SITUATION AWARENESS INFORMATION REQUIREMENTS FOR COMMERCIAL AIRLINE PILOTS

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ABSTRACT

Situation awareness is presented as a fundamental requirement for good airmanship, forming the basis for pilot decision making and performance. To develop a better understanding of the role of situation awareness in flying, an analysis was performed to determine the specific situation awareness information requirements for commercial aircraft pilots. This was conducted as a goal-directed task analysis in which pilots' major goals, subgoals, decisions and associated situation awareness information requirements were delineated based on elicitation from experienced commercial airline pilots. A determination of the major situation awareness information requirements for visual and instrument flight was developed from this analysis, providing a foundation for future system development which seeks to enhance pilot situation awareness and provide a basis for the development of situation awareness measures for commercial flight.

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INTRODUCTION

Piloting an aircraft is a complex and demanding activity. It requires a highly specialized skill set, discipline and judgment in the presence of considerable uncertainty and risk, and quick but prudent decision-making based on knowledge of one's aircraft, environment, team and self (Kern, 1997).

A pilot relies on his or her expertise in all of these areas to successfully accomplish a flight. In the process, s/he must be able to continuously input and evaluate a myriad of diverse and dynamic data to maintain an accurate, complete and up-to-date understanding of the evolving situation. Pilots often refer to this as "staying ahead of the airplane." Formally, it is referred to as "situation awareness" (SA), and it encompasses the pilot's mental model of the situation upon which all of his/her decisions rely. Fostering a pilot's ability to maintain good SA may prove to be a daunting challenge as the environment inside and outside the cockpit becomes even more complex and demanding.

While several definitions of SA have been offered, the most generally applicable definition is that provided by Endsley (1988). "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." While a description of these elements has been developed for several classes of military aircraft (Endsley, 1989; Endsley, 1993) and air traffic control systems (Endsley & Jones, 1995; Endsley & Rodgers, 1994), this has not previously been done for commercial aircraft. A clear elucidation of the elements in this definition as they apply to commercial airline pilots is a crucial step towards understanding situation awareness in this unique environment. The objective of this effort was to determine those elements for commercial airline pilots.

An overview of the role of situation awareness in decision making and performance in dynamic environments such as flight is provided in Endsley (1995b). Figure 1 presents a schematic description of SA in relation to decision making and performance. The pilot's perception of the elements in the environment as determined from various instruments, displays and communication channels forms the basis for situation awareness. The quality of a given pilot's SA based on that information is largely affected by his or her abilities, training and experience, preconceptions and objectives, and ongoing task workload.

Situation awareness forms the critical input to—but is separate from—decision making, which is the basis for all subsequent actions. Proper implementation of rules and procedures will depend on the quality of the pilot's SA. Even the best-trained and most experienced pilots can make wrong decisions if they have incomplete or inaccurate SA. Conversely, an inexperienced pilot may accurately understand what is occurring in the environment, yet not know the correct action to be taken. For this reason, it is important that SA be considered separately from the decision-making and performance stages. To further expand on the above definition, SA can be described in three hierarchical phases, as depicted in Figure 1**.**

Level 1 SA – Perception of the elements in the environment

The first step in achieving SA involves perceiving the status, attributes, and dynamics of relevant elements in the environment. The pilot needs to accurately perceive information about his/her aircraft and its systems (airspeed, position, altitude, route, direction of flight, etc.), as well as weather, air traffic control (ATC) clearances, emergency information, and other pertinent elements.

Level 2 SA – Comprehension of the current situation

Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present to include an understanding of the significance of those elements in light of the pilot's goals. Based upon knowledge of Level 1 elements, particularly when put together to form patterns with the other elements, a holistic

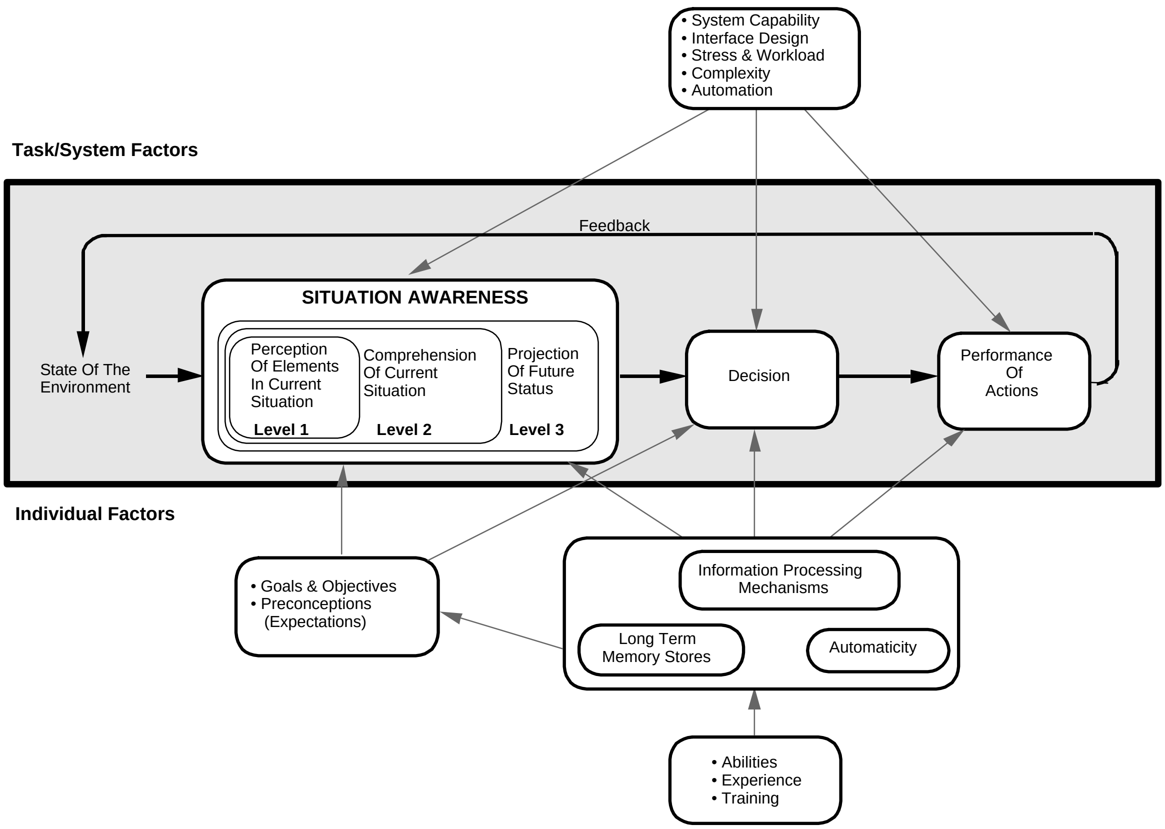

Figure 1. Model of Situation Awareness in Pilot Decision Making (from Endsley, 1995b)

picture of the environment will be formed, including a comprehension of the significance of information and events. The pilot needs to put together disparate bits of data to determine the impact of a change in one system's status on another, or deviations in aircraft state from expected or allowable values. A novice pilot might be capable of achieving the same Level 1 SA as a more experienced one, but may fall short in the ability to integrate various data elements, along with pertinent goals to comprehend the situation as well.

Level 3 SA – Projection of future status

It is the ability to project the future actions of the elements in the environment, at least in the near term, that forms the third and highest level of situation awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA). For example, the pilot must not only comprehend that a weather cell—given its position, movement and intensity—is likely to create a hazardous situation within a certain period of time, but s/he must also determine what airspace will be available for route diversions, and ascertain where other potential conflicts may develop. This ability gives the pilot the knowledge (and time) necessary to decide on the most favorable course of action.

Attributes of SA

While SA can be described as the pilot's knowledge of the environment at a given point in time, it should be recognized that SA is highly temporal in nature. It is not acquired instantaneously, but is built up over time. When assessing convective weather dynamics, a pilot relies in part on past experience and current conditions to project the state of the environment in the near future.

Second, SA is highly spatial in nature in this environment. In addition to a consideration of the spatial relationships between one’s aircraft and the ground, other aircraft, weather patterns, winds, etc., there is also a spatially-determined and goal-determined specification of just which subsets of the environment are currently important to SA, based on the tasks at hand. A pilot's scope of responsibility is typically focused on the safety of flight of his/her own aircraft. Within this focus, attention may be further subdivided based on importance to SA. For example, the focus may shift spatially and temporally inside and outside the aircraft, depending on current goals and tasks, or may shift functionally to include different aspects of a system being monitored. This subdivision can be dynamically modified as various tasks present themselves by refocusing on different elements within the problem space or by changing the boundaries of the problem space itself.

Within the list of elements that pilots find necessary for good SA, not all elements have equal importance at all times. When conditions are clear, for instance, weather may not be a primary consideration. Pilots may opt to shift attention away from some tasks to concentrate on others that may pose problems. It is important to note, however, that elements never become irrelevant or unimportant, just secondary at certain points in time. At least some SA on all elements is required at all times, in order to know which can be made secondary and which should be primary. And at least some SA is required even on secondary elements in order to know that they have not become primary.

Many times it is those elements that are deemed as secondary that cause serious errors when SA on those elements is totally lost. For example, in December 1978, a DC-8 crew preparing for landing at Portland, Oregon was faced with a landing gear problem. To give them time to diagnose the problem, they elected to circle in a holding pattern east of the airport. Soon preoccupied with the problem, the captain failed to recognize a developing low-fuel condition, despite the indications of his crew. The aircraft ran out of fuel and crashed, killing 10 people (NTSB, 1978).

SA and Performance in Aircraft Systems

Having a high level of SA can be seen as perhaps the most critical aspect for achieving successful performance in aviation. Problems with SA were found to be the leading causal factor in a review of military aviation mishaps (Hartel, Smith, & Prince, 1991). Endsley (1995a) conducted an investigation of causal factors underlying aircraft accidents involving major air carriers in the United States based on National Transportation Safety Board (NTSB) accident investigation reports over a four year period. Of the 71% of the accidents that could be classified as having a substantial human error component, 88% involved problems with SA. Of 32 SA errors identified in these accident descriptions, twenty-three (72%) were attributed to problems with Level 1 SA, a failure to correctly perceive some pieces of information in the situation. Seven (22%) involved a Level 2 error in which the data were perceived but not integrated or comprehended correctly, and two (6%) involved a Level 3 error in which there was a failure to properly project the near future based on the aircrew's understanding of the situation.

In the majority of serious accidents and mishaps, pilots are not having trouble ascertaining the correct action for the situation, nor in carrying out those actions, but rather are deficient in fully understanding the situation that they are in. For this reason, understanding situation awareness in aircraft cockpits and finding means of improving situation awareness through system design or pilot training has become a major goal.

OBJECTIVE & SCOPE

The objective of this effort was to determine the situation awareness information requirements of the commercial airline pilot, including perception (Level 1), comprehension (Level 2), and projection (Level 3) of elements per the prior definition of SA. These requirements can be used as input to system/equipment design, training, and research and evaluation efforts which need to consider the situation awareness needs of the pilot.

APPROACH

The requirements analysis was performed as a goal-directed task analysis based on the methodology of Endsley (1993). The SA information requirements were defined as those dynamic information needs associated with the major goals or subgoals of the pilot in performing his or her job. To accomplish this, the major goals of the job were identified, along with the major subgoals necessary for meeting each of these goals. The major decisions that needed to be made, pursuant to each subgoal, were identified. The SA information requirements for making these decisions and carrying out each subgoal were then identified. These requirements focused not only on what data the pilot needed, but also on how that information was integrated or combined to address each decision. Several caveats need to be mentioned in relation to this analysis.

(1) At any given time, more than one goal or subgoal maybe operating, although these will not always have the same priority. The analysis does not assume any prioritization among goals, or that each subgoal within a goal will always be relevant.

(2) The analysis is based on goals or objectives, and is as technology-free as possible. How the information is acquired is not addressed. In some cases, it may be through the cockpit displays, aural or visual alerts, communications with controllers or other pilots, or the pilot may have to determine it on his/her own. Many of the higher-level SA information requirements fall into this category. Information may be acquired differently on different aircraft equipped with different technological systems or differently per individual pilot preferences, training or airline directives. Nonetheless, the information that is needed to have perfect SA remains essentially the same.

(3) The analysis sought to define what pilots would ideally like to know to have perfect SA, even though they must routinely work with less than this ideal. Thus the analysis serves as a design goal, not necessarily a description of an existing system.

(4) Static knowledge, such as procedures or rules for performing tasks, is outside the bounds of this analysis. The analysis focused only on the dynamic situational information that affects what the pilots do.

(5) Most commercial cockpits operate with two or more crew members. This analysis does not specify which crew member is responsible for which information or tasks, as this division tends to be highly varied and dynamic and there is much overlap among crew members with regard to situation awareness requirements. The analysis was conducted from the point of view of the pilot flying the aircraft who must assure that all the goals and objectives of the flight are being met, either personally or through delegation to another crew member.

METHODOLOGY

Analysis to determine the SA information requirements for commercial airline pilots was comprised of several inter-related activities: (1) prior task analyses and available documentation were reviewed, (2) expert elicitation was conducted with experienced airline pilots, (3) initial review and revision of the resulting goal-directed task analysis by the participating subject matter experts, and (4) final review of the task analysis by independent subject matter experts.

Task Analysis Documentation Review

Several task analyses have been completed for commercial aircraft. For the most part these analyses document how tasks and functions are to be completed on specific models of aircraft. From the standpoint of SA, however, they do little to document the cognitive tasks that airline pilots must perform. Why are the tasks performed? What do pilots do with the information on the displays? What assessments are made? How are the different pieces of information used and integrated with each other to come up with intelligent decisions that meet operational objectives?

While very incomplete on these issues, two task analyses were used to form a basic foundation for the SA requirements analysis: a detailed job analysis for current airline pilots (Hoffman & al., 1997) and an analysis of the future flight deck environment (Alter & Regal, 1992). These documents were reviewed to ascertain the basic functional areas that needed to be covered and form questions for the subject matter experts in the next phase. They also served to insure completeness of the resulting analysis.

Expert Elicitation

Two active airline pilots served as subject matter experts. Together, they possessed a broad experience base, including international, domestic, regional and military aviation, with type ratings in six aircraft between them, as shown in Table 1. Each pilot was interviewed individually. In the first session, pilots were provided an introduction to the objectives of the project. Each pilot was interviewed over numerous sessions, each lasting between one and four hours. In the early sessions, the pilots were interviewed to determine the their overall goals and tasks. From this a basic goal structure was developed.

Table 1. Subject Matter Expert Experience

	Pilot 1	Pilot 2
Commercial Aircraft Experience and Type Ratings	ATP A-310 B-727 B-757 B-767 DC-9 MD-11	ATP B-727 B-757 B-767 DC-9 MD-11
Years of Commercial Flight Experience	12	15
Total Flight Hours	8,700	11,000

During following sessions, a detailed discussion of one or more major piloting goals (e.g., assess flight plan, avoid hazardous weather) was conducted. The pilots were queried as to: subgoals, decisions, and processing requirements associated with each goal, and thereby, the SA needed for successful fulfillment of each goal. Particular attention was paid to determining the desired form of information, and how that information was used (i.e., the higher-level SA information requirements), which could not be readily determined from available documentation.

Based on the information obtained from the pilots, a goal-directed task breakdown was created for each of the commercial pilots' major goals. This lists the major goals, relevant subgoals, questions to be determined in meeting each subgoal, and first-, second- and third-level SA elements required for addressing these questions.

In subsequent sessions, the goal-directed task breakdowns from previous sessions were reviewed with the pilot. Necessary corrections and additions to the breakdown were determined by the pilot. This occurred iteratively over a period of sessions until each pilot was satisfied that the depth and breadth of the job had been covered adequately.

Initial Review

A draft version of the complete goal-directed task analysis for all of the commercial pilot's major goals and tasks was then developed based on the inputs of the two pilots. The draft analysis was circulated to both of the subject matter experts for review. They were asked to examine the analysis for completeness and accuracy and to make any changes needed. This process allowed each of the subjects to review the document at his leisure, taking into account the SA information requirements of the entire job, and resolving any inconsistencies or language problems. These reviews were then incorporated to form a final draft of the SA analysis.

Final Review

The final draft SA analysis was distributed to ten commercial airline pilots for review. Reviews were returned by six of them. The mean years of experience in flying commercial aircraft for this group was 14.8 years (10,580 hours). Type ratings and experience are shown in Table 2.

The reviewers were instructed to make any corrections, changes, or additions that they felt were important. They were specifically asked to address the following questions: (1) Are there any major goals or subgoals that have been left out? (2) Are there other major decisions that you make in achieving each goal? (3) Do you need other information in order to make these decisions (in terms of dynamic situational information, not procedures, systems knowledge, flight skills, etc.)? They were asked to focus on what it is that they really wanted to know (as opposed to what may be available) in each case. The results of the reviews were then compiled into a single document which comprises the final SA requirements analysis.

Results & Discussion

From the above procedures, a goal hierarchy, presented in Appendix A, was constructed which contains the pilot's major goals and subgoals. Although the two pilots participating in this analysis were from different airlines and each approached problems and tasks differently, there was a good consensus regarding the major goals and objectives of the airline pilot. For example, while the pilot from one airline was more likely to follow the original flight plan provided by the airline and the other was more likely to rely on his own judgment, both were in agreement as to the basic questions that needed to be asked in assessing a flight plan and the information that was needed to make these assessments.

At the highest level, the overall goal was described as "getting the aircraft from the origin to the destination, safely, legally, with satisfactory levels of comfort and service to passengers, on schedule and in an efficient manner." Five major objectives can be seen in this goal statement: Safety, legality, passenger comfort and service, schedule, and efficiency. These high-level objectives recurred throughout the analysis. Airline

Table 2. Reviewer Experience

	Reviewer 1	Reviewer 2	Reviewer 3	Reviewer 4	Reviewer 5	Reviewer 6
Commercial Aircraft Experience and Type Ratings	ATP B-737 B-757 B-767 DC-9 Lear Jet	ATP B-737 B-757 B-767 MD-11	ATP B-727 B-737 B-757 B-767 DC-9	B-737 B-737-200 MD-88	ATP B-737	ATP B-727 B-737 DC-8 DC-9 L-1011 CV-440 CV-880
Years of Commercial Flight Experience	13	21	12.5	1.2	12	29
Total Flight Hours	6,570	17,000	13,000	910	8,000	18,000

pilots must routinely attempt to optimize these five factors in face of a variety of system perturbations (e.g., weather systems, other traffic, etc.).

Of particular note is the fact that these objectives may at many times be at odds with one another. For example, to meet schedule one may need to increase speed, although this may reduce flight efficiency. While safety was almost always considered to be the overriding objective, followed by meeting all legal requirements, pilots are forced to make constant tradeoffs among the goals of service, schedule and efficiency.

Application of these overriding goals was considered across four major task areas: (1) Selecting the best path to the destination, (2) executing the desired flight path safely, efficiently and with ride comfort, (3) managing resources effectively, and (4) satisfying the customer. Relevant subgoals associated with each are listed in Appendix A.

A listing of the major decision tasks and situation awareness information requirements at all three levels for each goal and subgoal shown in Appendix A were determined, and are contained in the goal-directed task analysis presented in Appendix B. Situation awareness requirements at all three levels are shown, including basic information requirements (Level 1 SA), the higher-level assessments that are made based on that information (Level 2 SA) and the projections that must be made to function effectively (Level 3 SA) in regard to each subgoal. It will be noted that considerable overlap is present in situation awareness information requirements between subgoals, as well as a large degree of inter-relatedness between subgoals, as would be expected.

The goal-directed task analysis in Appendix B was carefully reviewed to ascertain a list of SA requirements across the goals of the airline pilot. This is presented in Table 3. This list includes the pilot's major SA information requirements (for dynamic information), exclusive of static knowledge requirements, sources of the information, or associated tasks. These requirements have been broken down into each of the three levels: perception of elements (Level 1), comprehension of their meaning (Level 2), and projection of the future (Level 3).

As shown in Table 3, SA requirements for the commercial pilot are quite extensive. While some of these requirements are only important during certain phases of flight (e.g., taxiway information, approach plan), in many cases accurate knowledge of this information is needed in advance to allow good planning (and in some cases correct programming of the flight management system) in advance of that phase of flight. Other information, such as heading, altitude, and airspeed, remain high priority SA requirements almost throughout the flight.

The effect of automated systems, such as flight management computers or automated alerting systems, on these requirements should be mentioned, both because these systems are prevalent on many commercial aircraft and because more such automation is being incorporated into future aircraft systems. The use of automation to perform many of the tasks of the pilot does not in actuality remove major SA requirements from this list. The pilot still is required to insure that each goal is being properly met, either personally or through the automated system. The pilot still needs to have SA regarding the state of the automated system and the state of the parameters that system is controlling or monitoring. For instance, while the autopilot may keep the aircraft on a programmed course, the pilot is still responsible for insuring that the aircraft is holding to that course. In effect, a good form of automation for the cockpit will be one that helps insure the pilot has a high level of SA regarding information that must be monitored and which assists the pilot in getting the information that is needed (e.g., details regarding an alternate airport, or assessment of the impact of a system degradation on other system performance), rather than one which seeks to remove information from the pilot and subsume tasks independently.

This analysis should be useful for guiding the design and development of future cockpit systems. An explicit consideration of pilot SA information requirements, particularly at the higher levels, should be beneficial for designing more efficient interfaces and suitable automated assistance to ease pilot workload and enhance SA in the performance of their tasks. Obviously, all SA requirements do not need to be presented to the pilot simultaneously and at all times. This analysis provides a basis for ascertaining which information is needed and how that information needs to be combined in the pursuit of different subgoals. For some information, simply providing high-level information to allow the pilot to ascertain that a given subgoal does not need to be active is adequate (e.g., the system is working properly). For other subgoals, this analysis can be used to provide pilots with information in an integrated form rather than forcing them to go to multiple sources to find the information that is needed.

In addition, this list of SA information requirements can be used to direct SA measurement efforts as they pertain to system design evaluation, training technique evaluation, error investigation, or construct exploration. One measure of the adequacy of a given aircraft system design is the degree to which it provides the pilot with the SA needed to achieve good performance, as well as the degree to which it allows him or her to execute needed actions in a timely manner. Such an assessment can be made of existing system designs and future designs that are contemplated based on this standard.

Table 3. Pilot SA Information Requirements

LEVEL 1

Aircraft data
- Call sign
- Weight
- Weight distribution
- Center of gravity
- Aircraft type
- Engine type/capabilities
- Equipment on board
- CAT II/III qualified
- First aid on board
- Performance capabilities/restrictions
    - Maintenance carryover items

Aircraft state
- Heading
    - Magnetic
    - True
- Altitude
    - Absolute altitude
    - Pressure altitude
    - True altitude
    - Density altitude
        - Temperature
        - Elevation
    - Altimeter setting
- Airspeed
    - Indicated
    - Max and min airspeed for current configuration
    - Ground speed
- Airspeed rate of change
- Vertical speed
- Acceleration / deceleration
- Position
- Pitch attitude
- Roll attitude
- Turn rate
- Configuration
    - Gear position
    - Flap position
    - Slat position
    - Spoiler position
    - Stabilizer trim
    - Elevator trim
- Thrust setting
- Engines spooled evenly for takeoff
- Fuel
    - Fuel quantity
    - Fuel temperature
        - Fuel type
    - Fuel distribution
    - Fuel burn rate
    - Arrival fuel requirement
- Engine area clear/blocked
- Braking force
- Reverse thrust
- Stall
- Angle of attack
- System settings
    - Anti-ice
    - Packs
    - Autopilot engagement
- Wait time for de-ice
- De-ice fluid
    - Type
    - Mix ratio

Equipment malfunctions
- Areas of aircraft damage
- Operational status of aircraft systems
    - Reliability of systems
    - Severity of system failure/degrade
    - Validity of system failure/degrade
        - Pneumatic
            - Air conditioning
            - Pressurization
            - Thrust reversers
        - Hydraulic
        - Flight control
            - Flaps, slats
            - Control surfaces
            - Spoilers
        - Fuel
        - Electrical
        - Landing gear, brakes, anti-skid and nose-wheel, auto-braking
        - Navigation and instrumentation
            - Altimeter setting
            - Navigation system alignment
            - FMS programming
            - INS
            - GPS
            - ACARS
        - Powerplant
            - Engines
            - APU
        - Autoflight
            - Autopilot
            - FMS
        - Weather radar
        - Anti-ice
        - Fire protection
        - Audio panel
        - Communication system
        - Emergency systems and equipment
            - Oxygen
            - Smoke goggles
        - Doors
            - Unsafe exits
        - Lights
        - Warning systems
        - Cockpit voice recorder
    - Operational status of ATC/NAS systems
        - System failures/degrades

- Validity of system failure/degrade
    - Navigation aid
    - Communication system
- Area of ATC outage
- Command center outage
- Confidence level in airspace systems functioning
- Airport lighting

Airports
- Location
- Altitude
- Familiarity/recency
- Closures
- Altimeter setting
- Active runway(s)
- Approach in use
- Runway information
    - Length & width
    - Weight restrictions
    - Surface conditions
    - Closures
    - Procedures in effect
- Taxiway information
    - Width
    - Weight restrictions
    - Surface conditions
    - Slopes/grades
    - Closures/caution areas
    - Communication procedures
- Alternate airport
    - Refueling capabilities
    - Tug capabilities
    - De-icing capabilities
    - Passenger accommodations
        - Customs
        - Stairs/jetway
        - Availability of medical care
    - Served by airline
- Special information
    - Obstacles
    - Procedures
        - Noise abatement
        - Ground movement
        - Missed approach
        - Parallel approaches
    - Limitations
        - Landing curfew
- Lighting/signage
- Navigation ID and location

Flight plan
- Available routes
- Available altitudes
- Planned flight path
    - Distance
    - Altitude
    - Waypoints
    - Bearing
    - Discontinuities
    - Direction
    - Number of changes required
    - Difficulty of changes required
- Dispatcher's concurrence with plan
- Fuel reserve requirement
- Arrival fuel requirement
- Assigned runway
- Takeoff plan/settings/ critical points
- Planned airspeed profile
- Planned climb profile
- Planned cruise altitude
- Planned cruise airspeed
- Planned descent profile
- Approach plan
    - Approach category
    - Reference speed
    - Initial approach altitude
    - Marker-crossing altitude
    - Final approach fix altitude
    - Decision height
    - Minimum descent altitude
    - Missed approach point
- Scheduled time of arrival
- Terminal/Gate assignment
- Gate availability
- Door for deplaning

ATC
- Appropriate ATC organization/frequency
- Success rate of other aircraft requesting clearance
- English proficiency
- Local transition altitude
- Status of:
    - Checklists
    - Procedures
    - Briefings

Traffic
- Traffic on taxiway
- Traffic on runway
- Traffic on final
- Delays on ground
- Number of aircraft holding ahead
- Assigned sequence
- Spacing on final
- Expected Further Clearance time
- Other aircraft
    - Aircraft type/ capabilities
    - Position
    - Altitude
    - Communications present
    - Altitude rate
    - Airspeed
    - Pilot competence/ reliability
- TCAS instructions

Terrain/Obstacles
- Location
- Height
- Minimum altitudes

Weather
- Area affected
- Altitudes affected
- Conditions
  - Temperature
  - Dewpoint
  - Precipitation (level and type)
  - Visibility
  - Ceiling
  - Wind
    - Direction
    - Magnitude
    - Rate of change
    - Altitudes
    - Gusts
    - Crosswind component
  - Darkness
- Direction and speed of movement
- Intensity and rate of change of intensity
- Present ice buildup
- Ice accumulation rate
- Turbulence
  - Altitudes
  - Area
  - Intensity
- Airspeed gain/loss reports from other aircraft
- Wind shear location/ severity
- Aircraft go-arounds
- Airport conditions
  - Precipitation accumulation
  - Runway visibility
  - CAT II/III status
  - Minimums

NAS
- Special use airspace
  - Boundaries
  - Status
    - Activation level
  - Limits and restrictions
- Navaid information
  - Frequency
  - Identifier
  - Availability
  - Course

Clearance
- Pushback clearance
- Departure clearance
- Taxi clearance
- Position and hold clearance
- Takeoff clearance
- Clearance to transition
- Descent clearance
- Approach clearance
- Landing clearance
- ATC instructions / vectoring
  - Assigned heading
  - Assigned altitude or altitude restriction
  - Assigned time-to-fix
  - Assigned spacing or sequence
  - Assigned airspeed or airspeed restriction
  - Time by which to comply with clearance
- Reporting points
- Assigned runway
- Assigned taxiway
- Restrictions

Passengers/cargo
- Number
- Cargo load
  - Weight
  - Hazardous material
  - Human organs
- Serious illnesses/ injuries
- Medical personnel on board
- Sensitivity to descent rate
- Cabin temperature
- Cabin status
  - Seat belts on
  - Flight attendants seated
  - Carts stowed
- Type/status of meal service
- Provision status
  - Meals
  - Beverages
  - Pillows/blankets
  - Communications equipment
  - Movie
- Points of interest
- Hijacker(s)
  - Number
  - Profile
  - Demands

Human Resources
- Flight crew ability/ reliability
  - Cat II/III qualified
  - Experience in aircraft
  - Experience in crew position
  - Currency in aircraft
  - Familiarity with route and airport
  - Correctness of tasks executed
- Cabin attendants ability/reliability
  - Experience
  - Number
  - Time on duty
  - Languages
- Self (pilot) ability/ reliability
  - Fatigue
  - Stress
  - Attitude
  - Alertness
  - Time on duty
  - Workload level
- ATC ability/reliability
  - ATC facility
  - Stress/workload
  - Flexibility
- Ability/reliability of
  - Maintenance
  - Ground crew
  - Dispatch
- Communication channels
  - Dispatch
  - Maintenance

LEVEL 2

Aircraft parameters
- Confidence level in aircraft systems
- Deviation between aircraft state & aircraft limitations
- Deviation between current attitude and desired attitude
- Deviation between current gross weight and allowable gross weight
- Deviation between aircraft state & planned settings
- Severity of degrades
- Margin to V_1
- Airspeed relative to max turbulence penetration airspeed
- Margin to stall
- Validity of indications
  - Airspeed
  - Altitude
  - Fuel quantity
  - Stall
- Electrical power demands

Aircraft control
- Required control inputs
  - Heading correction
  - Pitch correction
  - Thrust correction
- Directional control responsiveness
- Stability of approach
- Available thrust
- Ramp maneuvering requirements
- Ability to abort / go around
- Deviation between current maneuver and optimal maneuver

Airport
- Availability of suitable alternate
- Ability to reach alternate

Flight planning
- Runway suitability
- Taxiway suitability
- Ability to reach destination
- Deviation between hold time and safe hold time

Flight plan conformance
- Deviation between plan and
  - Optimal profile
  - Safety/legal requirements
  - Aircraft capabilities
  - ATC requirements
- Fuel sufficiency
- Schedule deviation
- Track deviation
- Heading deviation
- Altitude deviation
- Airspeed deviation
- Allowable tolerance for deviations
- Discontinuities in plan

ATC conformance
- Deviation from assigned
  - heading or vector
  - altitude
  - time-to-fix
  - spacing
  - airspeed
- Conformance of clearance with expectations

Traffic
- Current separation from other aircraft
- Trajectory of other aircraft relative to ownship
- Closure rate
- Other aircraft's intended actions/path
- Maneuver
  - Aircraft
  - Timing
  - Type
- Aircraft ahead
  - Spacing
  - Type
- Wake turbulence areas

Passengers/cargo
- Comfort level
- Safety
  - Unsafe exits
  - Urgency of medical needs
- Hijacker(s)
  - Level of threat
  - Ability to meet demands

Compliance with Regulations/Procedures
- Compliance with noise abatement requirement
- Compliance with Standard Instrument Departure (SID) requirements
- Compliance with Standard Arrival Route (STAR) requirements
- Cleared to depart gate
- Distance from special use airspace
- Time until next communication needed
- Controller's understanding of own intent/needs

Terrain/Obstacles
- Relative distance, bearing and altitude
- Min/max climb/descent rate to clear obstacle

Priorities
- Relative priority of safety, legality, comfort schedule, efficiency

Customer satisfaction
- Acceptable schedule deviation
  - Connection requirements

Emergencies
- Risk of hazard to passengers/crew

Weather
- Confidence level in weather information
- Timeliness of information
- Hazard level
- Takeoff minimums
- Landing minimums
- Potential for
  - Icing
  - Thunderstorms
  - Turbulence
- Effectiveness of anti-ice measures
- Path of minimum weather exposure
- Deviation between current weather and projected weather
- Relative distance and bearing to weather areas

Impact
- Of aircraft malfunction / damage / abnormal condition on:
  - Aircraft performance/safety
  - Aircraft stability/ control
  - Stopping ability
  - Flight plan
  - Operational parameters / system status
  - Procedures
  - Passenger/crew safety
- Of weather on:
  - Aircraft performance
  - Fuel system
  - Aircraft control
  - Passenger comfort
  - Passenger/crew safety
  - Flight plan
  - Takeoff
  - Landing
- Of traffic on:
  - Separation / safety of flight
  - Schedule
- Of change in flight plan / aircraft maneuver on:
  - Safety of flight
  - Legality
  - Schedule
  - Fuel usage
  - Ride quality
  - Passenger connections
- Of deviations on:
  - Safety of flight
- Of action on:
  - Hazard potential
  - Safety of flight
- Of clearance on:
  - Safety of flight
  - Schedule
  - Efficiency
- Of thrust level / configuration / system settings on:
  - Aircraft performance
  - Safety of flight
  - Passenger comfort/ safety
  - Fuel usage/ economy
  - ATC clearances/ restrictions
- Of emergency on:
  - Safety of passengers/crew
- Of conditions/flight status/information on:
  - Passenger comfort
- Of automation on:
  - Safety of flight
  - Crew workload
  - Crew skills

Workload
- Time available to perform tasks
- To execute change in flight path
- Resources available
- Utility of automation
- Likelihood and cost of automation error
- Time and effort to program and monitor automation
- Time and effort to operate manually

Cost / Benefit
- Of change in:
  - Lateral flight path
  - Vertical flight profile
  - Takeoff runway
  - Departure route
  - Approach
  - Arrival route
  - Landing runway
  - Speed profile
  - Destination airport
- Of holding vs. diverting
- Of start/shut down of each engine
- Of level of automation
- Of evacuation

Equipment malfunctions/ Aircraft condition
- Deviation between system status and expected values
- Deviation between plan and programmed automation
- Impact of ATC degrade/outage on aircraft separation/ safety
- Emergency status

Human Resources
- Confidence level in human resources
  - Flight crew
  - Self
  - Cabin attendants
  - ATC
  - Crew of other aircraft
  - Dispatch crew
  - Gate agent
  - Maintenance/ ground personnel
- Areas of strength/weakness
- Workload level
- Ability to contain/calm unruly passenger(s)

LEVEL 3

Aircraft

- Projected trajectory
    - Own aircraft
    - Other aircraft
- Projected relative trajectories
- Projected separation between aircraft

Flight plan

- Projected taxi time
- Projected schedule deviation
- Estimated time of arrival
    - At destination
    - At fix
- Projected fuel requirements
- Predicted fuel usage
- Predicted fuel burn rate
- Projected time available on current fuel
- Probability of ATC granting clearance for change in flight path
- Probability of staying reliably on route
- Predicted duration of hold
- Predicted areas of congestion
- Predicted periods of congestion
- Predicted duration of delays
- Predicted time:
    - On taxi
    - To departure
    - In each phase of flight
    - To destination
    - To alternate
    - In hold
    - To next clearance
    - Aircraft can safely remain in present/ anticipated conditions
    - Until maneuver required

Weather trends/forecast

- Projected hazard level
- Projected area/severity of hazardous weather encounter
- Predicted wind shear
- Predicted turbulence along route
- Predicted changes in visibility
- Estimated time for weather to lift above minimums
- Projected escape routes
- Projected impact of changes/maneuvers/ weather on:
    - Safety of flight
    - Deviation from flight path

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