Cognitive Task Analysis of Commercial Jet Aircraft Pilots during Instrument Approaches for Baseline and Synthetic Vision Displays

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SUMMARY

The purpose of this paper is to describe the flight crew procedures for commercial jet instrument approaches in order to aid in the development of pilot computational models and for evaluation of new cockpit display technologies. New SVS displays were evaluated based on pilot performance and workload and were compared to a baseline (no SVS) displays. Both ILS and RNAV approaches were considered in this research. The Boeing 757 was the aircraft used in the evaluation of the SVS during approach and landing.

The paper provides background on the approach phases of flight and the approach types (visual and instrument) as well as precision and non-precision instrument approaches. The SVS approach is a combination of both visual and precision approaches and is compared to baseline displays.

The paper discusses the methods, procedures and terminology of a pilot’s approach comparing again, the instrument approach, the ILS approach and the RNAV approach. Some key points are that the plane is directed with both lateral guidance (centering the aircraft with the runway before landing) and vertical guidance (using the glide path to place the aircraft within the first 1000 feet of the runway threshold). Runway lighting provides lateral guidance to pilots as well as vertical guidance and is color coded to specify different sections of the runway. The final approach fix (FAF) is typically 1500 feet above ground level and once an aircraft intercepts with the FAF, the pilot must guide it in a set deceleration and angle of descent to land the plane on the centerline of the runway. Shortly after intercepting the FAF, the pilot can determine if the aircraft will miss the approach when he/she reaches the decision height (typically 200 feet above the runway). A “stable” approach is when the landing is not missed and the plane approaches the runway with acceptable speed, descent rate, attitude and engine thrust in order to pass through a series of sequential imaginary gates at various descending heights above ground.

The ILS involves the use of the glide slope transmitter to direct the aircraft along a typical 3 degree angle of descent. The aircraft must pass over marker beacons which send information to the pilot about the plane’s position in 3 dimensional space. The ILS approach has three segments that begin when the ATC (air traffic control) issues a clearance (initial approach). Once the plane intercepts the localizer, the intermediate approach phase begins and the aircraft is flown inbound with the guidance of the ATC. The final segment begins when the plane intercepts the glide slope, which usually occurs at the FAF. When the pilot descends along the glide slope, if he/she cannot visibly see the runway, they must abort the approach (Page 23).
The RNAV approach is used by almost all modern commercial aircraft and is supported by several independent navigation subsystems both on board and external to the plane. The RNAV provides guidance signals that both the pilot and autopilot can follow in order to fly the desired 3D path. The guidance signals are a series of waypoints between take off and landing. Each waypoint (VOR) has a latitude, longitude and inbound course, outbound course, crossing altitude, speed and unique name.

Both the RNAV and ILS systems use waypoints as well as decision heights to define whether pilots will miss a landing but the main difference is that RNAV does not use a ground-based localizer, glide slope transmitter or marker beacon signals. Consequently, RNAV approaches have higher decision altitudes than ILS approaches. Also, the ILS will allow the autopilot to fly the plane all the way to the ground, if the pilot does not take over; whereas, the RNAV will execute a missed approach, if the plane is not taken over by a certain point in time.

The SVS is a computer generated visual display of the terrain in front of the airplane and it has three component categories, including the sensors and database, the computation, and the display. Examples of which components fit into these categories are presented in the paper.

The next section of the paper discusses the pilot’s displays and controls in a B757. These controls can be generalized to most commercial aircraft. First, the controls common to the three types of approaches are introduced, then the controls unique to the ILS and the RNAV are discussed, and finally, the SVS approach technologies are introduced. The flight control modes, the mode control panel, the primary flight display (PFD) and the navigation display (ND) are first reviewed. The three types of flight control modes are manual, automatic and partially automated which coincide with the pilot’s level of involvement in flying the plane. For example, the manual mode is when the pilot is steering the plane manually with the yoke. In automated flight, pilots can choose which guidance method they prefer (ILS or RNAV). Pilots use the mode control panel to select guidance modes and to turn “on” and “off” the flight director. The PFD is the primary attitude instrument and both the pilot and co-pilot of the 757 have their own PFDs. The ND provides pilots with a view of the plane’s location on a map from a God’s eye view. Both the pilot and co-pilot of the 757 also have their own NDs which have several modes of operation that can be selected in real-time. The map mode is the most commonly used. The ND does not tell the pilot if, for example, the plane is drifting off course.

The flight management system (FMS) is part of the RNAV system and it assists the pilots in planning and executing a flight route. However, this flight planning provided by the aircraft’s FMS often conflicts with ATC instructions during the approach; therefore, the FMS is not usually carefully monitored during approach. The TCAS (traffic alert and collision avoidance system) in the FMS is used at lower altitudes to prevent airborne collisions and the altimeters (barometric and radio) provide altitude information.

The SVS display, in addition to terrain features, provides airport details, information about other aircraft, weather, wake turbulence, flight data information, and tunnel
navigation. The terrain map is a computer-generated image of the terrain from the pilot’s viewpoint. The flight data overlays the terrain map providing speed, heading and altitude information. The velocity vector is also called the flight path symbol, which represents the actual flight path of the aircraft. Tunnel navigation is another flight path guidance symbol. There are several different versions of tunnel symbology as part of the SVS. The intent of the SVS is to allow pilots to fly in low visibility conditions with a high level of safety, comparable to when visibility is adequate. At airports where ILS approaches are unavailable, the SVS could support a safe approach using the VFR (visual flight rules) criteria. The SVS also could also prevent the pilot from flying into terrain and help the pilot avoid landing short of the runway or beyond it.

The next portion of the paper presents a cognitive task analysis for both the ILS and RNAV approaches to an airport in Santa Barbara. It provides the duties of both the pilot flying (PF) and the pilot not flying (PNF). Typically the PF manipulates controls and the PNF monitors progress, reads checklists, moves gear and flap levers and communicates with ATC and flight attendants.

During the initiation of the approach, the crew sets the control and guidance system and communicates with ATC as needed. The crew also monitors the sub-systems, aircraft position and attitude, and the flight path. The task sequence in the approach involves communicating with ATC, setting radio frequencies, engaging automated flight control, maintaining airspeed, setting flaps, monitoring the localizer and glide slope transmitters, lowering the landing gear, arming speed brakes, setting missed approach altitudes, monitoring altitudes below 2500 feet AGL, executing before landing checklists, turning on landing lights, monitoring descent rate, disengaging the autopilot, flying manually, flaring and landing the plane. The non-sequential tasks are to monitor the flight path and progress, perform double-checks and verifications, monitor the radio and to monitor the aircraft systems.

The rest of the paper discusses the RNAV approach tasks, the ILS and RNAV task timelines, the ATC-directed missed approach, information requirements for approaches and pilot situation awareness, the SVS approach benefits, tunnel navigation and future work.

COMMENTS

This paper should explain more precisely what types of instrumentation, displays and symbology vary from aircraft to aircraft and how much they vary. This information would be useful in terms of understanding how cockpit interface technology might influence the cognitive task analysis for ILS, RNAV and SVS approaches. Also, it would be helpful if the authors pointed out which technologies are the most common in commercial aircraft and why. While this paper contains several pages of information, a few more (in an appendix) on, for example, different types of tunnels, might be helpful to readers.