centerline
    - Err right: steer left to intercept proper path
    - Err left: steer right to intercept proper path
  - Use differential thrust/ braking as required
- Avoid obstacles (acknowledge size of HSCT)
  - Identify obstacle/ airplane conflicts
    - Airplane nose
    - Landing gear
    - Wing tips
    - Nacelles
    - Tail
  - Maneuver to avoid obstacle
    - Avoid hitting different obstacle
    - Avoid going off taxiway
- Avoid foreign object ingestion
  - Identify foreign substances
  - Determine if substance is ingestible
    - Not ingestible: avoid substance
- Avoid upsetting other ground objects with jet exhaust
  - Identify objects behind and near airplane
    - Ground equipment
    - Other airplanes
    - Buildings/ facilities
    - Large amounts of snow/ ice/ standing water
  - Determine if conflict exists
    - Conflict exists: turn airplane to new heading/ limit thrust/ have ground crew clear area behind airplane
- Control speed
  - Set breakaway thrust/ reduce thrust as airplane starts to move

- Monitor ground speed
    - Fast: decelerate (brake/ decrease thrust)
    - Slow: accelerate (reduce brake/ increase thrust)
- Stop as required
    - Predict braking distance
    - Reduce thrust to idle
    - Brake as required
    - Set parking brake if necessary

- Avoid runway incursions/ stop at hold lines
    - Identify hold lines/ runway intersections
    - Confirm cleared to cross
        - By ground control
        - Visually
    - Exercise caution
- Taxi into gate for parking
    - Track centerline at gate
    - Stop at correct position line for airplane

COMMUNICATE/ FOLLOW PROCEDURES

- Receive pertinent information/ clearances/ requests from ATC (ground/ ramp control/ company)
    - Taxi control
    - Weather updates
    - Gate assignment
    - Passenger requirements
- Acknowledge receipt of ATC clearances
- Transmit requests to ATC
- Uplink/ downlink information as required
- Cabin crew as required
- Passengers as required

MANAGE SYSTEMS

- Configure for taxi/ gate arrival
    - External lights
    - Primary/ secondary flight control surfaces
    - Start APU if required
    - Set parking brake at gate

FLIGHT PHASE: POST FLIGHT DUTIES

SHUT DOWN ENGINES
- Monitor engines during shutdown

MANAGE SYSTEMS
- Set gate configuration
    - Fuel
    - Hydraulics
    - Pneumatics
    - Electrical
    - Parking Brake

COMPLETE PASSENGER-RELATED REQUIREMENTS
- Turn off seat belt sign

COMMUNICATE
- Ground crew
- Cabin crew
- Company
- Uplink/ downlink information as required

APPENDIX B--EFFECTS AND FUNCTION ANALYSIS FOR NON-NORMAL FLIGHT

See section 5.2 for details. Effects and functions indicated in **boldface** type are specific to supersonic flight.

NON-NORMAL CATEGORY: AIRPLANE SYSTEMS

ENGINE MALFUNCTION

- Immediate Effects: Attitude control effect (roll, pitch into dead engine), speed loss, potential loss of other engines, potential system malfunction, potential structural damage, loss of engine data
- Subsequent Effects: Efficiency effect (current flight route, altitude are not optimal), new altitude ceiling, decreased system redundancy, loss of thrust reverser, potential unknown damage to airplane
- Unaware: Potential loss of engine-related systems, potential autoflight problems

- Response:

  Maintain directional, attitude control
  Determine primary malfunction
  Take stabilizing action
  Determine secondary system effects
  Replan flight route as required
  Determine potential future effects of malfunctions and plan accordingly

ENGINE FIRE

- Immediate Effects: Same as engine malfunction + potential spread of fire, thermal problems, potential explosion
- Subsequent Effects: Same as engine malfunction
- Unaware:

- Response:

  Same as engine malfunction

ENGINE CONTROL SYSTEM PROBLEMS

- Immediate Effects: Same as engine malfunction + dynamic changes in directional control, thrust
- Subsequent Effects: Same as engine malfunction
- Unaware:

- Response:

  Same as engine malfunction

SYSTEM MALFUNCTION (FAIL-OPERATIONAL)

- Immediate Effects: Potentially degraded performance
- Subsequent Effects: Redundancy decrease
- Unaware: Potential difficultly with degraded performance, potentially unaware of reduced redundancy

- Response:

  Identify malfunction
  Modify system configuration to account for malfunction
  Determine potential future effects of malfunction and plan accordingly

SYSTEM MALFUNCTION (FAIL-SAFE)

- Immediate Effects: Potentially degraded performance
- Subsequent Effects: Potential total loss of system in future
- Unaware:

- Response:

  Identify malfunction
  Modify system configuration to account for malfunction
  Determine potential future effects of malfunction and plan accordingly (develop plan for potential loss of system)
  Replan flight route as required

SYSTEM MALFUNCTION (COMPLETE FAILURE)

- Immediate Effects: Total loss of system (potential loss of airplane)
- Subsequent Effects: No redundancy, need for substitute (creativity required)
- Unaware:

• Response:

Maintain control of airplane
Substitute failed system capability with other systems (if possible)
Replan flight route as required
Determine potential future effects of malfunctions and plan accordingly

CABIN DEPRESSURIZATION

• Immediate Effects: Passengers, crew need oxygen; cabin temperature, pressure decrease; condensation, dust, debris and wind; structural damage
• Subsequent Effects: Efficiency effect (need to fly at lower alt. for safety)
• Unaware: If not immediately aware, time available before complete depressurization is lost. Also in case of a growing leak, a small problem can turn into a much larger problem

• Response:

Maintain control of airplane
Verify depressurization
Initiate rapid descent
Don oxygen masks
Verify passengers oxygen working
Complete any other emergency procedures for depressurization
Determine secondary system effects
Replan flight route as required
Determine potential future effects of malfunctions and plan accordingly

THERMAL PROBLEMS

• Immediate Effects: Potential cabin environment problems, potential passengers/ crew discomfort/ incapacitation, potential condensation, hot surfaces; **potential structural overheat, structural damage; potential fuel overheat**
• Subsequent Effects: Potential irreversible situation with normal controls
• Unaware: Thermal situation may become critical

• Response:

Determine nature of thermal problem
Correct problem with normal controls, if possible
Decelerate, if necessary
Replan flight route as required
Determine potential future effects of thermal situation and plan accordingly

STRUCTURAL DAMAGE

- Immediate Effects: Potential directional control problems, potential loud, continuous noise, potential system malfunction, potential thermal problems
- Subsequent Effects: Potential worsening of condition, limited maneuverability, limited control rates; efficiency effect, effect on landing
- Unaware: Likely worsening of condition, but also more cues
- Response:

  Identify location, type of structural failure, if possible
  Take action to prevent spread of failure
  Limit g-loading
  Determine effect of control system, other systems
  Replan flight route as required
  Determine potential future effects and plan accordingly

FLIGHT CONTROL SYSTEM/ SURFACE FAILURE

- Immediate Effects: Directional control (may not be obvious), potential system malfunction, potentially critical situation in seconds, overstress, stall, or overspeed
- Subsequent Effects: Reduced redundancy, decreased maneuvering ability, potential random control command and response
- Unaware: Not aware of decreased redundancy, decreased maneuvering ability
- Response:

  Maintain control of airplane
  Reconfigure control systems as required for immediate control
  Determine nature of control problem
  Reconfigure systems as required
  Limit maneuvering to account for system failure
  Replan flight route as required

FLIGHT MANAGEMENT SYSTEM MALFUNCTION

- Immediate Effects: Appropriate guidance lost, some information sources lost, potential erroneous information input to pilot
- Subsequent Effects: Higher workload; more tasks allocated to human flight crew
- Unaware: Depends on which information is unreliable, e.g. may lead to unsafe speed, busted clearance with incorrect guidance, or may lead to incorrect performance information (range, fuel, power, etc.) with performance system malfunctions

• Response:

Determine which instruments are definitely reliable
Immediately fly airplane with reference to reliable instruments
Determine nature of FMS malfunction
Reconfigure FMS systems as required
Explore possible secondary effects of FMS malfunction

AUTOFLIGHT MALFUNCTION

• Immediate Effects: Directional control problems; potential incorrect path guidance. During autoland: potential rapid path divergence
• Subsequent Effects: More tasks allocated to human flight crew
• Unaware: Potential busted clearance; potential transgression outside flight envelope; potential incorrect path

• Response:

Revert to backup flight control (manual or other)
Immediately fly airplane with reference to reliable instruments
Determine nature of flight control problem
Reset/ reconfigure autoflight, if possible
Maintain increased vigilance over autoflight control

VISION SYSTEM PROBLEM (cracked window, failed sensor, etc.)

• Immediate Effects: If system is not immediately required (e.g. during high altitude cruise) rely on autoflight or other displays; if system is immediately required, other systems must substitute, and types of maneuvers should be limited to the capabilities of the substitute systems
• Subsequent Effects:
• Unaware:

• Response:

Positively determine vision system problem exists
Immediately fly airplane with reference to reliable instruments
Limit maneuvers to capabilities of reliable instruments
Correct vision system problem, if possible
Determine future effects of vision system problem

FLIGHT INSTRUMENT/ CONTROL CONTAMINATION

- Immediate Effects: Contaminated instrument temporarily unusable
- Subsequent Effects: Potential re-failure
- Unaware: Potential erroneous information to pilot when instrument needs to be used

- Response:

  Control flight path with reliable instruments
  Identify which instruments/ controls have been affected by contamination
  Attempt to reset contaminated instruments (priority to most necessary instruments)
    Verify reset instruments working and reliable
  Monitor reset instruments for potential re-failure

NON-NORMAL CATEGORY: ENVIRONMENTAL

HEAVY BIRD ACTIVITY

- Immediate Effects: Potential birdstrike, structural damage, engine malfunction
- Subsequent Effects:
- Unaware:

- Response:

Determine areas of heavy bird activity and avoid
If in high bird activity area,
  Avoid dense clusters of birds
  Maneuver normally

AIRPLANE ICING (meteorological; unremoved ice on airfoils)

- Immediate Effects: Reduced lift (potential HLFC blockage, if installed), increased drag, increased stall speed, increased T.O., landing rolls, potential flight control malfunctions; change in flight characteristics
- Subsequent Effects: Decreased performance (range, etc.); potential worsening toward unflyability
- Unaware: Not aware of worsening condition; potential incorrect analysis of situation

- Response:

Determine current level of icing and effect on airplane
Enable deicing systems as required
Modify flight control technique as required
Modify flight path as required to handle situation

WINDSHEAR CONDITIONS

- Immediate Effects: High workload, increased approach speed. If windshear occurs: effect on directional/ altitude/ airspeed control, potential stall, potential ground proximity, decreased climb capability
- Subsequent Effects: Potential divert, increased future vigilance required
- Unaware: More likely to meet a microburst; slower response to actual windshear; potential incorrect decision to continue an approach

- Response:

  Identify areas of windshear
  Determine whether to continue through/ near areas of windshear
  If continuing,
  - Increase approach airspeed as preventative measure
  - Prepare for windshear escape maneuvering
  - Increase monitoring of windshear detection equipment

  If windshear encountered,
  - Modify flight path/ increase thrust as required
  - Monitor vertical speed
  - Avoid ground contact
  - Reconfigure systems as required

  Replan flight route as required

SEVERE TURBULENCE

- Immediate Effects: Flight path control difficulties, potential ground proximity, potential traffic problems; potential overspeed, overload, stall; **potential engine unstart**, flameout; potential medical emergency (injured passengers, crew)
- Subsequent Effects:
- Unaware: Slower response to condition

- Response:

  Identify areas of turbulence
  Determine whether to continue through/ near areas of turbulence
  If continuing,
  - Decrease airspeed to turbulence penetration speed
  - Configure systems (engines) as required
  - Inform passengers/ cabin crew

  If severe turbulence encountered,
  - Control attitude
  - Avoid ground contact, overstress, stall, overspeed

  Reroute if required

VOLCANIC ASH

- Immediate Effects: Potential engine malfunction, structural damage, thermal problems
- Subsequent Effects:
- Unaware: Potential confusion due to unknown substance around airplane

- Response:

  Identify areas of volcanic ash
  Determine whether to continue through/ near areas of ash
  If continuing,
  - Avoid areas of ash, if possible

  If ash encountered,
  - Maintain control of airplane
  - Reconfigure systems (engines) as required
  - Determine fastest route out of ash

  Reroute if required

THUNDERSTORMS

- Immediate Effects: Heavy rain, turbulence; potential hail, lightning strike, icing
- Subsequent Effects: Need to optimize flight in areas of thunderstorms
- Unaware: Less prepared for adverse condition

- Response:

  Identify areas of thunderstorms
  Determine whether to continue through/ near areas of thunderstorms
  If continuing,
  - Optimize flight path through cells
  - Prepare for potential effects of thunderstorms
  - Continuously monitor weather conditions

  If cell entered,
  - Control airplane attitude
  - Avoid contact with ground
  - Determine fastest route out of cell

HAIL

- Immediate Effects: Potential structural damage, potential engine malfunction, potential system malfunction
- Subsequent Effects:
- Unaware:

- Response:

  Identify areas of potential hail
  If hail encountered,
  - Determine fastest route out of hail

HEAVY RAIN/ SNOW

- Immediate Effects: Potential increased effective wt., decreased lift; potential icing; potential vision system problem
- Subsequent Effects: Effect on landing: potential poor braking conditions
- Unaware:
- Response:

  Identify areas of heavy precipitation
  Determine whether to continue through/ near areas of heavy precipitation
  If continuing,
    Determine effect of precipitation on airplane
    Modify flight control technique to account for precipitation
    If on approach, go around if necessary
    Be prepared for poor braking conditions

LIGHTNING STRIKE

- Immediate Effects: Potential systems malfunction, potential structural damage
- Subsequent Effects: Potential subsequent lightning strikes
- Unaware: Potential unknown emergency
- Response:

  Maintain control of airplane
  Reconfigure systems as required
  Identify lightning strike has occurred
  Explore possible secondary effects of lightning strike
  Replan route as required

RADIATION EVENT

- Immediate Effects: **Physiological effect on passengers/ crew; potential systems problem**
- Subsequent Effects: **Need to confirm situation with other stations; entire supersonic airplane fleet descends to lower altitudes simultaneously**
- Unaware:
- Response:

  Identify radiation event has occurred
  Plan descent and concur with ATC
  Initiate descent to lower altitude as required
  Replan route as required

LOW VISIBILITY

- Immediate Effects: Decreased spatial awareness, decreased awareness of location of other aircraft, obstacles, ground vehicles
- Subsequent Effects:
- Unaware:
- Response:

Use instruments known to be reliable in all weather conditions
Determine effects of low visibility on other traffic, ATC (other vehicles cannot see you, tower cannot see you, potential arrival/ departure delays)
Replan route as required

NON-NORMAL CATEGORY: OPERATIONAL

UNSTABILIZED APPROACH

- Immediate Effects: High workload, potential high vertical speed, potential hard landing, long landing, short landing, off centerline landing, interference with other approaching traffic; potential stall, overspeed, overstress; potential ground proximity
- Subsequent Effects:
- Unaware: Potential very high workload near runway, possible go around
- Response:

  Identify approach is unstabilized
  Immediately determine if airplane is close to other traffic, obstacles, ground
  Determine whether approach can be restabilized by touchdown
  Continuously project future conditions
  Go around as required

SLOW ACCELERATION ON TAKEOFF

- Immediate Effects: Longer takeoff distance, potential off end of runway on abort, potential airplane will not reach VR, shallow climbout angle
- Subsequent Effects: Indication of potential problems (ice, engine problems)
- Unaware: Possibility of climbing out with insufficient thrust or lift
- Response:

  Determine abnormally low acceleration exists
  Abort takeoff as required
  If takeoff is continued,
    Maintain best climbout possible
    Control lateral flight path to avoid obstacles
  If takeoff is continued and sufficient climbout is not possible
    Execute off-airport landing

INCORRECT CONFIGURATION ON TAKEOFF

- Immediate Effects: Potential abnormal acceleration on takeoff, potential airplane feels different
- Subsequent Effects:
- Unaware:

- Response:

  Determine incorrect configuration exists
  Abort takeoff as required
  If takeoff is continued,
    Maintain best climbout possible
    Control lateral flight path to avoid obstacles
    Reconfigure airplane if possible
  If takeoff is continued and sufficient climbout is not possible
    Execute off-airport landing

ABORTED TAKEOFF

- Immediate Effects:
- Subsequent Effects:
- Unaware:

- Response:

  Execute abort procedure
    Idle thrust
    Use wheel brakes
    Extend spoilers
    Use reverse thrust as necessary
    Use flight control surfaces to keep airplane on runway
    Steer to centerline
  Decelerate as required to avoid going off end of runway stopway

NO BRAKING ACTION DURING LANDING

- Immediate Effects: No/ little deceleration; potential steering problem
- Subsequent Effects:
- Unaware:

- Response:

  Use maximum wheel braking
  Use reverse thrust as available
  Precise steering control
    Use flight control surfaces to assist

HIGH RATE OF DESCENT DURING LANDING

- Immediate Effects: Potential hard landing, potential bounce
- Subsequent Effects:
- Unaware:

- Response:

  Decrease rate of descent before touchdown
  Execute go around if required

AIRPLANE OFF END/ EDGE OF RUNWAY

- Immediate Effects: Difficult in steering/ braking, potential collision, potential jet blast
- Subsequent Effects:
- Unaware:

- Response:

  Steer airplane back toward runway
  Avoid ground obstacles
  Brake as required

FUEL MISMANAGEMENT

- Immediate Effects:
- Subsequent Effects: Potential below minimum fuel requirements for continued flight
- Unaware: Might not be able to divert in a timely manner

- Response:

  Determine
    Current fuel level
    Predicted usage rate
    Fuel required
    Potential future delays
  Replan flight route as required

UNUSUAL ATTITUDE (spin, etc.)

- Immediate Effects: Potential stall, overspeed, overstress; potential obstacle conflict; potential pilot incapacitated
- Subsequent Effects: Potential system malfunction
- Unaware:

• Response:

Rotate airplane toward safe attitude (as possible)
Avoid obstacle conflict, overstress, overspeed, stall
Determine secondary effects of unusual attitude
Replan flight route, if necessary

STALL

• Immediate Effects: Decreased lift, immediate descent; potential control problems, engine problems; potential spin, complex stall
• Subsequent Effects: Potentially off planned flight path; potential abnormal cause of stall
• Unaware:

• Response:

Immediate increased thrust
Avoid terrain conflicts
Nose down to proper pitch
Level wings
Re-intercept planned flight route
Determine secondary problems resulting from stall
Determine cause of stall

OVERSPEED

• Immediate Effects: **Potential thermal problems**, structural problems, overstress
• Subsequent Effects: Potential abnormal cause of overspeed
• Unaware:

• Response:

Immediate decreased thrust/ increased drag
Gentle pull-up to decrease speed
Re-intercept planned flight route
Determine secondary problems resulting from overspeed
Determine cause of overspeed

STRUCTURAL OVERSTRESS

• Immediate Effects: Potential structural damage, potential engine malfunction, potential abnormal dynamics (control problem)
• Subsequent Effects: Potential abnormal cause of overstress
• Unaware:

- Response:

  If no potential collision, control pitch rate to reduce g's
  Re-intercept planned flight route
  Determine secondary problems resulting from overstress
  Determine cause of overstress

CENTER OF GRAVITY (c.g.) MISMANAGEMENT

- Immediate Effects: Potential dynamics problems; potential structural problem; change in performance (stall speeds, fuel efficiency)
- Subsequent Effects: Potential dynamics problems in future states (e.g. landing); potential worsening situation
- Unaware: Not aware of potential dynamics problems in future states

- Response:

  Identify c.g. out of limits
  Reconfigure control system, if possible and required
  Configure airplane to bring c.g. back in limits
  If c.g. still out of limits,
    Determine how to best control airplane in current situation
    Determine how to best control airplane in future situations
  Determine secondary effects of c.g. out of limits
  Replan route as required

OFF AIRPORT LANDING

- Immediate Effects:
- Subsequent Effects:
- Unaware:

- Response:

  Identify off-airport landing site
  Align airplane with landing site or as required due to wind, waves (if time permits)
  Configure airplane for off-airport landing (if time permits)
  Inform passengers/ cabin crew (if time permits)
  Reduce speed to minimum controllable airspeed
    Wings level
    Maintain control of airplane (do not stall)
    Maintain proper pitch attitude
  After "landing"
    Evacuation

EVACUATION

- Immediate Effects:
- Subsequent Effects:
- Unaware:

- Response:

  Inform passengers, cabin crew to evacuate
  Configure airplane for evacuation

INFLIGHT MEDICAL EMERGENCY

- Immediate Effects: Potential divert
- Subsequent Effects:
- Unaware: May place airplane further from alternate airport

- Response:

  Determine situation
      Communicate with cabin crew as required
  Determine appropriate response
  If pilot is required in passengers cabin
      see Pilot(s) Incapacitated response
  Replan flight route as required

UNRULY PASSENGERS

- Immediate Effects: Distraction from cockpit duties, potential inflight medical emergency
- Subsequent Effects: Close communication with cabin crew throughout remainder of flight
- Unaware:

- Response:

  Control flight path (primary consideration)
  Communicate with cabin crew as required
  If pilot is required in passengers cabin
      see Pilot(s) Incapacitated response
  Replan flight route as required

NON-NORMAL CATEGORY: TRAFFIC/ ATC/ COLLISIONS/ COMMUNICATIONS

OBSTACLE CONFLICT (Airborne or Air/ Ground) (includes aircraft, terrain, structures, ground vehicles, etc.)

- Immediate Effects: Potential collision, high workload,
- Subsequent Effects: Reroute affects flight (potential weather, terrain, another aircraft conflict)
- Unaware:
- Response:

  Identify other obstacle as conflict (or potential conflict)
  Predict future action of other obstacle (if other obstacle is moving, if time permits)
  Plan avoidance maneuver (if time permits)
    Avoid terrain, weather, other aircraft conflicts
  Coordinate avoidance maneuver with ATC (if time permits)
  Execute avoidance maneuver
    Avoid stall, overspeed, overstress
  Reconfirm maneuver avoids terrain, weather, other traffic
  Replan flight route as required

OBSTACLE CONFLICT (Ground)

- Immediate Effects: Potential collision, potential hard braking
- Subsequent Effects: Potential reroute to surface destination
- Unaware: Potential FOD ingestion, structural damage
- Response:

  Identify other obstacle as conflict
  Brake if required (stop if uncertain)
  Predict future action of obstacle (if moving, and if time permits)
  Plan avoidance maneuver (if time permits)
    Note position of wingtips, nose, tail, engines, gear relative to other obstacles around airplane
    Determine effects of engine inlets, jet blast
  Coordinate avoidance maneuver with ATC (if time permits)
  Execute avoidance maneuver
  Replan taxi route, if required

ATC PROVIDES INCORRECT INFORMATION TO CREW

- Immediate Effects: See Response
- Subsequent Effects: Potential crew skeptical of future ATC commands
- Unaware: (Especially during periods of high workload) Potential crew acts on information given; crew may not explain its actions to ATC; information may get crew into trouble immediately or in future

- Response:

  If in time-critical situation, and information given by ATC is questionable,
    immediately take "safe" course of action (e.g. stop on taxiway, go around on approach)
  Compare ATC command/ information to other known information (i.e. cockpit displays, published procedures, etc.)
  If information sources mismatch,
    verify ATC instruction
    verify other "known" information
  Replan flight route if required

ATC RECEIVES INCORRECT INFORMATION (from any plane)

- Immediate Effects: Potential ATC provides incorrect information to crew
- Subsequent Effects: ATC skeptical of future information from crew if crew provided erroneous information
- Unaware:

- Response:

  Verify ATC receive incorrect information
  Provide correct information

ATC FAILS TO CONTROL AIRPLANE

- Immediate Effects:
- Subsequent Effects:
- Unaware: Potential crew proceeds assuming clearance unchanged (not necessarily particularly cautiously)

- Response:

  Same as ATC provides incorrect information

BUSTED CLEARANCE

- Immediate Effects: Potential collision (traffic/ terrain); off track (non-optimal profile); high workload; potential cascade effect on arrival flow
- Subsequent Effects:
- Unaware:

- Response:

  Inform ATC of deviation or potential future deviation as soon as possible
  Determine if traffic, terrain, or obstacle conflict exists
  Initiate corrective action (change in flight path)
  Replan flight route as required

WAKE TURBULENCE/ JET BLAST

- Immediate Effects: Similar to turbulence and windshear
- Subsequent Effects:
- Unaware:

- Response:

  Identify areas of wake turbulence/ jet by location and size of other airplane and wind direction and speed
  Otherwise same as windshear

CONTROLLER BUSY

- Immediate Effects: ATC provides no special requests; potential hard to hear (audio communications); no time for clearance readback; potential failure to control, potential ATC provides incorrect information
- Subsequent Effects: Potential upcoming route changes; expect higher workload
- Unaware:

- Response:

  Identify your flight entering busy sector
  Communicate (and listen) carefully, tersely
  Prepare for reroutes
  Follow instructions precisely

OTHER AIRCRAFT IN DISTRESS

- Immediate Effects: Potential delays
- Subsequent Effects: Higher workload; slower controller response to crew requests
- Unaware:

- Response:

  Expect rerouting and delays
  Assist airplane in distress, if possible
  Replan (divert) if necessary

NON-NORMAL CATEGORY: FLIGHT CREW

PILOT(S) FATIGUED

- Immediate Effects: Potential slower response to time critical situation; increased chance of information transfer errors; decreased manual flying skills; poor judgement
- Subsequent Effects: Possible errors in later, more critical phases of flight
- Unaware: Not prepared for high workload

- Response:

  Identify situation (pilot or crew fatigued)
  Follow stan... perating procedures
  Pl... high workload situations
  ... ross-check information transactions
  ... essary
  ... ATC of situation

...NESS OF ATTITUDE/ SYSTEMS/ WEATHER/ LOCATION

...tial high workload, potential multiple non-normal situations, ...ntial pilot vertigo, potential improper airplane or system ...guration, potential obstacle conflict

...l crew informed by outside source (ATC, flight attendants, ...or future cue (EICAS message); flight continues at prior

...te, take safe action (e.g if unsure spatially, climb and

...ble

ER... PUT FROM PILOTS (to systems)

- Im... om system informing crew of error; potential ...al change of state
- Sub...
- Una... input may reappear later

• Response:

Constantly recheck all critical information
If in doubt, follow response to Lack of Crew Awareness

ERRONEOUS INFORMATION INPUT TO PILOTS (from systems)

• Immediate Effects: See Response
• Subsequent Effects: Crew potentially skeptical of same system providing valid information
• Unaware: Crew thinks information is valid, leading to potential serious problems; crew may receive subsequent cue which alerts it to erroneous information

• Response:

If in time-critical situation, and critical information provided is questionable, immediately take "safe" course of action (e.g. go around if localizer signal questionable)
Compare questionable information with other sources of same information
Determine which system is unreliable
Reconfigure unreliable system for proper operation, if possible
If not possible
  Ignore unreliable system
Reverify current state
Replan flight route, if required

DEGRADED MANUAL FLYING SKILLS

• Immediate Effects: Potential off flight path; potential stall, overspeed, overstress; potential information input/ output errors; high workload
• Subsequent Effects: Potential loss of situational awareness
• Unaware:

• Response:

Identify off-path situation
If necessary, execute safe maneuver (e.g. go around on approach)
Determine poor flying skills cause
Transfer flight path control duties
  to autoflight system
  to other pilot
  to reserve pilot

HIGH WORKLOAD

- Immediate Effects: Potential information transfer errors; potential difficulty in manual flying skills; ATC communications difficulties (missed calls); missed procedures
- Subsequent Effects: Potential not planning in advance
- Unaware:
- Response:

  Organize crew responsibilities
  Prioritize tasks
  Complete highest priority tasks
  Delay lowest priority, non-critical tasks until workload decreases
  Exercise increased vigilance in information transaction tasks
  If necessary, inform ATC of condition and request clearance deviation

LOW WORKLOAD

- Immediate Effects: Potential missed events, potential information input/ output errors, slow scan
- Subsequent Effects: Potential not prepared for time-critical event, potential pilot fatigued
- Unaware:
- Response:

  No set procedure

POOR INTRACREW COMMUNICATION

- Immediate Effects: Lack of total information in cockpit; pilot not aware of other crewmembers' states
- Subsequent Effects:
- Unaware:
- Response:

  No set procedure

LOW EXPERIENCE IN AIRPLANE TYPE

- Immediate Effects: Potential input output errors; potential lack of manual flying skills; potential unfamiliar with procedures and systems
- Subsequent Effects: Potential assistance required in time critical situations
- Unaware: Potential overconfidence in situation

- Response:

Determine if one/ both pilots are low time/ recency
For low time/ recency pilots
    Follow standard operating procedures
    Verify each control is proper control
    Verify appropriate response to all control inputs
More experienced pilot monitors less experienced pilot carefully

INSTRUMENT FIXATION

- Immediate Effects: Slow scan; loss of total situational awareness
- Subsequent Effects:
- Unaware:

- Response:

If pilot spends too much time on one instrument, the pilot must determine whether he has become fixated
If so, see Lack of Awareness response

PILOT INCAPACITATED

- Immediate Effects: High workload for able pilot; deviation from standard operating procedure
- Subsequent Effects:
- Unaware:

- Response:

Each pilot continuously monitors other pilot for partial or full incapacitation
If incapacitation identified,
    Take control of airplane if required (flight path control is primary consideration)
    Determine actual state of other pilot

Take corrective action to assist other pilot
- Other pilot may only need to be made aware of his partial incapacitation
- Other pilot may need to be relieved by spare pilot (if available)
- Other pilot may need medical attention from cabin crew
- Reallocate duties as required

Determine potential future effects of corrective action taken

See Inflight Medical Emergency response, if required

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This study provides a detailed description of the functional requirements necessary to complete any normal commercial flight or to handle any plausible abnormal situation. This analysis is enhanced with an examination of possible future developments and constraints in the areas of air traffic organization and flight deck technologies (including new devices and procedures) which may influence the design of 2005 flight decks. This study includes a discussion on the importance of a systematic approach to identifying and solving flight deck information management issues, and a description of how the present work can be utilized as part of this approach.

While the intent of this study was to investigate issues surrounding information management in 2005-era supersonic commercial transports, this document may be applicable to any research endeavor related to future flight deck system design in either supersonic or subsonic airplane development.

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