

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

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## **Abstract**

This paper describes flight crew tasks and procedures during commercial jet instrument approaches. The objective is to provide the necessary background information to support computational human performance modeling under two experimental conditions: (1) a baseline that assumes current aircraft displays, controls and navigation guidance (e.g., a Boeing 757 flying instrument landing system (ILS) and area navigation (RNAV) approaches); and, (2) the addition of a prototype synthetic vision system (SVS).

## **1. Introduction**

Human performance modeling (HPM)<sup>1</sup> is a valuable research tool for understanding new systems and their impact on human task performance and workload, without resorting to the more costly methods of human-in-the-loop experiments or simulations. This paper describes task analyses of jet transport pilot tasks during approach to landing, using instrument landing system (ILS), area navigation (RNAV), and synthetic vision system (SVS) display methods in support of on-going HPM research.

The ultimate goal of the research is to understand the impact of SVS on pilot performance, workload, and other human factors considerations. The ILS and RNAV models will serve as baseline conditions. HPM and simulation can be used to compare the baseline and SVS models to illustrate advantages and disadvantages in pilot performance.

Using HPM for understanding the benefits and drawbacks of any new system must be part of a continuum of research methods. The continuum ranges from pencil and paper (mathematical) analyses, to pre-development modeling and human-in-the-loop simulations, all the way to usability testing with actual systems or components. Good practice dictates starting with the less expensive evaluation methods (e.g., mathematical analysis) and progressing to user tests before fielding a new system. Typically, the less expensive methods help focus the objectives of the more expensive methods, thus maximizing the application of system engineering resources (Small & Bass, 2000).

### **1.1. Context for HPM Task Analyses**

The NASA Aviation Safety Program (AvSP) was created to perform research and develop technology to reduce the rate of fatal aircraft accidents in the US. Under AvSP, the System-Wide Accident Prevention (SWAP) project uses current knowledge about human cognition to develop mitigation strategies to address current trends in aviation accident and incident profiles. System-Wide Accident Prevention is comprised of four elements, one being Human Performance Modeling. The objective of the HPM Element is to develop predictive capabilities to identify likely performance improvements or error vulnerabilities during system operations. During the time period of interest (FY02), this element investigated the application of HPM to predict the human performance of flight crews using SVS in the cockpit. It began with analyses of pilot tasks to support HPM development. SVS is a developmental system whose details have not been fully determined. It is intended to present to the pilots a clear, 3D, out-the-cockpit view of terrain, obstacles, traffic, and runways, regardless of the actual visibility or weather conditions.

### **1.2. Baseline & SVS Models**

The first step in the FY02 SVS effort was to analyze pilot tasks in order to create a baseline human performance model of the flight crew *without* SVS. In other words, the baseline model will represent today's flight deck equipment and operations. NASA decided that the example flight deck for this HPM effort would be the Boeing 757 (B757). This decision was driven by the fact that preliminary

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<sup>1</sup> All acronyms are defined in Section 9 at the end of this paper.

SVS flight tests used a NASA-owned B757. Data collected from the flight tests may be used for comparison with the HPM predictions. The NASA HPM element directed the FY02 effort to focus on the approach and landing phases of flight because improved pilot situational awareness of terrain and obstacles during approach and landing is expected to be one of the biggest benefits of SVS.

Micro Analysis and Design (MA&D) began the *baseline* (no SVS) effort by analyzing B757 approach tasks for ILS- and RNAV-guided approaches. Then, MA&D conducted a preliminary task analysis for the SVS HPM.

## **2. Technical Objectives**

The objectives of the research reported herein are to:

- Analyze and enumerate the pilot tasks for the baseline conditions (i.e., B757 approaches using ILS and RNAV guidance).
- Analyze and describe the pilot tasks for the SVS condition.

Assumptions for the analyses include:

- Analytic results from above will be used by human performance modelers, so enough context is needed to model a rich enough environment for valid HPM experiments.
- HPM modelers do not have aviation domain expertise; therefore the task analyses must include all relevant task information (i.e., the *what*, *how*, and *why* for each task).
- Pilot tasks include visual, auditory, cognitive, and psychomotor elements.
- Approaches do not include abnormal or emergency situations; although, since safety is paramount, planning for a missed approach or go-around is always part of flying an approach.

## **3. Background Information**

Although this research assumes a B757 aircraft, this background information applies to practically all commercial jet aircraft. Air carriers (i.e., scheduled and charter airlines, cargo carriers, and business jets) typically file instrument flight rules (IFR) flight plans. Aircraft on IFR flight plans follow air traffic control (ATC) instructions; in return, ATC assumes responsibility for the safe separation of IFR aircraft.

Because of the complexity of the approach phase and the potential benefit offered by SVS, the initial HPM research focuses on this phase of flight. Figure 1 shows the relationship of the approach phase to the other phases of a *normal* flight (adapted from Alter & Regal, 1992).

While the missed approach and subsequent divert phases are shown in Figure 1, their occurrence is rare among professional pilots. Two of the professional pilots with whom we spoke estimated the occurrence of actual missed approaches to be about one missed approach per year per pilot. Therefore, based on an average of 20 landings per month per pilot, there would be 1 missed approach per 240 landings. Even though rare, a missed approach is still considered a normal phase of flight because pilots prepare for it each time they fly an approach. However, abnormal or emergency situations are presently outside the scope of this research.

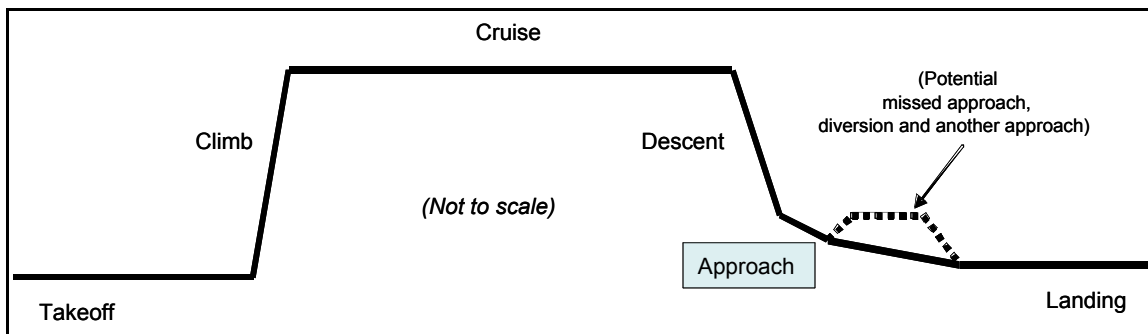


Figure 1. Normal phases of flight (approach phase highlighted).

The following sub-sections describe the approach phase and the four types of landing guidance that are relevant to our objectives: visual, ILS, RNAV, and SVS.

### 3.1. Approach Phase of Flight

The approach phase, which is the focus of the task analyses, begins at the bottom of descent and ends at main wheel touchdown in the landing phase. The purpose of an approach is to transition the aircraft in a carefully prescribed manner from typical intermediate altitudes after descent to a position, speed and configuration from which the pilots can land their airplane. During the approach, pilots normally follow published approach procedures, which designate mandatory courses, altitudes, and oftentimes speeds to a particular runway. Published approaches safely and expeditiously guide arriving aircraft into an airport by keeping aircraft away from high terrain, obstacles (e.g., radio antennas), aircraft departing from the airport, the approaches to other runways, and traffic patterns from nearby airports. Published approaches are most useful when visibility is poor because they enable the pilots to find the runway when they would not be able to otherwise. ATC gives permission, or *clearance*, to fly a specific approach, which is normally based upon weather, wind, and traffic conditions.

### 3.2. Approach Types

There are two basic types of approaches: visual and instrument. Instrument approaches are further delineated into precision and non-precision approaches. A non-precision approach provides only lateral guidance to the runway, whereas a precision approach provides both lateral and vertical guidance. Lateral guidance enables the pilots to align their aircraft with the runway centerline before landing. Vertical guidance enables the pilots to fly a steady descent angle, known as a *glide path*,<sup>2</sup> so as to land within approximately the first 1000 feet of the runway.

This HPM research focuses on two existing types of precision approaches (ILS and RNAV), as well as an “under development” SVS approach, which is, in essence, a combination of visual and precision approach types. Following, we explain a visual approach, and then an instrument approach with emphasis on a precision approach (ignoring the non-precision approach type for the remainder of this paper).

#### 3.2.1. Visual Approach

A visual approach is when the pilots can see the airport and runway from a distance (usually at least 10-20 miles away). In this situation, pilots commonly follow other aircraft in the landing sequence

<sup>2</sup> The term glide path is a misnomer because the aircraft does not glide to landing. Rather, the descent to landing is a powered maneuver flown within specific tolerances of airspeed, thrust, configuration, pitch and roll.

and are responsible for spacing from the other aircraft, avoiding terrain and obstacles, and aligning their aircraft with the runway. Courses and altitudes are the pilots' choice, as long as they remain in the landing sequence. A typical ATC clearance for a visual approach is, "NASA-113, Santa Barbara Approach: Follow the 737 ahead; cleared for a visual approach to Runway 7. Contact the tower for landing clearance." This clearance identifies the aircraft (NASA-113) to whom ATC is talking (since the radio is a "party line" communication method), the ATC facility who is calling (Santa Barbara Approach), the current instructions ("follow the 737 ahead"), the clearance ("cleared for a visual approach to Runway 7"), and directions for what to do next (contact the tower).

Runway numbers are determined by the magnetic heading of an aircraft as it aligns with the runway centerline. So, an aircraft aligned with Santa Barbara's Runway 7 has an approximate heading of 070°. An airplane aligned with the same stretch of runway pavement, but at the opposite end and facing the opposite direction, has a heading of 250°, which is the reciprocal of 070°. That runway's number is 25. The single degree units are dropped, as is a leading zero, in most cases. Aviation compasses have 000° or 360° as due north, 090° as east, 180° is south, and 270° is west. (A runway facing north is numbered 36 not 0.)

All major airports have runways with specialized lighting systems, which are most useful at night or when visibility is limited due to weather (e.g., fog). There is lighting that outlines the runway and some that extends from the runway threshold along the approach path (up to 3000 feet in length) to help visually guide the pilots to the runway threshold. Most of the lights along the approach path and runway are designed to provide lateral guidance to the pilots. However, another type of lighting is the visual approach slope indicator system (VASI). The VASI provides pilots with vertical guidance (i.e., glide path) information by projecting narrow beams of light along the glide path. The lights are situated such that the pilots see white lights when above the glide path, and red lights when below. When the aircraft is on glide path, the VASI light bars show red over white (Figure 2). VASI lights are visible as far as 20 miles away in clear weather.

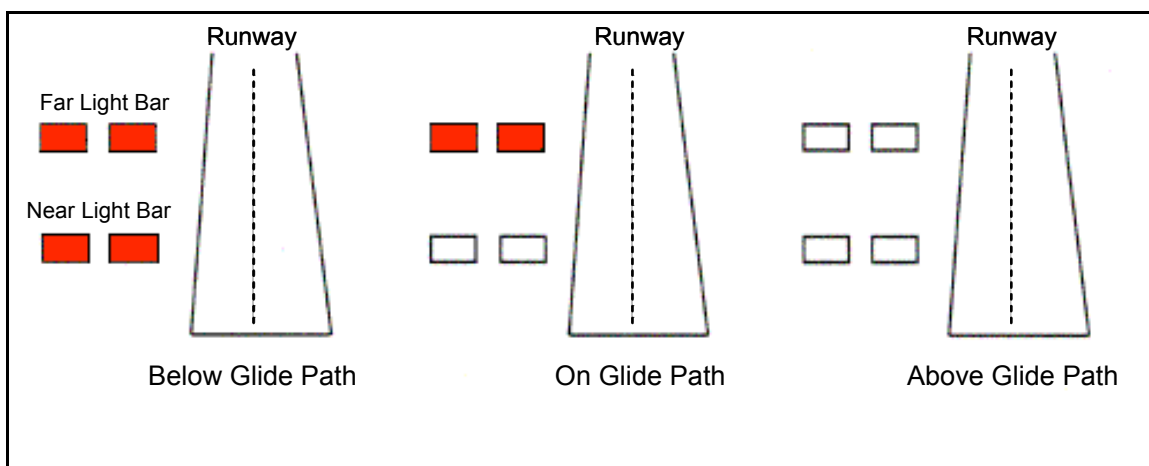


Figure 2. VASI lights and their meaning.

Even when visibility is good, pilots study, have available, and use applicable portions of the published instrument approach procedure for the designated runway as a prudent safety measure. Also, published procedures contain such useful information as communication radio frequencies, navigation radio frequencies, a diagram of the airport and runway with obstacle positions, and recommended courses and altitudes (which are especially useful at unfamiliar airports).

### **3.2.2. Instrument Approach**

A typical ATC clearance for an instrument approach is “NASA-113, Santa Barbara Approach: Fly heading 120; cleared for ILS Runway 7; maintain 3000 and 200 knots until established on the approach. Contact the tower at ROCKY.” The similarities to the visual approach clearance should be apparent. The differences are in the level of control exercised by ATC, usually because pilots cannot see the airport or surrounding terrain and obstacles. In this example, Santa Barbara Approach needs NASA-113 to maintain a specific heading (120°) to intercept the lateral approach guidance to the runway. Also, ATC requires a specific altitude (“maintain 3000” – feet are implied) and speed (“200 knots”) until the aircraft is in a position to safely descend toward the specified runway on the published approach procedure (the ILS to Runway 7 – Santa Barbara is implied). The last portion of the clearance tells NASA-113 to radio the tower when at a navigation location called ROCKY. In aviation terminology, ROCKY is known as a *fix*. In this hypothetical example, ROCKY is a specific type of fix – the *final approach fix* for Runway 7 at Santa Barbara Airport.

As implied by the above instrument approach clearance explanation, published approaches are comprised of segments: initial, intermediate, and final. Figure 3 illustrates these segments using two views: the top portion shows the altitude or vertical profile; the bottom portion shows the course or lateral view. The initial approach segment is for beginning to descend toward the final approach fix altitude, and for beginning to align with the designated runway. For example, if the aircraft flew from New York to California (east to west) and if the destination airport, say Santa Barbara, is landing to the northeast on Runway 7 (due to its current winds), the pilots need to fly from a southwesterly heading to an northeasterly heading to eventually align with the runway. The initial approach segment starts this process. The intermediate segment continues the alignment and descent process, and usually includes slowing and configuring (i.e., lowering the landing gear and flaps).

So, by the time the aircraft reaches the final approach fix (FAF), all that remains for the pilots to do is descend at an appropriate rate and speed while remaining aligned with the runway centerline in the proper landing configuration. The final segment is from the FAF to the landing, or to the missed approach, if the pilots decide to abandon the landing. The overall purposes of the initial and intermediate segments are to ensure the aircraft is in the correct position, configuration, and orientation relative to the runway, at the FAF.

When the final approach segment proceeds as desired, it is known as a “stable” approach. A typical FAF altitude is about 1500 feet above the runway altitude. As the aircraft descends from the FAF to the landing, there are imaginary *gates* at 1000 feet above ground level (AGL) and 500 feet AGL. Most air carriers require their pilots to be stable at one or both of these gates (even for visual approaches). A stable approach is when the aircraft is in the correct configuration, and within established tolerances for speed, descent rate, attitude, and engine thrust. The aircraft must also be within tolerances for the published course and glide path. If any one of these conditions is not met, executing a missed approach is the appropriate action.

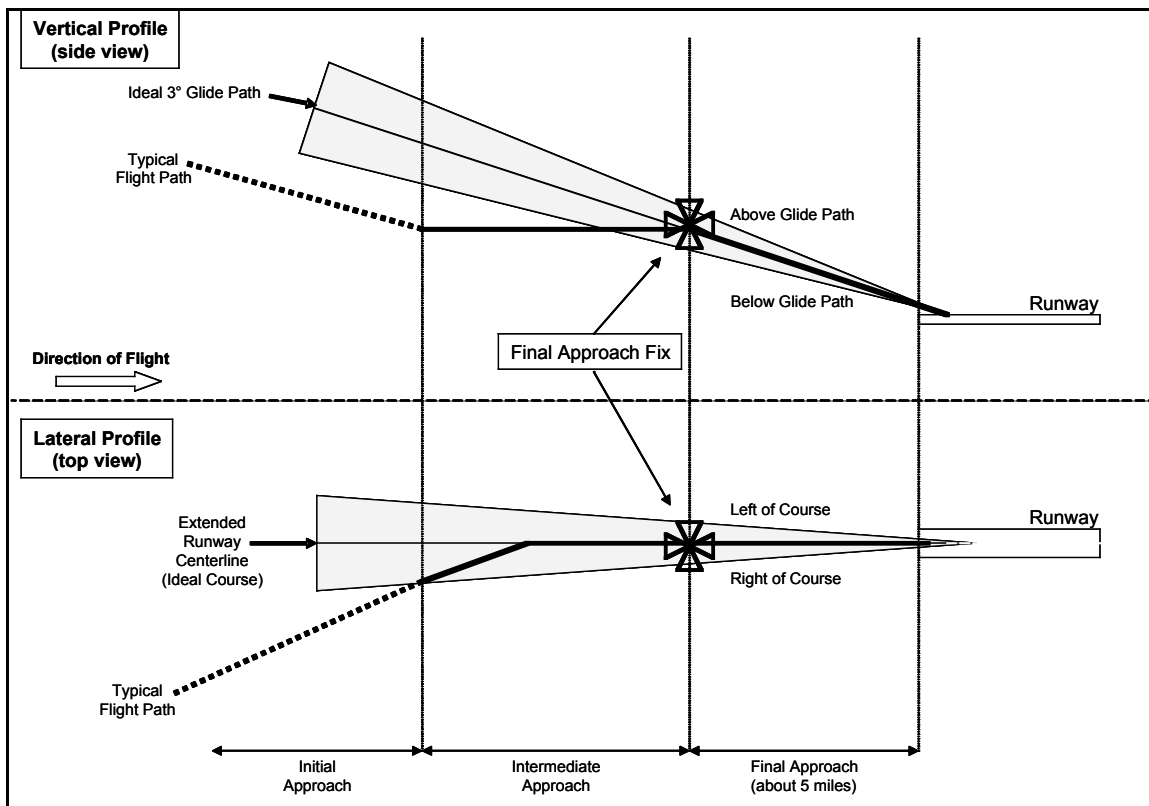


Figure 3. Two views of a typical instrument approach.

### 3.2.3. ILS Approach

An instrument landing system (ILS) approach is one type of precision approach. The system is comprised of three transmitters near the runway, and a receiver in the cockpit that the pilots tune to the appropriate frequency for the specific runway. The **localizer** transmitter provides lateral guidance aligned with the runway centerline. The **glide slope** transmitter provides vertical guidance to direct the aircraft along a glide path (typically  $3^\circ$ ) that will intersect with the runway about 1000 feet from the approach end or threshold. Although  $3^\circ$  is a typical glide slope, false glide slopes, due to reflections of the signal off the ground, can occur at around  $9^\circ$ . To avoid flying a false glide slope, ILS approach procedures require that aircraft intercept the glide slope at an altitude low enough to inhibit false glide slope capture, but high enough to avoid terrain and obstacles (shown in the top half of Figure 3 by the typical flight path intercepting the glide slope cone from below).

**Marker beacons** signal when the aircraft flies over a particular spot on the ground. The beacon transmits vertically, so that the combination of the three ILS transmitters gives the pilots a definite location in 3D space. For ILS approaches, there is a marker beacon at the FAF; this marker beacon is also known as the *outer marker*. The altitude at which a vertical line from the *outer marker* intersects the ILS glide slope is noted on published ILS approach charts. Thus, if the aircraft is aligned with the ILS glide slope, it should cross the outer marker at the specified approach chart altitude. If the actual altitude differs from the charted altitude by a significant amount, the pilots should suspect a false glide slope and take appropriate actions (e.g., execute a missed approach if the runway is not in sight). A light on the ILS receiver unit in the cockpit flashes when the aircraft passes over a marker beacon. The *middle marker* is usually about 3000 feet from the runway threshold.



There are several *categories* of ILS based upon system accuracy, which help the pilots fly closer to the ground before reaching **decision height** – the minimum height above the runway at which the pilots decide to land or execute a missed approach. We are only concerned with Category I, the least accurate, with a typical decision height of 200 feet above the runway. If the aircraft is on the glide slope, crossing the middle marker occurs simultaneously with reaching the 200-foot AGL decision height.

As with generic instrument approaches, ILSs have three segments. The initial segment begins when ATC issues a clearance (altitude, heading, and possibly speed) that will result in the aircraft intercepting the localizer. Normally, only a single clearance is needed. However, when the controller must slow multiple aircraft for spacing and sequencing or when the instrument approach procedure requires it, this segment may necessitate multiple clearances (for any combination of altitude, heading, and speed) for each aircraft. In any case, the last of the clearances in this segment will place the aircraft on a heading to intercept the localizer, and at an altitude to intercept the glide slope from below. To simplify the scope of this work, the assumption is made that this segment will involve a single clearance (as noted in the example at the start of Section 3.2.2).

Once the aircraft has intercepted the localizer, the intermediate approach segment begins. The pilots fly the localizer inbound and continue following ATC instructions for altitude and speed, if given. The last altitude assigned by ATC is often the glide slope intercept altitude (GSIA), and is usually noted on the approach chart. However, if ATC directs an altitude that differs from the altitude specified on the approach chart, then the ATC-directed altitude takes precedence over the altitude from the approach chart (as is the case with any discrepancy between ATC clearances and an approach chart). The intermediate approach segment ends, and the final approach segment begins, when the aircraft intercepts the glide slope. This point is usually also the FAF, if the aircraft is at the GSIA. If ATC directs a different altitude than the published GSIA, the final approach still begins at the actual glide slope intercept, but will result in a shorter or longer final approach segment – shorter if the actual GSIA is below the published GSIA, longer if above.

During final approach, the aircraft descends along the ILS glide slope while maintaining alignment with the runway centerline via the localizer. No later than decision height, the pilots must be able to see the runway environment (i.e., the runway itself or any approach lights) to proceed with the landing. If the pilots cannot see the runway environment, or for any reason decide that it is imprudent to land (e.g., due to an unstable approach or wind shear), they execute a missed approach. The final approach segment ends upon landing or if executing a missed approach. A missed approach is a portion of the published approach that directs the aircraft to a safe altitude and location so that the pilots may attempt another approach, or divert to a different airport. Pilots begin a missed approach by accelerating, climbing, and raising the landing gear and, usually, the flaps. Then they typically inform ATC of their missed approach and follow the charted missed approach instructions (if ATC issues no other instructions). Because actual missed approaches are rare, the later task analyses (Section 4) only address planning for a missed approach, not flying one.

#### **3.2.4. RNAV Approach**

Virtually all modern commercial aircraft use an Area Navigation (RNAV) system for flight navigation. An RNAV system is comprised of several independent navigation subsystems, both internal and external to the aircraft, as well as subsystems to program and update the desired 3D route of flight. The RNAV system combines information from the navigation subsystems as a means to crosscheck and verify the computed location to the required level of accuracy. Based upon the actual computed aircraft position and the planned route of flight (entered by the pilots before flight and

updated as needed during flight), the RNAV system provides guidance signals which the pilots or autopilot can follow to capture and fly the desired 3D path.

The RNAV flight path is a series of waypoints between takeoff and landing. A waypoint may be a navigation fix, such as an FAF, and usually has the following properties: latitude, longitude, inbound course, outbound course, crossing altitude, speed, and a unique name (such as ROCKY in the example in Section 3.2.2). Paths between waypoints are analogous to the approach segments, described earlier, in that waypoints delineate flight path changes in the form of changes to course, altitude, speed, or a combination of these parameters. The RNAV system's objective is to guide the aircraft to the next (*active*) waypoint.

A naïve observer might not see any difference between flying an RNAV approach and an ILS approach. Both approach types use waypoints to separate segments of the approach and both use a published decision height or altitude to define the point by which the pilots must decide to land or to execute a missed approach. The main difference is that the RNAV approach does not use ground-based localizer, glide slope, or marker beacon signals. Instead, an RNAV approach uses the same computations as during the rest of the flight. As such, RNAV is less accurate, and so RNAV *decision altitudes* are higher than ILS *decision heights*.

Another major difference involves the behavior of the aircraft under autopilot control. For an ILS, the autopilot will fly the glide slope all the way to the ground, unless the pilots take control. But, due to the inherent inaccuracies of RNAV, the autopilot will automatically execute a missed approach at the decision altitude. There are also minor terminology differences: RNAV uses lateral navigation (LNAV) for course guidance, not a localizer; vertical navigation (VNAV) for altitude and altitude change guidance, not a glide slope; and, has a decision altitude, not a decision height.

Figure 4 shows an example of a pilot's RNAV approach chart used in NASA simulations (i.e., not operationally certified). While much of the detail is outside the scope of this discussion, the following paragraphs explain some of the items.

Upper right corner:

- Title of the approach – in this case the RNAV (GPS) RWY 33L, Santa Barbara Muni. RNAV signifies the approach type. GPS refers to the type of navigation system used to determine positions. (GPS is global positioning system, a network of satellites used for determining the latitude, longitude and altitude of vehicles that have GPS receivers.) RWY 33L is an abbreviation for Runway 33 Left. The runway is at the municipal airport in Santa Barbara, whose three-letter identifier is SBA.

Upper center section (in boxes):

- Various information and radio frequencies.

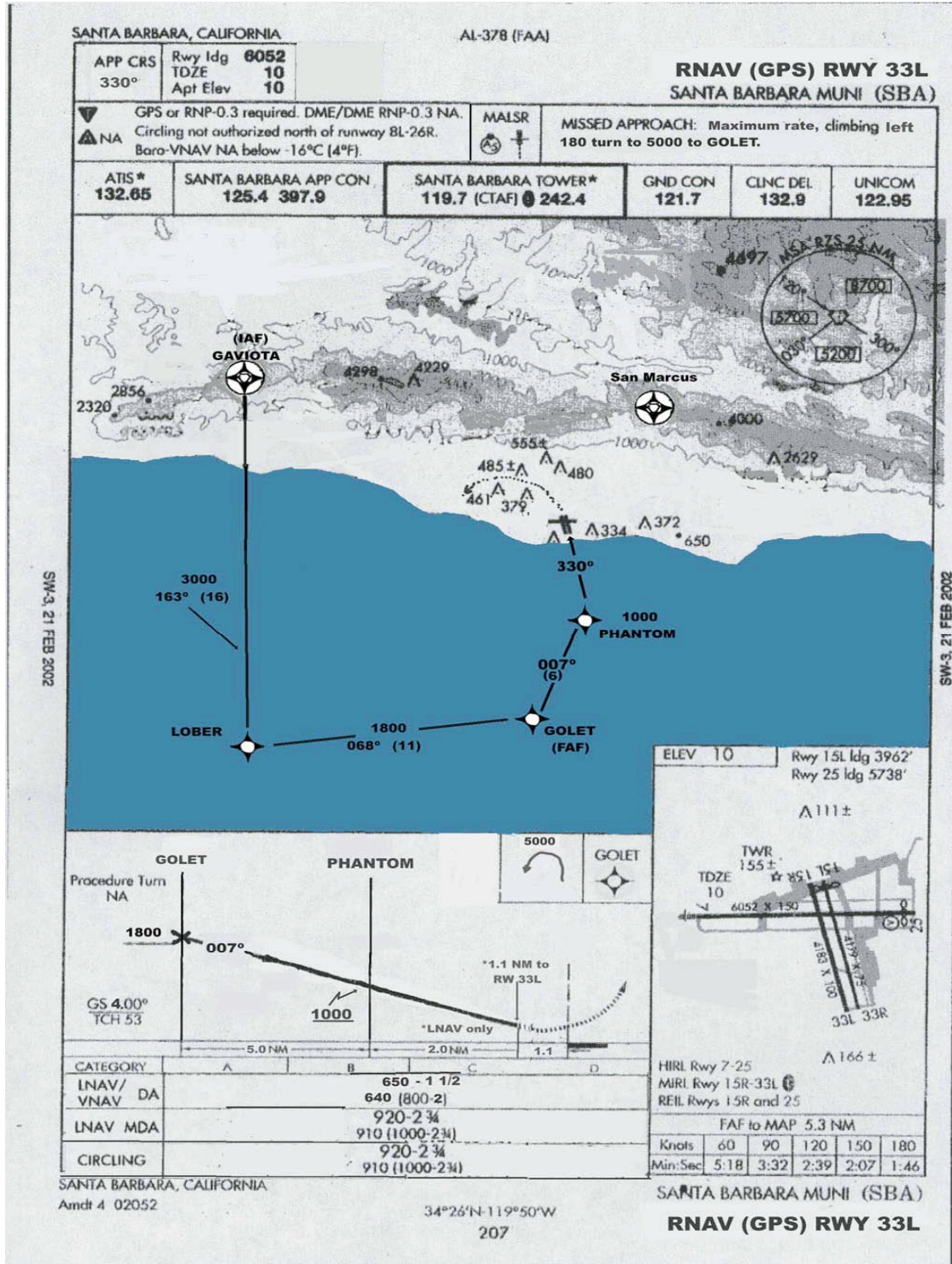


Figure 4. RNAV approach chart for Santa Barbara Airport's Runway 33L.

Middle section:

- A graphic that shows the relevant geography around the Santa Barbara airport, and the approach's route of flight superimposed on the geography image. The image is oriented north up, with the coastline clearly discernable.
- Terrain elevation lines depict the high terrain near the airport. Dots with numbers give the location (dot) and altitude (in feet above mean sea level (MSL)) of mountains, hills, and ridges.
- Upside-down Vs with dots and numbers show the location (dot) of obstacles, usually radio towers or buildings, and their height in feet MSL.
- Black stars with white middles are waypoints. Waypoint names are unique; in this example they are GAVIOTA, LOBER, GOLET, and PHANTOM. The GAVIOTA waypoint is the initial approach fix (IAF), which starts the approach. GOLET is the FAF.
- The approach's initial segment is from GAVIOTA to LOBER and has a course line of 163° at 3000 feet MSL for 16 nautical miles (nm).
- The intermediate segment is from LOBER to GOLET at 1800 feet, 068° and 11 nm.
- The final segment is from GOLET to the runway and includes PHANTOM. GOLET is offset from the runway centerline, probably because traffic for Runway 33R (Runway 33 Right) comes in from the other direction, and since RNAV is not as precise as ILS guidance, there is a dog-leg to the final runway centerline alignment.
- Runway graphic – shows the runway configuration and relative alignment. (A more detailed graphic of the runways is in the lower right corner of the chart.)
- Dashed line with arrow – depicts the missed approach path, which is also described in words right below the approach chart's title.

Lower right section:

- Runway graphic and details – shows the runways in black and taxiways in gray.
- Numbers alongside each runway give its dimensions (length x width).
- Numbers at the end of each runway give its name (7, 33L, 33R, 25, 15L, 15R).
- Symbols at the ends of some runways denote the lighting system for that runway.
- Upside-down Vs with dots and numbers show obstacle positions and heights.
- In the upper left corner is the field elevation, 10 feet MSL, which is the height of the highest terrain in the runway, taxiway and parking areas of the airport.

Lower left section:

- This graphic illustrates the vertical approach path from GOLET, the FAF, to the runway, including the missed approach (dashed line and arrow).
- Below the vertical profile are the various approach *minima*, the cloud ceiling and visibility criteria for flying this approach. The first row shows the LNAV/VNAV decision altitude (DA) of 650 feet MSL, with minimum visibility of 1.5 miles. Beneath those numbers are 640 for feet AGL (which is the 650 feet MSL DA minus 10 feet field elevation), and two numbers in parentheses, “800-2”. The 800 is the lowest cloud ceiling height in feet MSL that the airport weather observers can give for pilots to legally begin the approach. The 2 is the lowest weather observation visibility for pilots to begin the approach. Both the observed ceiling and visibility must be above minima (800 and 2) for pilots to legally begin this published approach.

### **3.2.5. SVS Approach**

Because the synthetic vision system (SVS) is under development and evolving, the information herein should only be considered a “best estimate” as of this writing. With that caveat in mind, the overall

concept and anticipated use of SVS is to help pilots operate in poor visibility conditions (Norman, 2001). Therefore, an SVS approach is similar to either an ILS or RNAV approach, except that the pilots look at the SVS display, rather than out the window.

SVS is a cockpit system that allows pilots to view a computer-generated image of what is ahead of the aircraft, independent of weather or time of day (NASA Langley, 2001). The system will use satellite navigation signals to orient the presented image with the actual location of the aircraft relative to the terrain. This allows the terrain image to dynamically represent what the pilots would see out the front windows on a clear day as the flight progresses.

Because pilots are concerned with more than just terrain information, SVS is a very complex system with components in three major categories: sensors and database, computation, and display. Components in the sensors and database category include: forward looking infrared, millimeter wave radar, weather radar, navigation database, aircraft state data, and hazard information systems. The components in the computation category include: a dedicated computer for performing perspective transformations, data fusion, image object detection, display generation, integrity monitoring, and interface communication; and other existing aircraft subsystems, such as the RNAV, ground proximity warning, and central alert and warning systems. The components in the display category are: the primary flight display, navigation display, vertical situation display, head-up display, electronic moving map and other auxiliary displays (Norman, 2002).

### **3.2.6. Approach Summary**

We have described four specific types of guidance for aircraft approaches: visual, ILS, RNAV, and SVS. The choice of which approach type to actually fly for any given situation depends upon the visibility, the type of guidance equipment available for the designated runway, and the corresponding instrumentation available on the flight deck.

The approach types are similar in that the ultimate objective is for the pilots to land on the designated runway. However, they are also very different in that a visual approach primarily relies on a pilot's vision, experience, and judgment. An ILS approach relies on ground-based transmitters. RNAV mainly uses internal systems for guidance. And, SVS has the goal of combining the best features from the previous three types. Because SVS is primarily a display system from the pilot's perspective, we next describe the baseline aircraft displays and controls and then discuss how the SVS enhances the baseline displays.

## **3.3. Pilot Displays & Controls**

The following explanations of pilot displays and controls are specific to the Boeing 757 aircraft, but virtually all modern jet aircraft have analogous displays and controls, with similar appearances, modes, and control capabilities. First, we describe displays and controls that are common to all types of approaches; then we describe displays and controls unique to the ILS, RNAV, and, most importantly, SVS approaches.

### **3.3.1. Common Displays & Controls**

The B757 flight deck is referred to as a "glass cockpit" because computers present aircraft attitude, navigation, and system information in an integrated and graphical fashion on flight-worthy computer displays. The left half of Figure 5 shows the B757 flight deck. The right half shows an older B727 flight deck that has dedicated gages for individual pieces of information. It was the change from many independent gages to combined information on fewer computer screens that led to the phrase "glass cockpit." For example, there are 15 engine gages in the center section of the front instrument



panel in the B727, but one computer screen for similar information in the B757 (red circles in Figure 5).

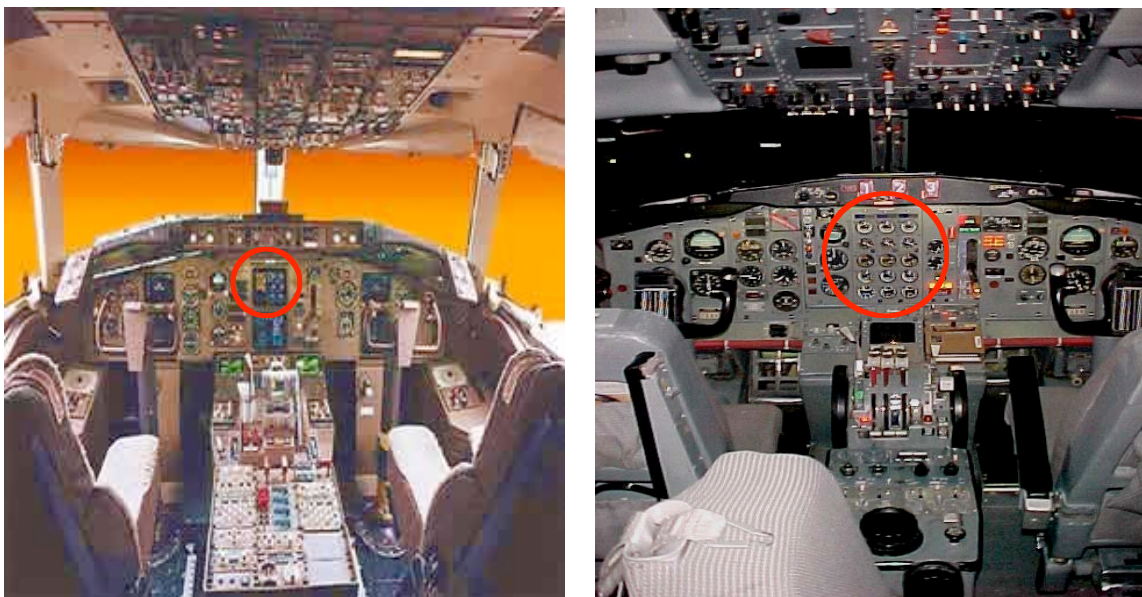


Figure 5. (a) B757 and (b) B727 flight decks (red circles compare engine instruments).

Because of a need to focus on specific displays and controls for approaches, we refer the reader to a web site to learn more about the B757 flight deck, if interested. The web site is: [http://www.meroweather.com/767/767\\_main.html](http://www.meroweather.com/767/767_main.html). Even though this site presents a B767 flight deck, the B757 and B767 are identical in layout (but the 767 is larger). The web site has a feature that allows a visitor to point to specific items in the photo to learn more about that item.

Figure 6 shows the layout of the most important flight deck displays. The reader should note the orientation of these important displays within the cockpit (Figure 5a). First we describe the controls and control modes, then the key displays. The key displays pointed to in Figure 6 are the primary flight display (PFD), navigation display (ND), airspeed indicator, altimeter, and engine instruments. Figure 6 also points to the gear handle (for lowering and raising the landing gear, or wheels) and flap position indicator – two other important items whose roles are further amplified, later, in the task analyses.

### 3.3.1.1. Flight Control Modes

There are three basic modes to control flight path: manual, automated, and partially automated. Manual flight is when the pilots steer the aircraft using the control wheel (or *yoke*) located in front of each pilot. The yoke is analogous to a car steering wheel, except that pilots also push or pull the yoke to descend or climb, respectively. The pilots also control speed via the engine throttles, located in between the pilots on the center console. To fly an approach manually, the pilots either look out the windows, if flying in good visibility, or use their instruments for guidance when steering their aircraft toward the desired landing spot on the runway.

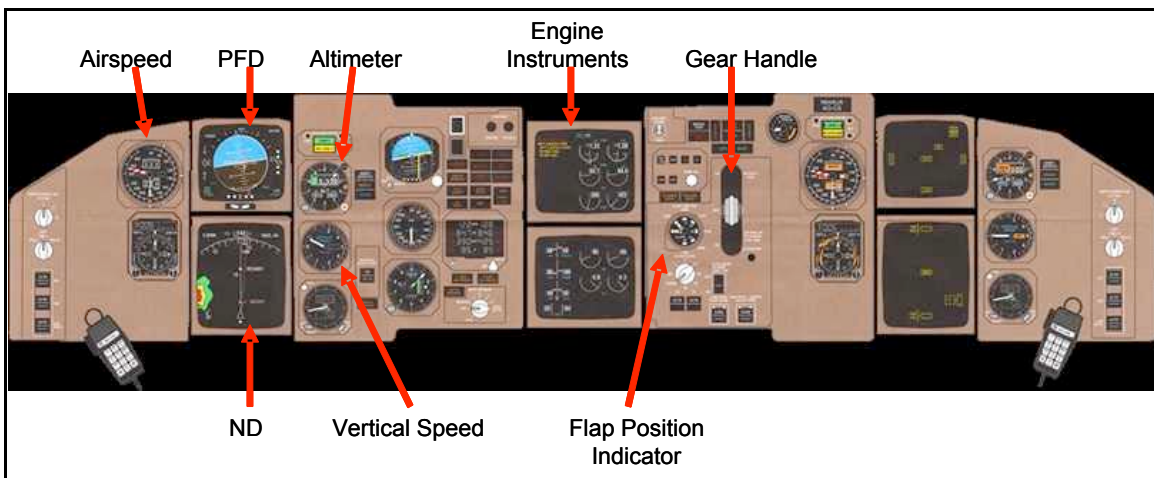


Figure 6. B757 center instrument panel, with labels for key items.

In automated flight, the pilots select the guidance method first (e.g., ILS or RNAV), and then engage the autopilot and auto-throttles to maintain the desired lateral and vertical paths, and speed. Even when in fully-automated flight control, the pilots have their hands resting on the controls in the event of a malfunction that would require their immediate response. Pilots also loosely hold the controls so that when they decide to land, they already have the feel of the control positions, as set by the autopilot, so they can more smoothly fly the landing.

In partially-automated flight, the pilots might use the autopilot, but not the auto-throttles, and so control airspeed themselves via the engine throttles. Or they might use only the auto-throttles for speed control and fly lateral and vertical paths themselves. Another option is to use the autopilot and auto-throttles, but steer using manual entries into the guidance functions via the mode control panel (MCP), described next.

### 3.3.1.2. Mode Control Panel (MCP)

The pilots use the MCP to select control and guidance modes for changing the aircraft path as needed. It is located at the top of the front instrument panel. As such, it has all the necessary controls for selecting flight control modes (automated to manual) and guidance cues in an up-front central location with easy access for both pilots (Figure 7).

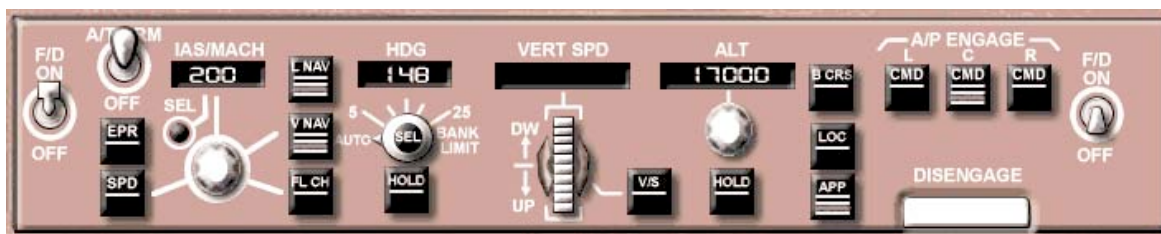


Figure 7. Mode Control Panel (MCP).

Each pilot has a flight director switch for turning on or off the flight director (F/D), which provides lateral and vertical steering guidance to the pilots on their primary flight display (more about the F/D in the PFD section, Section 3.3.1.3). Then, working from left to right, is the auto-throttle (A/T) switch for turning the auto-throttles on or off. Next is the airspeed or mach control. The pilots rotate the dial to select the desired speed. Buttons around the dial are for selecting the manner by which speed is controlled. EPR is engine pressure ratio, which gives units of thrust. Selecting EPR means that the

pilots wish to control speed by thrust only. SPD is speed, which means that the pilots want to control speed by any method (engine thrust or pitch changes). The LNAV button selects the RNAV's lateral navigation for lateral guidance. The VNAV button is for choosing RNAV vertical path guidance. The bottom button in that column is FL CH, which is flight level change, a mode for climbing or descending to a specific altitude. In our approach examples, the pilots might use FL CH during the initial approach segment when descending from, say, 5000 to 3000 feet. The FL CH mode would use idle thrust and a moderate nose-down pitch to descend; airspeed could increase to any value in FL CH.

Moving to the right is the HDG, or heading controls. Pilots dial the desired heading (usually as instructed by ATC) using the middle knob where the bank limit is also set. Pushing the HOLD button holds the selected heading, overriding LNAV.

The middle thumb wheel, VERT SPD, allows the pilots to set a specific climb or descent vertical speed. For most approaches, the pilots could set a vertical speed of 500 to 1000 feet per minute, but are more likely to use VNAV or approach modes.

The next window, ALT, is for setting the desired altitude. As with heading (HDG), there is a button to HOLD the set altitude, thus overriding VNAV.

The next column of three buttons is for specific approach guidance. Ignoring B CRS, we will turn to LOC, which the pilots use for localizer guidance. The bottom button, APP, is for both localizer and glide slope (i.e., ILS), or LNAV and VNAV (i.e., RNAV) approaches. The three horizontal buttons are for selecting which autopilot (A/P) to engage. Redundancy is required for approaches where the A/P flies to landing. The bar beneath the A/P buttons is for quickly disengaging any engaged autopilot(s).

As a quick review, Figure 7 shows that LNAV, VNAV, Approach, and the center autopilot are selected. Plus, the auto-throttles and left flight director are on. Speed is set for 200 knots, heading is set to 148°, and altitude is set for 17000 feet. However, these settings are not guiding the aircraft because the pilots have selected LNAV, VNAV and Approach, along with the A/T and center A/P. So, the autopilot ignores the settings in the three windows and flies the LNAV and VNAV paths and speed. These settings could be used to prepare for the missed approach, which in this example would be to climb to 17000 feet at 200 knots on a heading of 148°.

Because the guidance modes that are engaged or armed on the MCP can be difficult to decipher based on a quick glance at the MCP, the armed and engaged modes are also annunciated on the primary flight display, described next.

### **3.3.1.3. Primary Flight Display (PFD)**

The PFD is the primary attitude instrument. Both the captain (left seat) and first officer (right seat) have a PFD. The information provided by the PFD (Figure 8) is as follows.





Figure 8. Primary flight display (PFD).

Center of display:

- Artificial horizon depicted by blue and black ball. The blue half represents the sky; black is the ground.
- Transparent “aircraft wings” (outlined in white) depict the current attitude of aircraft in terms of pitch and roll.
- “Yellow cross” (looks pink-orange in the figure) depicts the Flight Director (F/D) command bars, which shows pitch and roll commands generated by the currently selected guidance source (e.g., ILS or RNAV). Typically, the autopilot or pilot rolls and pitches the aircraft to align the “aircraft wings” with the F/D command bars.

Upper left corner:

- GS200 – Ground speed in knots (200 knots in this example).

Upper right corner

- DH150 – Selected decision height or altitude in feet AGL (150 feet in this example).
- 1750 – Current AGL altitude in feet provided by radio altimeter (1750 feet in this example). The radio altimeter uses reflected radio waves from the ground to determine the height of the aircraft above the surface.

For the next two groupings, the depicted abbreviations are called flight mode annunciations (FMAs). FMAs in green font indicate the associated mode is *engaged* (active). FMAs in white font indicate the associated mode is *armed* and will engage under normally expected conditions when the *capture* conditions occur. For example, LOC armed means the localizer guidance will capture and engage when the aircraft enters the localizer cone (bottom half of Figure 3).

Lower left corner (for speed and vertical path modes):

- A/T (in green) – this location on the display indicates auto-throttle system status. In this example, the auto-throttles are engaged.
- SPD (in green) – this FMA means the pilots are using the auto-throttles to hold a selected speed (as opposed to flying a selected vertical path regardless of airspeed).
- G S (in white) – this location is for pitch control modes. In this example, G S (for glide slope) is armed, which means the glide slope will capture and engage when the aircraft flies within the glide slope cone (top half of Figure 3).
- V NAV (in green) – this FMA means VNAV is engaged and providing guidance for vertical navigation.

Lower right corner (for autopilot and lateral path modes):

- CMD (in green) – the autopilot or flight director status. In this example, CMD means the autopilot is actively flying the aircraft. If FD is displayed instead, it means the flight director command bars are displayed on the PFD and the autopilot is disengaged. If blank, the autopilot is disengaged and the flight director is off.
- LOC (in white) – this location on the display is for roll mode. In this example, LOC (for localizer) is armed.
- LNAV (in green) – this FMA means that LNAV is engaged and providing guidance for lateral navigation.

Bottom center:

- White dots and pink marker – localizer pointer (pink) and scale (white) indicate the center of the localizer beam with respect to the aircraft. In this example, the pink marker is right of center so the aircraft needs to turn to the right to fly to the center of the localizer cone. This is consistent with the F/D, which is commanding a turn to the right.

Center right:

- White dots and pink marker – glide slope pointer (pink) and scale (white dots) indicate glide slope position with respect to the aircraft. In this example, the pink indicator is above the center mark so the aircraft is below the glide slope. This is also consistent with the F/D, which is commanding a pitch up. A term often used by pilots is *one dot below glide slope*. This term refers to the pink indicator pointing at the first white dot *above* the center mark, but the aircraft is actually *below* the glide slope. On initial glide slope intercept, pilots use the “one dot below” indication as the latest time to configure the aircraft for the final approach if on the GSIA. Glide slope intercept usually occurs shortly thereafter.

Center left:

- White diamonds and pink marker – The fast/slow indicator depicts deviation from the pilot-selected or VNAV-directed airspeed. In this example, the indicator is centered, so no speed adjustment is needed.

Because the control modes and abbreviations can be confusing, Table 1 gives an overview of the MCP modes and corresponding FMAs. The MCP allows guidance modes to be either **engaged** or **armed**. A guidance mode that is engaged means that the guidance mode is actively providing signals to the displays, autopilot, or auto-throttles. A guidance mode that is armed means that the guidance mode will engage (i.e., become active) when the required conditions for its engagement have been met (e.g., intercept the localizer cone).

**Table 1.** Typical flight mode annunciations for approach (adapted from Casner, 2001).

Guidance Function	How it works	FMA on PFD (see Section 3.3.1.3)		
		Roll	Pitch	Thrust
HEADING SELECT	Roll used to maintain heading dialed into “HDG” window on MCP. 1) Dial new heading.	HDG SEL		
ALTITUDE HOLD*	Pitch used to maintain present altitude. 1) Dial desired altitude. 2) Push altitude “HOLD” button to maintain present altitude.		ALT	
SPEED	Adjustments to thrust used to maintain speed dialed into “IAS/MACH” window on MCP. 1) Dial new speed. 2) Push “SPD” button.			SPD
LOCALIZER*	Roll used to fly selected localizer course. 1) Dial ILS course and frequency on ILS panel. 2) Arm function by pushing “LOC” button. 3) Function captures localizer.	LOC		
APPROACH* (localizer + glide slope)	Roll used to fly localizer. Pitch used to fly glide slope. Adjustments to thrust used to maintain speed dialed into “IAS/MACH” window on MCP. 1) Dial ILS course and frequency on ILS panel. 2) Dial new speed (if needed). 3) Arm function by pushing “APP” button. 4) Function captures localizer and glide slope.	LOC	G S	SPD
FLIGHT LEVEL CHANGE	Thrust of engines set to idle. Pitch used to maintain speed dialed into “IAS/MACH” window on MCP. 1) Dial new altitude. 2) Dial new speed (if needed). 3) Push “FL CH” button. 4) Descends to new altitude and then switches to ALTITUDE HOLD.		FLCH SPD	HOLD

\* Guidance functions that can be armed prior to engagement.

As can be seen in the Table 1, the HEADING SELECT, ALTITUDE HOLD, and SPEED guidance functions are each dependent on only a single state – roll, pitch, and thrust, respectively. The commands for HEADING SELECT and SPEED come directly from pilot entry into the MCP. For example, if HEADING SELECT is engaged, the aircraft will begin to turn as soon as the pilot changes the heading value in the “HDG” window on the MCP (Figure 7).

The command for ALTITUDE HOLD comes from two possible sources. In the first case, by pressing the “HOLD” button under the “ALT” window on the MCP, the aircraft will hold the current altitude indefinitely. In the second case, the altitude entered in the “ALT” window on the MCP becomes the target altitude. However, in this latter case, in order for the aircraft to change to the target altitude, FLIGHT LEVEL CHANGE must first be selected. When FLIGHT LEVEL CHANGE is engaged, the ALTITUDE HOLD function is said to be *armed*. In this case, when the aircraft descends and reaches the target altitude, the armed condition is met and the guidance function disengages FLIGHT LEVEL

CHANGE and engages ALTITUDE HOLD. In addition, the engaged pitch FMA on the PFD switches from “FLCH SPD” to “ALT” (not shown in Figure 8), and the engaged thrust FMA on the PFD switches from “HOLD” to “SPD.” (The terms *flight level* and *altitude* are used interchangeably in this context).

Another guidance function that is armed prior to being engaged is APPROACH. As an example, consider an aircraft flying with constant heading, altitude, and speed via HEADING SELECT, ALTITUDE HOLD, and SPEED functions. If APPROACH is armed, it becomes engaged when the aircraft intercepts the localizer (assuming, of course, that it is on an intercept course). The engaged roll FMA switches from “HDG SEL” to “LOC.” At this point, if the autopilot is engaged, the aircraft flies the course corresponding to the localizer. When the aircraft intercepts the glide slope, the engaged pitch FMA switches from “ALT” to “G S,” corresponding to aircraft commands to fly the glide slope. The thrust FMA remains unchanged displaying “SPD.”

#### **3.3.1.4. Navigation Display (ND)**

The ND provides the pilots with a map view (Figure 9) of the area in which the aircraft is headed. Both the captain and first officer (FO) have an ND. The ND can be configured in various modes with *map* mode being the most common. In fact, during approach, it is common for the ND of one of the pilots to be in map mode and the other pilot to be in ILS mode. ILS mode allows the raw ILS signal data to be displayed. Using different modes allows the pilots to crosscheck information. For example, the map mode displays information based on the RNAV-computed position. If the aircraft location is in error for whatever reason (e.g., drift in the inertial navigation system), there would be no way to know this from the map mode. However, if the ILS mode is being used by the other pilot and there is an ILS signal detected, then the discrepancy would become apparent by crosschecking the two displays. Details of the ND, by region of the display, are as follows.

Bottom center:

- White triangle – aircraft symbol. The apex of the triangle indicates the aircraft position relative to display.
- White dashed line – curve trend vector. Indicates predicted airplane track in 30, 60 and 90 second intervals when turning.

Center:

- “AMBOY” and “KTTN” with waypoint symbols – indicate waypoints. White for inactive, magenta for active (there is no active waypoint shown in the figure).
- “SOJ” with VORTAC symbol – indicates VORTAC navigation aid. When the NAVAID switch is on, all appropriate navigation aids within the range scale appear, in addition to those navigation aids which are standard or active to denote fixes.
- “MMP” with blue circle – indicates the MMP airport. (Airports have unique three-letter identifiers; e.g., LAX. In this example MMP is fictitious.) When the ARPT switch is on, the ND displays airports within the map area.
- Pink solid line with tic marks – indicates the course based on a prediction using the present heading and wind.
- “80” – the range from the aircraft to the associated tic (80 nm in this example). Also indicates half of the range selected on the ND range selector. In this example, the ND range selector is set to 160 nm, displaying a moving map 160 nm in front of the aircraft.
- Magenta solid line – indicates planned lateral route of flight.
- Pink dashed line – indicates the heading set in the MCP. In this example, the heading is set to 035 degrees.



Bottom right corner:

- Vertical white line and tics with pink diamond – the vertical deviation indicator, which depicts the altitude deviation from the RNAV's vertical profile (VNAV path). In this example, the airplane is slightly below the desired VNAV path.

Bottom left corner:

- White arrow and “120” – the wind display. Indicates wind direction relative to map display orientation, and speed in knots. In this example, the aircraft is experiencing a 120-knot right-quartering tailwind.
- Multicolored blob – weather radar symbol. The highest intensity is displayed in red, lesser intensity in amber, and least intense in green. Turbulence is displayed in magenta (not shown in this example).

Center left corner:

- TFC – means the TFC button is on, which means the TCAS traffic display is on.

### **3.3.1.5. Miscellaneous Controls & Displays**

There are a few other systems that are relevant to approaches and our objectives: the flight management system, the traffic collision avoidance system, and two types of altimeters.

#### Flight Management System

The flight management system (FMS) is one instance of an RNAV system. The FMS assists the pilots in planning and executing the flight route. During flight planning, the pilots enter the flight route, aircraft weight, and expected weather conditions into the FMS via the central pedestal control display unit (Casner, 2001). Information about the flight route includes the *expected* departure runway and departure procedure, cruise speed and altitude, arrival and approach procedures, and the *expected* runway assignment. The *actual* flight route can differ from the plan (and oftentimes does) depending on weather and ATC requirements. Changes enroute require the pilots to re-program the FMS. The FMS calculates the optimal flight path and economical speeds during the climb, cruise, and descent phases of flight. The FMS-calculated lateral path is presented on the ND as the magenta line between waypoints (in Figure 9).

Although the FMS paths can theoretically be followed from takeoff to just prior to landing, the reality is that ATC clearances during the descent and approach phase of flight often differ from what has been programmed into the FMS. Pilots do not typically re-program the FMS to account for ATC clearances just prior to or during the approach for two reasons. First, reprogramming the FMS requires a significant amount of time and cognitive workload, and it distracts the pilot doing the programming from other important tasks, such as monitoring the aircraft position, speed and configuration (Degani et al, 1995). Second, ATC clearances just prior to or during the approach do not typically require complex lateral or vertical path planning. Rather, these ATC clearances instruct the aircraft to change heading, altitude, and speed (or any combination of the three). Therefore, pilots use the MCP to comply with pre-approach clearances (i.e., during initial or intermediate segments).

#### Traffic Alert and Collision Avoidance System

The traffic alert and collision avoidance system (TCAS) is an airborne collision avoidance system based on each aircraft's ATC radar beacon signals. TCAS operates independent of ground-based equipment, and gives the pilots traffic advisories and collision avoidance guidance. TCAS is a backup system to ATC, which is the primary system for keeping aircraft safely separated.

### Altimeters

Commercial jet aircraft have two types of altimeters, barometric and radio. Barometric altimeters function based on relative air pressure. They are generally pressure corrected to measure the altitude above mean sea level (MSL). Radio altimeters, on the other hand, measure the absolute distance to the ground by transmitting a signal from the aircraft to the ground and measuring the time to receive the reflected signal. While the pressure-based altimeter is used during all phases of flight, the radio altimeter is primarily used during the approach and landing phases to measure the exact distance above ground level (AGL). Most radio altimeters are active when the aircraft is below 2500 feet AGL; it is inactive above this altitude.

Since we have explained the relevant controls and displays for ILS and RNAV approaches during the above discussion, we now turn our attention to the unique synthetic vision display concept.

### **3.3.2. Synthetic Vision System (SVS) Display**

This section provides a detailed description of SVS as it applies to approach and landing, and a discussion of the concept of operations for the system. It is important to realize that, as a developing product, the details of system implementation will change as experiments and tests are completed and new system components are integrated. As such, the system components and detailed descriptions provided here represent only a snapshot in time of system configuration and implementation. In addition, multiple companies are developing SVS concepts. This document uses examples from two different concept designs.

The SVS display includes terrain and airport details and may include other aircraft, weather and wake turbulence information. In addition, flight data information is overlaid on the terrain background along with a tunnel navigation aid that presents a “highway-in-the-sky” for the pilots to follow. Figure 10 shows one example SVS terrain display with a flight data overlay (without the tunnel).

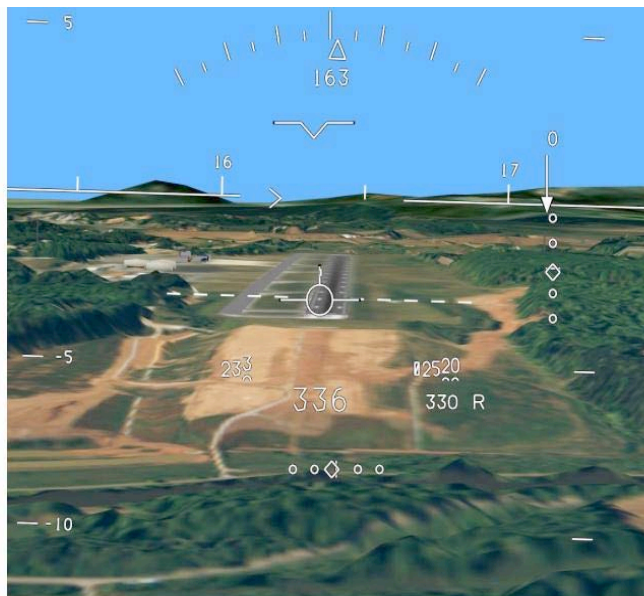


Figure 10. SVS terrain and airport display with flight data overlay.

Following are descriptions of the concepts and display components for the system. The purpose here is simply to present some of the differences in the design concepts to give the reader an idea of the



range of possibilities being explored, and to illustrate the similarities. It should be understood that the concept designs will change as the NASA AvSP program continues.

### Terrain Map

The terrain map is the computer-generated image of the terrain from the pilot's viewpoint. It is expected that the image will be highly intuitive as it replicates what a pilot would see out the front window in good visibility daylight conditions. The image is generated by the SVS sensors and a terrain database, and can be implemented in a number of different ways. In one of the NASA concepts, a technique called photo-realism is used to combine the terrain database information with high-resolution photos of the area (Figure 11a). The Rockwell Collins concept uses a graphical texturing technique and terrain altitude information to create the image (Figure 11b).

### Flight Data

The flight data overlays include speed and altitude information on vertically oriented bars on either side of the display, and heading on a compass arc at the top of the display. Approach guidance information for horizontal and vertical path orientation and an artificial horizon are also included. These PFD-like images do not differ much between the two example SVS concepts.

### Velocity Vector

The velocity vector (pointed to by red arrows in Figure 11), also called the flight path symbol, represents the actual flight path of the aircraft. Flight control inputs by the pilot or autopilot cause the symbol to move, providing instant feedback. In essence, the pilots use the aircraft controls to fly the velocity vector in the display to the desired location. While the velocity vector is not available on current B757 instruments, it is available on other aircraft. A velocity vector is implemented in both concepts discussed here.

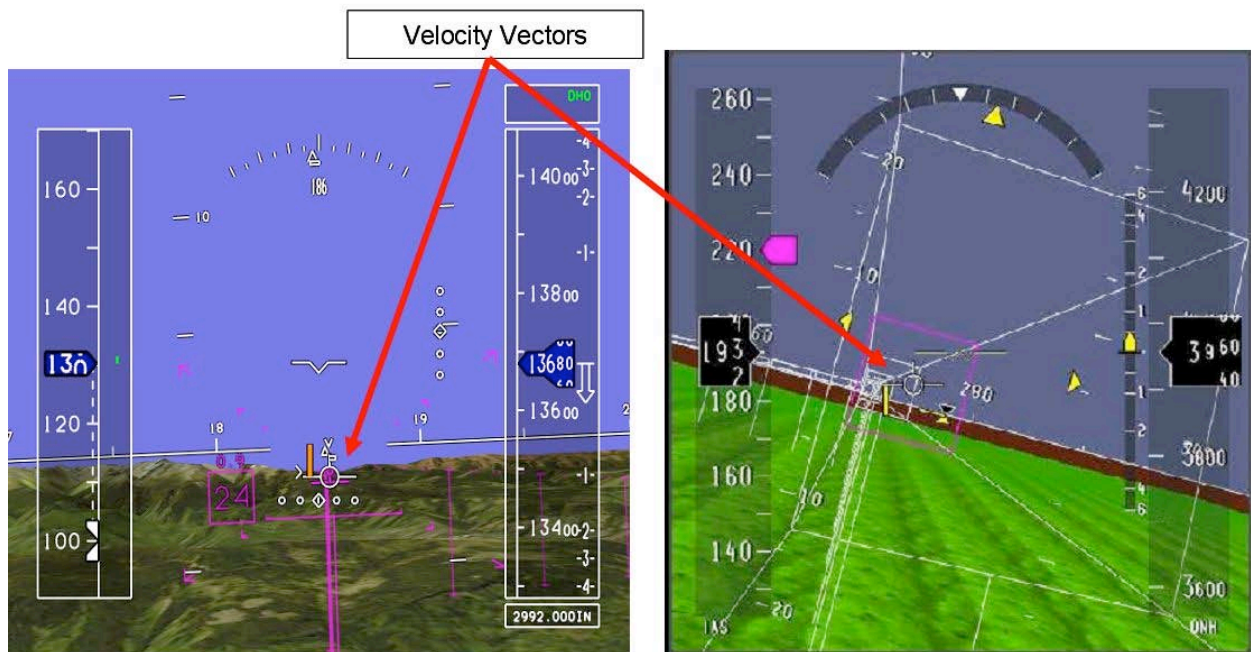


Figure 11. (a) NASA SVS concept and (b) Rockwell Collins concept.



### Tunnel Navigation

The tunnel navigation or highway-in-the-sky is a flight path guidance concept. Graphics on the terrain display show the desired flight path as it extends out in front of the aircraft. The NASA tunnel graphic uses small magenta brackets to indicate the corners of the tunnel and a T shape or *goal post* to indicate the bottom of the tunnel and distance to the ground. It also uses a graphic of an aircraft, sometimes called a *ghost* aircraft that travels ahead of the aircraft along the path of the tunnel. These tunnel and ghost aircraft symbols are very subtle and difficult to see in Figure 11. The Rockwell Collins tunnel graphic uses connected squares that reduce in size to present the image that the tunnel extends ahead of the aircraft. A magenta colored box moves ahead of the aircraft along the path of the tunnel. The Rockwell Collins concept does not have a ghost aircraft. It only requires that the velocity vector be inside the magenta box. The NASA concept uses the ghost, but it is difficult to see in this image as the velocity vector is right on top of it.

#### **3.3.2.1. Concept of Operations**

The designers of SVS have defined a concept of operations for the system that ranges across all phases of flight and focuses on safety and improved operating efficiency (Williams et al., 2001). This section presents a basic overview of this concept followed by a more detailed concept of operations for the approach phase of flight.

The intent of the SVS is that it allows aircraft to operate in low visibility conditions with the same or greater level of safety and by similar rules as those used during conditions of good visibility. Visual Flight Rules (VFR) assume that a pilot can see other nearby aircraft. As such, the rules allow for reduced aircraft spacing. This translates into a greater operational tempo as more aircraft can occupy a given volume of airspace. Also, the pilots can see the airport and any obstacles to the approach path at a much greater distance. In low visibility conditions the flight rules change to Instrument Flight Rules (IFR) to reduce the risk created by the loss of visibility. IFR requires increased aircraft spacing and specific airport-aircraft instrument combinations to continue operations. As such the operational tempo is reduced (Williams et al., 2001).

The SVS concept of operations supports the operational tempo and safety levels of VFR during IFR conditions down to the lowest visual minimums, while using non-ILS equipped airports and runways. In other words, airports that are not currently equipped with ILS systems should be able to use VFR aircraft spacing in very low visibility conditions, if the aircraft are equipped with SVS.

In addition, the SVS concept includes path guidance and hazard avoidance. Path guidance (e.g., the tunnels described above) enables the pilots to follow a desired flight path. The tunnel navigation concept of current SVS designs is focused on improving path control beyond current instrument guidance systems. The focus on hazard avoidance is one of the critical safety elements of SVS. The system should increase the ability of pilots to detect, identify, prioritize, and avoid hazards, which includes traffic, terrain, obstacles (e.g., radio towers), wildlife (e.g., a flock of birds), and weather.

In addition to the potential change to aircraft spacing rules, SVS supports several other approach operations (Williams et al., 2001). At airports where ILS or other approach system components are inoperative or unavailable, SVS could support approaches using VFR criteria. An example might be the ability to use lower visibility minima when approach lighting or the glide slope signal is inoperative. SVS could also be used to augment current instrument systems either as an independent check of accuracy, or as an addition that supports the use of lower visibility minima than would otherwise be allowed based on a published ILS or RNAV approach for a given runway.

Approach path control will be enhanced by the tunnel navigation component of SVS to include *circling*, and published visual approaches. Circling approaches involve flying an approach to one runway, then aligning with and landing on a different runway. Published visual approaches follow specific terrain features, such as flying over a river to keep aircraft noise away from populated areas. Both of these approach types, which are normally only flown in good visibility, could be performed when visibility is poor, using an SVS.

SVS would also help mitigate the serious problem of controlled flight into terrain. It is presumed that, given a view of terrain hazards similar to daytime VFR, pilots will avoid flying into a hillside, mountain, or other terrain, as sometimes tragically occurs during conditions of reduced visibility (e.g., due to fog or heavy rain). Pilots will also use an SVS (and its velocity vector) to avoid landing short of, or beyond, the desired touchdown point on the runway.

The location of the SVS display is open for debate and depends upon retrofit capabilities of various aircraft. One prototype has the display in front of the left seat pilot only (Figure 12).

### **3.3.3. Displays & Controls Summary**

The cockpit controls and displays, when combined with radio information and out-the-window observations, provide all of the needed information for pilots to safely plan and fly the desired flight path. There is one last detail of background information to mention before presenting the pilot tasks that serve as the foundation of the human performance models. This last detail is flight crew responsibilities.



Figure 12. SVS in a NASA test aircraft.

### **3.4. Flight Crew Responsibilities (PF and PNF)**

The B757, like most modern commercial jet aircraft, has a two-pilot flight crew. The crew consists of a captain and first officer. The captain sits in the left seat, and the first officer sits in the right seat. The aircraft can be flown from either position. The pilot currently flying the aircraft is known as the **pilot flying** (PF). The other pilot is the **pilot not flying** (PNF). Pilots exchange duties throughout a typical day of flying to multiple destinations so that both pilots maintain their skill levels through all phases of flight. Air carriers establish crew responsibilities and coordination procedures to keep both pilots actively aware of the aircraft position and condition throughout the whole flight.

Normally, the PF actually manipulates the flight controls or the autopilot control modes (via the MCP), while the PNF monitors progress, reads checklists, moves gear and flap levers (as instructed by the PF), and communicates with ATC and the flight attendants. The idea is to minimize the distractions for the PF, but keep the PNF sufficiently aware of the aircraft state so that, in the event of an emergency, either pilot can assume aircraft control. If the PF is hand-flying the aircraft (i.e., not using the autopilot), then the PNF will also set values and modes on the MCP. The reason is that hand-flying takes two hands: one on the control yoke, the other on the throttles. Such a situation occurs during landing when the PF is busiest ensuring that the airplane touches down on the desired spot on the runway. Occasionally, the PF opts to use the auto-throttles while hand-flying, in which case one hand might be free to set MCP modes, for example. Even then, the PF's "throttle hand" (right hand for the captain; left hand for the first officer) stays near the throttles in case of a malfunction.

#### **4. Approach Task Analyses**

Each approach type (visual, ILS, RNAV and SVS) has similar tasking for the pilots in terms of human performance. A common taxonomy for analyzing human performance is the VACP method (Wickens, 1984). The VACP method examines an operator's Visual, Auditory, Cognitive and Psychomotor (manual) workload. Briefly, the visual component for pilots is to visually monitor their instruments and acquire the runway. The auditory component is for communications between the pilots, to and from the cabin crew, to and from ATC, as well as any cockpit system annunciations. Pilot cognitive workload is due to interpreting the observations of their instruments and communications, deciding how much automation to use, and deciding to land or execute a missed approach. The last component, psychomotor, refers to manipulating automation or flight controls to achieve the desired approach path. Also, actual landings are manually flown.

This section discusses the tasks and key decisions for the approach phase of flight for the B757. The specific information, presented in sub-sections, covers the following:

- 4.1 General and ILS approach tasks
- 4.2 RNAV approach tasks
- 4.3 ILS and RNAV task timelines
- 4.4 Cognitive decisions
- 4.5 Typical approach problems and errors
- 4.6 Information requirements and situation awareness
- 4.7 SVS approach benefits

##### **4.1. General and ILS Approach Tasks**

The task analyses focus on the approach phase of flight. Following the cruise and descent phases (Figure 1), the pilots transition to the approach for a specific airport. The approach is the portion of the flight during which the pilots fly the aircraft into the appropriate location, attitude, and configuration to land. For both manual and automated flight, this involves incrementally slowing to landing speeds, descending to appropriate altitudes for landing, and aligning the aircraft with the runway such that the landing can be executed at the correct attitude (wings level and within pitch tolerances) and correct speed (within tolerance), within the appropriate runway touchdown zone. The maneuvers performed by the crew for both the approach and landing must be within the limitations of the aircraft, the procedures of the airline, and the requirements of ATC, while ensuring the safety and comfort of any passengers.

During the approach, the pilots make a series of speed reductions and wing flap deployments in order to maintain the necessary pitch window and descent rate of about 300 feet per mile (3 degrees) to

land at the correct speed. Landing at too fast a speed requires too much wheel brake and reverse thrust energy to stop the aircraft; landing at too slow a speed risks stalling the aircraft and crashing. Slowing to landing speed requires the use of flaps to maintain pitch tolerances. Without flaps, the pitch has to be too high (nose up) to be safe at the slower landing speeds, and again risks a stall. Also, as flaps are lowered, the pilots maintain certain speed ranges to avoid over-speeding the flaps or flying too slow for that increment of flap setting. A minimum flap setting is a function of the weight and airspeed of the airplane, so that, as the airplane slows toward landing speed at a given weight, progressively greater flap settings are required. Flap settings for a typical B757 landing weight of 180000 pounds are in Table 2. (This data was provided by one of the subject matter experts, a United Airlines B757 pilot.)

**Table 2.** Typical B757 flap settings.

<b>Airspeed</b>	<b>Minimum flap setting</b>	<b>Maximum flap setting</b>
(knots)	f(weight, speed)	f(speed only)
240	0	1
220	0	5
210	0	15
205	1	15
195	1	20
185	5	25
165	15	25
145	20	30
125	30	30

During the initial approach segment, the crew also sets the guidance and control systems based on the type of approach for the selected runway. In the case of an ILS approach, the settings enable the autopilot to intercept the runway localizer and glide slope guidance signals. In addition, the crew communicates with ATC as needed to obtain appropriate altitude, approach and landing clearances, and other information and instructions. The crew also monitors the aircraft sub-systems, position, attitude, and flight path.

The tasks are shared (usually by established procedure) between the PF and the PNF. The primary tasks of the PF involve all aspects of the aircraft attitude, position and path control. The PNF performs necessary communications, sets required navigation and radio frequencies, accomplishes checklists, responds to requests from the PF for flap and gear deployments, and double-checks PF actions. Usually, tasks of monitoring the displays and looking out the windows for traffic, obstacles, and the runway are performed by both pilots.

For the purposes of the ILS approach task analysis, we made several basic assumptions about the aircraft and set several initial conditions for the beginning of the approach phase tasks. The following are the assumptions and initial conditions of the aircraft and flight, and a brief narrative of the approach and landing task sequence.

For this scenario, it is assumed the B757 aircraft weighs 180,000 pounds. The associated speed and flap settings are listed with the task table. The aircraft has finished the descent phase of flight and has begun the approach phase. The flight is proceeding under IFR towards an ILS runway. The aircraft is approximately 15 miles from the runway threshold flying at 3000 feet AGL at 200 knots, with flaps

set at 5 degrees. The pilots have intercepted the localizer and the tasks begin as they receive approach clearance.

Upon receiving the approach clearance from approach control and instructions to slow to 180 knots, the PF sets the MCP approach mode, the MCP speed to 180, and calls for flaps 15. Once the PF sees the glide slope pointer begin to move from the top of the scale (known as “glide slope alive”), the PF calls for the landing gear, reduces speed again, and calls for flaps 20. Before glide slope capture (usually corresponding to what pilots refer to as “one dot below glide slope”) the PF again reduces speed and calls for flaps 25. As the aircraft intercepts the glide slope, the PF reduce speed again and directs the PNF to set flaps 30 (the final flap setting), which completes the Before Landing Checklist.

After glide slope capture, the crew sets the missed approach altitude and heading. Upon crossing the outer marker at about five miles from the runway threshold, the pilots confirm their final approach preparations, and the PNF changes the radio to the tower frequency. Upon changing frequency, the PNF calls the tower and receives landing clearance. Approaching decision height, the crew makes their landing decision. If they cannot see the runway, they perform a missed approach. If they see the runway and decide to land, the PF announces that decision aloud and normally takes manual control of the aircraft. If the runway is in sight before the decision height is reached, the PF will often switch to manual flying at that sighting. The point at which the PF begins to manually fly the aircraft varies, but is usually associated with the ability to see the runway.

Detailed task descriptions follow for all approaches and for the ILS approach specifically. After these task descriptions, we describe the unique RNAV approach tasks, and then we present the baseline (ILS and RNAV) tasks in a timeline table.

#### ***4.1.1. General Approach and ILS Task Descriptions***

First we describe the sequential tasks, then the non-sequential tasks. The distinction between sequential and non-sequential tasks is important to human performance modeling and will affect how the specific tasks are represented within the models

##### **4.1.1.1. Sequential Tasks**

###### Communicate with ATC

When the crew communicates with ATC, it is either initiated by the crew or in response to communication from ATC. Contact initiated by the crew usually takes the form of an identification call or a request for clearance or information. Responses usually involve reading back ATC instructions or providing requested information (such as present speed). Voice communication requires the PNF to press one of the microphone (mic) buttons on the yoke or on the center console while speaking into the PNF’s headset microphone. To end a radio call, the PNF releases the mic button.

###### Set Radio Frequencies

The two radio control panels on the center pedestal between the two pilots allow for two communication radio frequencies to be selected. A toggle switch on the panel allows the crew to switch from one frequency to another. During the approach, the crew uses the approach control frequency. At or near the FAF, the PNF flips the switch to select the tower frequency.

###### Engage Automated Flight Control

Arming the approach mode, and engaging the auto-throttles and an autopilot, is how the PF selects automated flight control. These selections enable the autopilot to fly the localizer and glide slope

until the pilots take manual control. If the PF does not choose automated flight, then the PF must follow the ILS guidance pointers or flight director to maintain the correct lateral and vertical paths. Arming the approach mode requires pressing the approach mode button labeled APP on the MCP; selecting an autopilot requires pressing the selected button, also on the MCP (Figure 7).

### Maintain Airspeed

Maintaining airspeed requires looking at one of the two airspeed indicators. The indicators include movable markers along the outside of the dial called *bugs* that are set to reference speeds during approach preparations. The pilots set the bugs using checklist-like charts that list the target airspeeds for given aircraft weights and flap settings. The bugs are memory aids, since the correct speeds change from flight to flight with aircraft weight. The PF refers to the bugs to set the MCP speed during automated flight; the auto-throttles maintain the set speed. Setting the speed requires turning the speed dial until the desired speed is indicated by the digital display above the dial (Figure 7). Verifying that the correct speed has been set requires looking at this display.

### Set Flaps

The flaps are usually set by the PNF but the flap lever is easier to reach from the right seat, since it is to the right of the throttle controls. When the flaps are set from the left seat, it requires more care to reach around the throttles, and the flap lever position is more difficult to determine. Setting the flaps requires using one hand to move the flap lever to the correct position and requires the pilots to look at the flap indicator on the front instrument panel (Figure 6) to confirm the correct flap position. The flap lever slides into a detent for each available flap increment (1, 5, 15, 20, 25, and 30 degrees). During approach, the PNF (usually) moves the lever to the next appropriate position when called for by the PF. Pilots may also feel the position of the flap lever with their throttle hand to check if the lever is settled into the correct detent.

### Monitor Localizer and Glide Slope

As the approach continues under automated flight, both pilots monitor their PFDs to ensure proper following of the localizer and glide slope signals (Figure 8). They also monitor the FMAs and MCP to ensure that the correct modes are engaging after being armed.

### Lower Landing Gear

Lowering the landing gear requires moving the landing gear lever all the way down. As with the flaps, the lever is closer to the right seat (Figure 6) because a default assumption is that the captain (left seat) is the PF, while the first officer (right seat) is the PNF. The gear lever requires only one hand to pull the lever out slightly and then push it down. If done from the left seat, it requires leaning the upper body toward the lever to reach it. Verifying that the gear is locked down requires looking at the three indicator lights directly above the landing gear lever. The lights are positioned in a triangle (nose, left and right gear). If all three lights are green, then the landing gear is, in pilot terms, *down and locked*. Both pilots check the gear lights, usually after they hear the gear lower into position with a distinct “thunk” sound, to be sure the gear are down and locked.

### Arm Speed Brakes

The speed brakes are controlled using a lever on the left side of the throttles. The lever is moved back (aft) to deploy the speed brakes (or spoilers), which are panels on the top of the wings that spoil the lift of the wing and allow the aircraft to descend faster or slow down more quickly. The speed brakes also work automatically upon touchdown of all landing gear to slow the aircraft. In the forward position, the lever is in a detent indicating that the speed brakes are stowed (i.e., flush with the wing surface). The next aft setting is the *armed* position used for automatic deployment during the landing

roll. Beyond that, the lever can be moved farther aft to vary the amount the spoiler panels are raised. Pilots use varying spoiler positions depending upon how quickly they wish to decelerate. To verify that the speed brakes are armed for landing during the final approach segment requires the pilot to look at the lever position, and to sometimes use one hand (again, the throttle hand) to feel that the lever is in the armed detent. The speed brake lever is easier to reach from the left seat, since it is left of the throttles. Deploying the speed brakes from the right seat, if the FO is the pilot flying, requires the FO to reach around the throttles.

#### Set Missed Approach Altitude

The missed approach altitude is the altitude to climb to in the event of a missed approach and is given on the approach chart. Setting this missed approach altitude requires using the altitude knob on the MCP to dial the correct altitude (Figure 7). Typically, the PF sets this altitude, which must be done after glide slope intercept, and the PNF verifies it.

#### Monitor Altitude below 2500 Feet AGL

The reading for the radio altimeter is on the PFD just below the decision height (DH) reading (Figure 8). The PNF calls out AGL altitudes, typically at 1000 and 500 feet, to denote the standard stabilization gates. Both pilots check for the aircraft being within stable approach parameters. The PNF also calls out “Approaching decision height” (usually 100 feet above) and “Decision height” if the PF has not yet indicated that the runway is in sight.

#### Before Landing Checklist

The Before Landing Checklist is a sequence of steps that are executed by the PNF which are designed to verify that certain critical tasks have been completed prior to landing. Each step is called out by the PNF and an associated check is done. Depending on the airline, the PF is not required to verbally respond to any of the checks as they are the duty of the PNF. However, the PF will usually follow along with the checks and verify each one as the PNF reads through the list. Most airlines require the landing checks to be done by reading the steps from the checklist card, rather than from memory, to avoid missing any critical item.

#### Turn on Landing Lights

The controls for the landing lights are three switches (for left wing, right wing and nose gear lights) on the middle overhead panel. The PNF turns the landing lights on while accomplishing the Before Landing Checklist, if not sooner. The lights are required to be on, unless using them is distracting (when, for example, it is night in the clouds and the reflected light would harm the pilots’ night vision).

#### Monitor Descent Rate

The descent rate is determined by looking at one of the two vertical speed indicators, which are analog dials showing the vertical speed in feet per minute (Figure 6). For a typical precision approach and B757 ground speeds, the vertical speed should be about 700 feet per minute to fly the desired glide path.

#### Disengage Autopilot

The PF disengages the autopilot via the MCP or by using a button on the control yoke when he or she decides to fly the aircraft manually. Prior to disengaging the autopilot, the PF will put both feet on the rudder pedals and place his or her hands on the yoke and throttles. Once the PF is ready to assume control, he or she will press the yoke button with his or her thumb. Or the PF may ask the PNF to press the MCP disengage bar (Figure 7), or do so him- or her-self. A cockpit alarm sounds as

the autopilot disengages. If the PF uses the yoke button to disengage the autopilot (which is the typical method), then the PF presses that button again to silence the alarm.<sup>3</sup>

#### Fly Manually

Manual flight by the PF requires both hands, both feet, and visual scans of the instruments and out the front window. It also requires some attention to the radio and PNF who may call out information that the PF needs to know. Scan patterns vary from pilot to pilot, but most pilots spend roughly equal time looking out the window, and looking at the PFD and surrounding instruments during final approach. If visibility is poor, the PFD is the primary focus. The PF makes constant minor adjustments to maintain runway alignment, wings level, on speed, and the desired descent rate using the yoke, rudder pedals and throttles.

#### Flare

To flare the aircraft, the PF gradually pulls on the yoke when over the runway to bring the pitch up to the landing attitude, while reducing the thrust to idle on both engines. The flare also requires the PF to keep the wings level and the airplane aligned with the runway centerline while permitting the airspeed to decrease to touchdown speed (usually about 5-10 knots below final approach speed). An ideal flare to touchdown occurs when the pitch reaches the desired angle and the engines reach idle thrust as the main landing gear simultaneously contact the runway.

Next are the non-sequential tasks.

### **4.1.1.2. Non-sequential Tasks**

#### Monitor Flight Path and Progress

This task is periodically performed by both crewmembers throughout all phases of flight. The task primarily involves scanning the instruments to ensure that the aircraft has not deviated from the expected path, altitude, attitude, airspeed and overall flight plan. Looking at the ND (Figure 9) allows the pilots to determine if the aircraft is on the desired flight path, as programmed into the FMS. Looking at the PFD and its FMAs allows the crew to verify that the aircraft is in the prescribed attitude and that the automated flight systems are functioning normally. Pilots mainly look out the windows, if visibility is good, to verify the correct airplane attitude. Other displays such as the vertical speed indicator allow the crew to monitor the progress of various changes or determine that unexpected changes may be occurring.

#### Double-Checks and Verifications

Throughout the approach and landing process both pilots check and double-check the accuracy of settings that include altitude, speed, and flaps. Sometimes these checks require consulting a reference such as the speed versus flaps settings based on the weight of the aircraft. Other times the same steps are done so frequently that the crew has expectations of what the settings will be. In these cases double-checks are more of a mental process of determining if an expectation has been violated. For example, if the PNF is expecting a particular flap setting and the PF asks for a different one, the PNF would query the PF to determine the reason for the difference.

#### Monitor the Radio

This task involves listening for communications on the current radio frequency. Auditory information is received through the ear piece, headphones, or cockpit speaker. The information may include specific communications from ATC directed at the crew, or communications between ATC

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<sup>3</sup>Small, R.L. (5/23/03). Personal communication with Delta Airline's Captain Bill Jones, a B757 pilot.



and other aircraft. This monitoring task requires no workload when there is no communication traffic on the frequency because there is no information available to monitor. Attention is directed to the radio when the pilots initiate a transmission or when attention is drawn by communications on the radio. When communications do occur, the crew quickly determines if the information is directed at them based on their call sign (e.g., NASA-113 in the earlier examples). They also quickly determine if the communication is coming from ATC or from another aircraft. When the radio call is for the crew, they will closely attend to the information – even writing down clearances to ensure accuracy. The pilots also monitor communications between ATC and other aircraft because it helps them anticipate what ATC may direct them to do and how ATC is managing the airspace, especially during the approach phase. ATC calls to them will either confirm their expectations regarding approach and landing clearances, or require them to make some sort of change. Listening to communications from ATC to other aircraft helps the crew build a mental picture of where they are in the airspace relative to the other aircraft and provides them with an idea of what to expect as they get closer to the airport. The pace of radio communications will vary depending on a variety of factors including the weather and the quantity of aircraft approaching the airport. At its worst, the calls on the radio can be continuous as ATC and flight crews initiate calls and respond to each other, which require some level of constant attention by the pilots. At such times, it can be difficult to find a break in the communication flow to initiate a call. It is not unusual during such situations for multiple aircraft to “talk over” each other at the same time, which adds to the confusion and hectic tempo.

#### Monitor Aircraft Systems

This task is periodically performed by both pilots throughout all phases of flight. The status of all of the different aircraft systems can be checked using several different cockpit displays. Checking such displays helps the crew verify that the aircraft systems are operating within normal tolerances. These displays are also used to determine the nature of a malfunction, if one occurs. The system displays include alert flags, problem annunciators, and alarm tones for the most serious malfunctions, all of which draw the pilots’ attention if a problem occurs. Consequently, the scan of these instruments in the absence of flags or alarms is infrequent.

## **4.2. RNAV Approach Tasks**

This section describes unique aspects of an RNAV approach; that is, only those tasks that are different from those described in Section 4.1.

As previously mentioned, in RNAV the aircraft uses two guidance systems combined with the autopilot and auto-throttles to guide the aircraft between the waypoints programmed into the FMS. The lateral navigation (LNAV) guidance function directs the course of the aircraft, while the vertical navigation (VNAV) guidance function directs the pitch and thrust of the aircraft. When the VNAV mode is engaged and the aircraft is following the vertical path programmed into the FMS, the aircraft is in the VNAV PATH mode.

During descents, as a safety feature, the pilots must specifically pay attention to altitude when using the VNAV PATH mode. As the aircraft descends towards 3D waypoints, it will not keep descending unless the pilots have selected a lower altitude in the MCP, even though the next waypoint’s altitude may be below the aircraft’s present altitude. That is, the RNAV system (i.e., the FMS) will not automatically change the MCP’s target altitude when reaching a waypoint during a descent. To keep descending, the pilots must set the next lower altitude into the MCP before reaching the active waypoint. If a new altitude is not set, the aircraft will establish level flight at the MCP altitude, drop out of the VNAV PATH mode, and enter ALT HOLD mode. For the pilots, this means that during most of the descent and approach, they must stay aware of their altitude and keep setting lower

altitudes in the MCP as ATC clears them to those altitudes. When they set a new altitude, the aircraft will maintain the desired descent profile until the next waypoint is reached, provided VNAV PATH is maintained.

However, during an RNAV approach, the pilots must set an MCP missed approach altitude that is higher than the current altitude of the aircraft, even though they intend to keep descending from the FAF to the decision altitude. To properly set the missed approach altitude, the pilots must spin the MCP altitude dial (Figure 7) quickly enough to avoid “capturing” an altitude and dropping out of VNAV PATH mode during the final approach segment, which is fairly time critical and task saturated. Usually, the pilots spin the MCP ALT dial so quickly that they overshoot the desired missed approach altitude, and then dial more slowly down to that desired setting. The alternative is to risk an undesired altitude capture, if they dial the missed approach altitude too slowly.

#### **4.2.1. RNAV Task Descriptions**

As with the ILS approach tasks, we make several basic assumptions about the aircraft and set several initial conditions for the beginning of the RNAV approach phase tasks:

- The pilots follow ATC instructions to intercept an RNAV approach procedure and use a chart similar to that shown in Figure 4.
- The approach is programmed into the FMS and both the autopilot and auto-throttles are engaged.
- The PF uses the MCP heading, altitude, and speed functions to comply with ATC instructions until established on the approach, and then uses the approach mode.
- After descending from the FAF altitude, the pilots set the missed approach altitude.
- Upon sighting the runway, the PF assumes manual control of the aircraft, since an automated RNAV approach ends in a missed approach by default.

Again, the reader should note similarities between RNAV and ILS approach tasks. Of course, there are differences, too, as follows.

##### **4.2.1.1. Unique RNAV Tasks**

###### Verify LNAV and VNAV PATH Modes

Verifying that the aircraft systems are in LNAV and VNAV PATH involves looking at the flight mode annunciators on the Primary Flight Display (Figure 8). The green letters “V NAV” and “L NAV” appear in the lower left and lower right corners of the PFD, respectively (as actually depicted in the example PFD of Figure 8). In addition, the pilots verify that the decision altitude waypoint and missed approach path are correctly programmed into the FMS. The ND (Figure 9) shows the waypoints, distance and time to the next waypoint, and indicates the aircraft’s actual vertical path relative to the planned path (in the lower right section of the ND in Figure 9).

###### Check Position along Flight Path

The ND also shows the position of the aircraft relative to the RNAV approach path. This information includes the current heading, the current wind speed and direction, and any relevant traffic or weather.

###### Set Missed Approach Altitude on the Mode Control Panel

The missed approach (MA) altitude is defined as the altitude to climb to in the event of a missed approach. The MA altitude is on the approach chart (Figure 4, for example has a missed approach altitude of 5000 feet MSL), which both pilots review prior to flying the approach. Setting the MA altitude during an RNAV approach while in VNAV PATH requires spinning the dial fast enough to

prevent the aircraft from capturing the new altitude and dropping out of the VNAV PATH mode. After setting the MA altitude, the pilots verify that LNAV and VNAV PATH remain active on the PFD and that the aircraft maintains the desired vertical path.

#### Executing Missed Approach

If the pilots decide they need to execute a missed approach they perform several actions in quick succession. The sequence involves advancing the throttles to go-around thrust, setting the flaps to 20, establishing a positive climb profile and (usually) retracting the landing gear. Some of these actions will be executed by the automatic systems if the DA is reached during an RNAV approach. A missed approach can be executed during any approach at any point. It is described here because it is more likely to occur during an RNAV approach than an ILS or SVS approach because of a higher decision altitude, which increases the likelihood of not seeing the runway.

There are no unique non-sequential RNAV tasks.

### **4.3. ILS and RNAV Task Timelines**

Tables 3 and 4 list the sequential and non-sequential tasks, respectively, performed by the pilots during the two types of baseline approaches (ILS and RNAV). SVS approach tasks are not yet defined, but many of the approach tasks will be very similar. Because of the variability in the initial approach segment, the task tables start with the intermediate approach segment and finish with main wheel touchdown.

The sequential task table (Table 3) is grouped into sequences of tasks associated with specific events. Usually, the crew will perform a sequence of tasks in response to a location (e.g., nearing the FAF) or communication (e.g., landing clearance) stimulus. Non-sequential tasks are performed throughout an approach, as needed or desired, as opposed to being in response to a specific event. A task execution sequence is usually followed by a period of monitoring as the pilots verify configuration changes or anticipate the next task initiator.

Each flight crew performs the tasks slightly differently. Often the callouts and double-checks occur simultaneously with system setting tasks, especially when a pilot's task performance timing overlaps with the other pilot's tasks. As such, an overall time has been given for each sequence of tasks rather than providing timing information for each individual task.

Tables 3 and 4 also list the distribution of tasks between PF and PNF in the operator column. Each event is listed with a descriptive title and approximate aircraft position and time remaining to touchdown. Altitudes are in feet AGL; speeds are in knots. Task descriptions are either short statements of an action or, when in quotes, represent a spoken phrase. Types of tasks are discrete, intermittent or continuous. Discrete tasks require a single non-recurrent performance, such as activating or deactivating a system, making a setting, or speaking a phrase. Intermittent tasks require multiple recurrent performances such as monitoring a display. Continuous tasks require variable but uninterrupted performance, such as controlling aircraft heading or speed (McGuire 1991).

For both baseline approach types (ILS and RNAV), the task analysis uses hypothetical, but realistic, examples of approaches into Santa Barbara airport in California. The example RNAV approach chart is Figure 4. We assume that the pilots are following ATC directions during the initial approach segment, rather than the initial segment of the published approach. Such ATC directions are very common and serve to sequence traffic arriving into the airport area from many different directions.

Table 3. B757 approach task timeline for sequential tasks.

Event and Task Descriptions	Approach Type	Operator	Task Type
<b>Receive approach clearance</b>			
<ul style="list-style-type: none"> <li>B757 weight = 180000 pounds, visibility is poor.</li> <li>3000 feet MSL, ~3000 feet AGL, 200 knots, flaps 5.</li> <li>~15 miles from runway threshold.</li> <li>The ATC communication and read-back take approximately 10 seconds.</li> <li>In parallel with the PNF read-back, the PF may set the new speed. The task sequence after the read-back takes approximately 10 seconds for the crew to complete.</li> <li>As the aircraft slows the PF calls for flaps 15.</li> </ul>			
ATC Communication: "NASA-113, cleared for the ILS approach to Runway 07, slow to 180."	ILS only	ATC	Discrete
"NASA-113 cleared ILS to 7, slowing to 180"	ILS only	PNF	Discrete
<b>Or:</b> "NASA-113, cleared for the RNAV approach to Runway 33 Left, slow to 180."	RNAV only	ATC	Discrete
"NASA-113 cleared RNAV to 33 Left, slowing to 180"	RNAV only	PNF	Discrete
Check airspeed	ILS & RNAV	PF	Discrete
Set speed to 180	ILS & RNAV	PF	Discrete
Check speed setting	ILS & RNAV	PNF	Discrete
Check speed against reference bugs	ILS & RNAV	PF	Discrete
Set approach mode	ILS & RNAV	PF	Discrete
"Approach mode set"	ILS & RNAV	PF	Discrete
"Flaps 15"	ILS & RNAV	PF	Discrete
Move flaps lever to 15 and state, "Flaps 15"	ILS & RNAV	PNF	Discrete
<b>Aircraft configuration</b>			
<ul style="list-style-type: none"> <li>Flap deployment from 5 to 15 degrees takes about 15 seconds.</li> <li>The aircraft is approximately 13 miles from the runway threshold.</li> <li>As the flaps lower, the PF monitors attitude, speed, and FMAs.</li> </ul>			
Glance at flap indicator to confirm setting	ILS & RNAV	PF & PNF	Discrete
Feel pitch change	ILS & RNAV	PF & PNF	Continuous
Monitor PFD	ILS & RNAV	PF & PNF	Intermittent
<b>Glide slope alive (ILS), or about 11 miles from runway threshold (RNAV)</b>			
<ul style="list-style-type: none"> <li>The task sequence listed for this event takes approximately 30 seconds to complete.</li> <li>Distance from runway decreases to ~ 6 miles (ILS) and to ~10 miles (RNAV).</li> </ul>			
"Glide slope alive, gear down"	ILS only	PF	Discrete
"Almost 10 miles from runway, gear down"	RNAV only	PF	Discrete
Lower gear lever and reply, "Gear coming down"	ILS & RNAV	PNF	Discrete
"Flaps 20"	ILS & RNAV	PF	Discrete
Set flaps 20 and reply, "Flaps 20"	ILS & RNAV	PNF	Discrete
Glance at gear lights and state, "Gear down and locked"	ILS & RNAV	PNF	Discrete
Glance at gear lights and reply, "Roger, three green"	ILS & RNAV	PF	Discrete

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Glance at flap indicator to confirm setting	ILS & RNAV	PF & PNF	Discrete
“Set speed bug plus 20”	ILS & RNAV	PF	Discrete
Set speed	ILS & RNAV	PNF	Discrete
Check speed setting	ILS & RNAV	PF	Discrete
Monitor PFD	ILS & RNAV	PF & PNF	Intermittent
<b>One dot below glide slope (ILS), or about 9 miles from runway threshold (RNAV)</b>			
<ul style="list-style-type: none"> <li>This event begins when the glide slope pointer on the PFD (Figure 7) is next to the dot just above the point where the glide slope is captured (ILS), or within a mile of the RNAV FAF.</li> <li>The task sequence associated with this event takes 10 seconds to complete.</li> </ul>			
“Flaps 25”	ILS & RNAV	PF	Discrete
Set flaps 25 and reply “Flaps 25”	ILS & RNAV	PNF	Discrete
“Set speed bug plus 5”	ILS & RNAV	PF	Discrete
Set speed	ILS & RNAV	PNF	Discrete
Check speed setting	ILS & RNAV	PF	Discrete
Monitor PFD	ILS & RNAV	PF & PNF	Intermittent
<b>Final flaps and complete Before Landing Checklist</b>			
<ul style="list-style-type: none"> <li>The task sequence associated with this event takes ~30 seconds to complete.</li> </ul>			
“Flaps 30”	ILS & RNAV	PF	Discrete
Set flaps 30 reply “Flaps 30”	ILS & RNAV	PNF	Discrete
“Before Landing Checklist	ILS & RNAV	PF	Discrete
Refer to checklist and read steps	ILS & RNAV	PNF	Discrete
“Gear Down?”	ILS & RNAV	PNF	Discrete
Double-check gear lights; check lever full down	ILS & RNAV	PF & PNF	Discrete
“Down and checked”	ILS & RNAV	PF	Discrete
“Down and checked”	ILS & RNAV	PNF	Discrete
“Flaps 30?”	ILS & RNAV	PNF	Discrete
Check flap indicator setting; check flap lever in detent	ILS & RNAV	PF & PNF	Discrete
“Flaps 30”	ILS & RNAV	PF	Discrete
“Flaps 30”	ILS & RNAV	PNF	Discrete
“Speed brakes armed?”	ILS & RNAV	PNF	Discrete
Check speed brakes	ILS & RNAV	PF & PNF	Discrete
“Armed”	ILS & RNAV	PF	Discrete
“Armed”	ILS & RNAV	PNF	Discrete
“Before Landing Checklist is complete”	ILS & RNAV	PNF	Discrete
“Roger, checklist complete”	ILS & RNAV	PF	Discrete
<b>Glide slope capture (ILS), or FAF (ILS &amp; RNAV)</b>			
<ul style="list-style-type: none"> <li>~130 knots.</li> <li>~5 miles from touchdown (ILS) or ~8 miles (RNAV); ~3-4 minutes from touchdown.</li> <li>The task sequence associated with this event takes about 20 seconds to complete.</li> </ul>			
“Glide slope capture”	ILS only	PF	Discrete
“That’s the FAF”	RNAV only	PF	
Verify correct FMAs on PFD	ILS & RNAV	PF & PNF	Discrete
Verify thrust and pitch decrease to fly glide slope	ILS only	PF	Discrete

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Verify thrust and pitch decrease to fly VNAV path	RNAV only	PF	Discrete
“Setting missed approach altitude” (RNAV only – fast dial spin)	ILS & RNAV	PF	Discrete
Sets missed approach altitude and points to the MCP display	ILS & RNAV	PF	Discrete
“Roger, missed approach altitude set”	ILS & RNAV	PNF	Discrete
<b>Switch radio to tower frequency</b>			
<ul style="list-style-type: none"> <li>• ~4-7 miles out; ~1500 feet AGL; ~125 knots.</li> <li>• ~2-3 minutes from touchdown.</li> <li>• The time associated with this task sequence can vary depending on how long it takes for the radio dialog.</li> <li>• It should take less than 45 seconds for this whole sequence.</li> </ul>			
Scan instruments; if no warning flags, “Flags checked”	ILS & RNAV	PNF	Discrete
“NASA-113 contact the tower; good day”	ILS & RNAV	ATC	Discrete
“NASA-113 switching; good day, sir”	ILS & RNAV	PNF	Discrete
Switch radio to tower frequency	ILS & RNAV	PNF	Discrete
“Santa Barbara Tower, NASA-113, ROCKY inbound”	ILS only	PNF	Discrete
“NASA-113, Santa Barbara Tower, cleared to land Runway 07; winds 060 at 5; ceiling reported at 200 feet”	ILS only	ATC	Discrete
“NASA-113 cleared to land on 7, copy 200-foot ceiling”	ILS only	PNF	Discrete
<b>Or:</b> “Santa Barbara Tower, NASA-113, GOLET inbound”	RNAV only	PNF	Discrete
“NASA-113, Santa Barbara Tower, cleared to land Runway 33L; winds 350 at 5; ceiling reported at 800 feet”	RNAV only	ATC	Discrete
“NASA-113 cleared to land on 33L, copy 800-foot ceiling”	RNAV only	PNF	Discrete
“Cleared to land, ceiling at minimum”	ILS & RNAV	PNF to PF	Discrete
“Roger, cleared to land”	ILS & RNAV	PF	Discrete
Turn on landing lights, if they are not already on	ILS & RNAV	PNF	Discrete
<b>500-foot call-out (ILS) or 1000-foot call-out (RNAV)</b>			
<ul style="list-style-type: none"> <li>• 500 feet AGL (ILS), or 1000 feet AGL (RNAV).</li> <li>• ~1-2 minutes from touchdown.</li> <li>• (See Transition from Automatic to Manual Flight Event, Table 4.)</li> </ul>			
Call 500 feet, speed relative to bug and descent rate	ILS only	PNF	Discrete
<b>Or:</b> Call 1000 feet, speed relative to bug and descent rate	RNAV only	PNF	Discrete
“Roger”	ILS & RNAV	PF	Discrete
<b>100 feet to decision height (ILS), or 100 feet to decision altitude (RNAV)</b>			
<ul style="list-style-type: none"> <li>• ~300 feet AGL (ILS), or ~800 feet AGL (RNAV).</li> <li>• ~45-90 seconds to touchdown.</li> <li>• (See Transition from Automatic to Manual Flight Event, Table 4.)</li> </ul>			
“100 feet to decision height”	ILS only	PNF	Discrete
<b>Or:</b> “100 feet to decision altitude”	RNAV only	PNF	Discrete
“Roger”	ILS & RNAV	PF	Discrete

<b>Decision height (ILS), or decision altitude (RNAV)</b>			
<ul style="list-style-type: none"> <li>• ~200 feet AGL (ILS), or ~ 700 feet AGL (RNAV); ~30-60 seconds to touchdown.</li> <li>• The point at which the PF begins hand-flying the airplane could take place before this location whenever the runway is sighted (see Transition from Automatic to Manual Flight event in Table 4).</li> <li>• If the runway is not sighted by the time decision height or decision altitude is reached, then the PF initiates a missed approach.</li> <li>• (See Transition from Automatic to Manual Flight Event, Table 4.)</li> </ul>			
“Minimums”	ILS & RNAV	PNF	Discrete
If runway is in sight, call out “Runway in sight, landing.”	ILS & RNAV	PF	Discrete
<b>Manually fly the landing</b>			
Scanning out window (mostly) and to PFD, airspeed, and vertical speed indicators	ILS & RNAV	PF	Continuous
Manipulate controls as needed for proper touchdown	ILS & RNAV	PF	Continuous
Monitor instruments	ILS & RNAV	PNF	Continuous
<b>100 feet above the runway call-out</b>			
<ul style="list-style-type: none"> <li>• ~100 feet AGL; ~10 seconds to touchdown.</li> </ul>			
“100 feet”	ILS & RNAV	PNF	Discrete
“Roger”	ILS & RNAV	PF	Discrete
<b>Flare and Touchdown</b>			
<ul style="list-style-type: none"> <li>• ~30 feet AGL; ~117 knots; ~3 seconds to touchdown.</li> </ul>			
Flare and let aircraft settle onto main landing gear	ILS & RNAV	PF	Continuous

Table 4. B757 approach task timeline for non-sequential tasks.

<b>Event and Task Descriptions</b>	<b>Approach Type</b>	<b>Operator</b>	<b>Task Type</b>
<b>Transition from Automatic to Manual Flight</b>			
<ul style="list-style-type: none"> <li>• This event normally occurs once during the approach and landing phase. The PF decides when to begin manually flying the aircraft. This is usually associated with being able to see the runway.</li> <li>• Once the PF begins flying manually, his or her attention is out the window, primarily, making sure to properly align with the runway. The PNF monitors the instruments and performs the required call-outs.</li> </ul>			
Place hands and feet on aircraft controls	ILS & RNAV	PF	Discrete
Press autopilot disengage button when ready to assume control	ILS & RNAV	PF	Discrete
Turn off alarm	ILS & RNAV	PNF	Discrete
Scanning out window (mostly) and to PFD, airspeed, and vertical speed indicators	ILS & RNAV	PF	Continuous
Manipulate controls as needed to maintain proper flight path	ILS & RNAV	PF	Continuous
Monitor instruments to ensure maintaining proper flight path (within acceptable tolerances)	ILS & RNAV	PNF	Continuous

<b>Monitor Flight Path and Progress</b>			
<ul style="list-style-type: none"> <li>This task is ongoing throughout all phases of flight and consists of periodic instrument scans. The crew periodically looks at the ND to verify that the aircraft is traveling along its assigned path and at the PFD to verify that the aircraft is at its assigned altitude and appropriate attitude. While the ND and PFD are the primary instrument displays used by the crew, other instruments are occasionally included in periodic scans.</li> </ul>			
Monitor PFD	ILS & RNAV	PF & PNF	Intermittent
Monitor ND	ILS & RNAV	PF & PNF	Intermittent
Monitor other aircraft displays and indicators	ILS & RNAV	PF & PNF	Intermittent
<b>Monitor the Radio</b>			
<ul style="list-style-type: none"> <li>This task occurs throughout all flight phases, but neither constant nor intermittent attention is required. Instead, attention is directed when a voice is heard from the radio.</li> </ul>			
Monitor radio communications	ILS & RNAV	PF & PNF	Intermittent & Discrete
<b>Monitoring Aircraft Systems</b>			
<ul style="list-style-type: none"> <li>This task occurs throughout all phases of flight. Even though the aircraft systems are designed to flag or otherwise alert the crew to system problems, the crew will periodically scan the system displays looking for abnormalities.</li> </ul>			
Monitor system displays	ILS & RNAV	PF & PNF	Intermittent

#### **4.4. Cognitive Decisions**

Now that we have detailed approach tasks, this section discusses a summary of the key decisions during the approach and landing.

##### **4.4.1. Missed Approach**

The decision to execute a missed approach could be caused by any of the following:

1. ATC-directed
2. Too high on glide slope
3. Too low on glide slope
4. Too far left or right of the extended runway centerline
5. Too fast
6. Failure to see the runway at decision height because of poor visibility
7. Other weather-related events

##### **4.4.1.1. ATC-Directed**

An ATC-directed missed approach is of little interest to this research because it removes the pilots from the decision-making process. The pilots comply when directed to go missed approach, and only have to execute the missed approach as published or as modified by ATC.



#### **4.4.1.2. Too High on Glide Slope**

If the aircraft is too high on the glide slope, the aircraft could overshoot the runway. As the aircraft approaches decision height, the decision to continue the landing involves evaluating several quantitative and qualitative factors:

Quantitative factors:

- How high above glide slope is the aircraft?
- Will the aircraft be able to safely touchdown based on its present position?
- How much runway is needed to stop once the airplane touches down?
- How much stopping distance will the runway provide?
  - How long is it?
  - Has the tower directed the pilots to land and hold short of an intersecting runway?
- What are the conditions on the surface of the runway (ice, snow, rain puddles, etc.)?
- Are all needed aircraft systems operational (e.g., brakes, thrust reversers)?
- Is there enough fuel for a 20-minute missed approach and another approach?
- How heavy is the aircraft? (A light airplane stops more quickly than a heavy one.)

Qualitative factors that may affect the decision to continue to a landing:

- Maintaining schedule
- Passengers with missed connections
- The pilots want to get off this airplane and go home

With a strong emphasis on safety, if any of the quantitative factors clearly indicate that a landing might be unsafe, the pilots execute a missed approach. In addition, the pilots do not need to wait until the decision point to do so – they can execute a missed approach at any time during an approach. If the quantitative factors do not make the decision easy, one would expect that the qualitative factors might become relevant.

#### **4.4.1.3. Too Low on Glide Slope**

If the aircraft is too low on the glide slope, the aircraft could hit the ground prior to the runway threshold. The decision to continue the landing involves the same qualitative factors as the “too high on glide slope” case, but there are fewer quantitative factors:

Quantitative factors:

- How far below glide slope is the aircraft?
- Are there obstacles or high terrain that may jeopardize safety?
- If the aircraft continues the descent at the same rate, where will it touchdown?
- How much of a descent rate adjustment is needed to fly *safely* over the runway threshold?
- Is there enough fuel for a 20-minute missed approach and another approach?

#### **4.4.1.4. Too Far Left or Right of Extended Runway Centerline**

If the aircraft is too far left or right of the runway, the aircraft might not physically be able to reach the runway. Or it might land on the runway, but then skid or roll off of it. The decision to continue the landing involves similar qualitative factors as the other cases, but fewer quantitative:

- Can the aircraft align with the runway centerline in the amount of time left until touchdown?
- Is there enough fuel for a 20-minute missed approach and another approach?

#### **4.4.1.5. Too Fast**

The kinetic energy of an aircraft is proportional to its speed squared. Hence, if a pilot is coming in 20% faster than desired, the braking energy to stop the aircraft will be 40% higher than planned. Because of this energy dissipation issue, pilots are very concerned with their speed, particularly at airports with short runways.

- How much runway is needed to stop, once the aircraft touches down?
- How much will the runway provide?
  - How long is it?
  - Has the tower directed the pilots to land and hold short of an intersecting runway?
- What are the conditions on the surface of the runway?
- Are all needed aircraft systems operational (e.g., brakes, thrust reversers)?
- Is there enough fuel for a 20-minute missed approach and another approach?
- How heavy is the aircraft? (A light airplane stops more quickly than a heavy one.)

#### **4.4.1.6. Failure to See the Runway at the Decision Point Because of Poor Visibility**

If the runway is sighted and the aircraft is not properly aligned (too high, too low, etc.), one of the other decisions listed above becomes relevant. Until the runway is sighted though, the following elements are considered by the pilot:

- The pilots have already received a report of the cloud ceiling altitude.
- As the aircraft approaches the ceiling altitude, the pilots have an expectation of seeing the clouds begin to break up.
- Below the ceiling altitude, but above decision height:
  - If there is no indication that the clouds are breaking up, the pilots mentally prepare for a missed approach.
  - If the clouds are starting to break up, the pilots plan to continue with the approach.
- Just prior to decision height:
  - The pilots are looking for any changes in visibility to reaffirm or disprove their earlier predisposition to:
    - Continue the landing (most likely the runway is in sight by this time).
    - Execute a missed approach (most likely the runway will not appear).
- At decision height, unless something very unusual happens (e.g., the aircraft exits a very well-defined cloud layer instantaneously), the pilots have already made their decision and act accordingly.

#### **4.4.1.7. Other Weather-Related Events**

Wind shear and micro-bursts are other weather related events that can cause missed approaches. Pilots know these conditions are out of their control so they are likely to be very conservative with their decision to continue the approach. Pilots understand that any missed approach, regardless of the circumstances, will not reflect negatively on their skills, abilities or job security.

#### **4.4.2. Controlling Speed**

Controlling speed is not a single decision point *per se* because the need to control speed is often required throughout the approach. Controlling speed is a more difficult task for the B757 during approach compared to older commercial aircraft (e.g., B727) because of its very good glide performance (high lift over drag ratio). While the auto-throttles can automatically increase thrust if additional speed is needed, there is no *automatic* equivalent for slowing the B757. For quick deceleration, the good glide performance precludes just setting the engines to idle, particularly when the aircraft is descending anyway. The speed brakes can be used manually to slow down the aircraft, but it violates procedures to use the speed brakes during the final approach segment. The flaps

provide additional drag, but flap extension is a function of airspeed; they cannot be lowered at too high of a speed or else they will be damaged. Another method for slowing the aircraft is to extend the landing gear earlier in the approach phase since the landing gear adds considerable drag to the aircraft. But, the wheels also have a maximum speed at which they can be extended. The point is that the pilots must focus on reducing speed as early in the approach as possible.

Sometimes, though, this is easier said than done. For example, during the initial approach segment when ATC has several aircraft sequenced for landing, if all but the first two aircraft are properly spaced, but the distance between the first and second is too close, then it is much easier for ATC to instruct the first aircraft to speed up to increase its spacing from the second aircraft. This saves the controller from having to instruct the several other aircraft further back to slow down. Therefore, even though the pilots want to slow down early in the approach, it is not always possible.

Approaches are fraught with the potential for problems and errors, as alluded to above. Next, we further amplify potential approach problems and errors.

#### **4.5. Approach Problems and Errors**

Many aviation accidents and incidents are due to chains or sequences of problems. Some of the problems that are part of these chains are known as *latent* errors that were committed or occurred either well before or early in the flight and compound or create problems later on in the flight. Although these errors and error chains are important in terms of aviation safety, the focus of this research has been on the approach and landing phases of flight. In addition, the human performance modeling efforts that follow this task analysis research will focus on comparisons of equipment used primarily during approach and landing. As such, the errors discussed in this section are limited to those that can occur during the approach phase, but are not specific to either ILS or RNAV approaches.

##### Aircraft Spacing

Spacing errors become a problem as ATC tries to prescribe aircraft locations and require maneuvers that may be difficult or impossible for the crew to perform. Problems can occur when ATC asks the crew to maintain a particular speed when they really need to be slowing or when they are asked to maintain spacing behind an aircraft they know can slow down faster than the B757. It is up to the crew to keep out of bad situations. The pilots use TCAS and radio call information to maintain their awareness and spacing from other aircraft, while still complying with ATC instructions. A result of a spacing error can be insufficient time for a preceding aircraft to clear the runway before the following aircraft lands. In this case, the following aircraft may have to execute a missed approach.

##### Stabilization Gates

The crew must be able to achieve particular stabilization gates. That is, at certain locations during the approach, the crew must have achieved a certain attitude and speed in order to continue the approach. At 1000 and 500 feet AGL the speed, sink rate, and alignment suitable for landing should be within tolerances. If the aircraft is not stable then a missed approach is mandatory.

##### Speed Brakes

For each of the last three problem areas there is some help on the B757. If the pilots find that they are coming in too high or fast, the PF may use the speed brakes. On the B757, using speed brakes is part of the standard procedure during approach and landing. The PF normally deploys the speed brakes for a short period to help the autopilot achieve a necessary altitude or speed requirement. While the use of the speed brakes is common practice for the B757, there are also problems

associated with using the speed brakes. The primary error is to forget that they are deployed and try to land. Doing so induces a high sink rate and increased deceleration that the autopilot and auto-throttle will try to counteract. In addition, if the speed brakes are deployed during landing, the tail is likely to strike the runway upon flaring.

### FMS Reprogramming

Another problem relates to the reprogramming of the FMS. Due to weather or traffic issues, ATC may change the approach clearance from that expected by the pilots and programmed into their FMS. Such changes can occur at any point during the flight and can be a common occurrence at crowded airports. If such a change is made, the pilots may want to reprogram the FMS to reflect the new flight plan, but may have insufficient time to do so.

The general rule is that pilots should not attempt to reprogram an approach when below 10000 feet MSL. The problem is that there may not be enough time to make the changes and still perform the necessary slowing and configuration tasks. In addition, the attention of the PNF working with the FMS is directed down and away from other instruments and the cockpit windows. This attention mismanagement can yield failures to monitor altitude restrictions or course changes, both of which can have disastrous results.

### Radio Frequency

Approach frequency errors of the communication and navigation radios can also occur. This happens usually as a result of haste, the failure to double-check, or through simple entry errors. Such errors are usually caught using sufficient crew coordination practices. Also, if two navigation radios are set to mismatched frequencies then warning flags alert the crew. However if both pilots fail to set the radios or make appropriate changes, there are no flags to alert them to the problem. Unlike the navigation radios, there are no alarms for miss-setting the communication radios. Usually, upon changing the radio frequency, the PNF initiates a call or hears other communication. If no communication is heard or there is no response, the PNF normally returns to the previous frequency to request a repeat of the new frequency.

The consequences of errors setting the communication radios can range from not receiving a clearance, thus incurring a missed approach, to more serious issues of spacing in heavy traffic patterns. The consequence of errors setting the navigation radio frequency can be a failure to capture the localizer, which can lead to serious position errors.

### Distractions

Distractions are not uncommon during flight. There are many circumstances that can divert the crew's attention from a current task. Some of these are events or issues that must be attended to while others can represent simple nuisances. If the pilots become distracted, they may not remember to return to an important task or may not complete that task in a timely manner.

Other distractions may function as performance shaping factors that make normal tasks more difficult. Changes made by ATC to the approach plan can become distractions. This is especially true if the aircraft is close to the airport and the crew has to change routing during an already busy phase of flight. A high volume of communication traffic on the radio can distract the crew from other tasks as they attempt to comprehend all the information that is being spoken. Periods of high air traffic associated with the approach phase at busy airports will also provide distractions as the crew attempts to maintain visual contact and spacing from nearby aircraft. Weather can actually be more distracting when it is minor. Serious weather, that significantly reduces visibility, usually results in changes to the

aircraft spacing rules and runways that are used. However, scattered or intermittent clouds may make it difficult to identify and follow other aircraft during marginal visual approach conditions. Likewise, approaches and landings done at night over large brightly lit areas can make it difficult to see the lights of other aircraft and the airport as those identifying lights become lost in background glare. Finally, equipment problems or failures can represent serious distractions depending on the system, severity of the problem, and phase of flight.

#### **4.5.1. RNAV Specific Errors**

The following errors are specific to RNAV approaches. In each case they involve undesirable changes in the automatic flight modes based on actions or inactions by the crew.

##### Lateral Navigation

The LNAV mode keeps the aircraft on the lateral course to the next waypoint programmed in the FMS. The FMS accounts for any required heading changes to reach the active waypoint. Small heading changes might be required due to crosswinds. If the aircraft is in the Heading Select mode rather than LNAV, the aircraft will follow the set heading without accounting for any crosswinds. In this situation, the aircraft might be blown off the proper course to the next waypoint. If VNAV is engaged with Heading Select, then the vertical profile of the approach would continue the descent, while the lateral course might be erroneous. There are no system warnings to prevent or recover from this error; it is up to the pilots to detect and correct, which is especially problematic when visibility is poor. Certainly the pilots would notice lateral alignment problems when the runway is sighted. However, if this error occurs in poor visibility during approach to an airport with nearby steep terrain, then the result could be disastrous.

##### Failure to Set Decision Altitude (DA)

Prior to reaching the FAF the pilots must set the DA in the MCP. In the example from Figure 4, the aircraft is flying level at 1800 feet approaching the FAF at GOLET. If they do not set the DA in the MCP prior to reaching GOLET, the aircraft systems will switch to Altitude Hold mode and drop out of VNAV PATH. Although LVAV will continue to provide course guidance, the aircraft will continue to fly at 1800 feet. The cockpit systems provide some help to prevent this situation by alerting the pilots to reset the MCP altitude just prior to reaching a waypoint where a change in altitude is programmed. This alert message is presented on the front instrument panel (below the engine instruments in Figure 6) but does not include an aural annunciation. Of course, the pilots might notice that the descent has not begun as expected after passing through the waypoint.

##### Setting Wrong Decision Altitude

If the pilots do set a DA prior to reaching the FAF, it is still possible to set an incorrect altitude into the MCP. If they set an altitude that is higher than the desired DA, the aircraft will execute a missed approach sooner than expected. If the crew is able to quickly diagnose the problem they will then have to decide whether or not to continue with the missed approach or take manual control of the aircraft and try to land. If the pilots set an MCP altitude that is lower than the desired DA and they do not break-out below the cloud deck prior to reaching that altitude, the aircraft will execute the missed approach but at a lower altitude than the published DA. The consequence of this error depends upon how close the aircraft flies to the terrain and whether or not the PF takes manual control before the miss-set DA.

##### Failure to Set Missed Approach (MA) Altitude

Once the aircraft is stabilized on the final descent above the DA, the crew needs to set the missed approach altitude in the MCP so that the autopilot executes the correct missed approach at the DA. If

the crew fails to set the MA altitude, the aircraft will switch to Altitude Hold mode at the DA. In the example RNAV approach (Figure 4), Alt Hold would occur at 700 feet (even though the DA is 650 feet MSL, the MCP can only be set to the nearest hundred feet). The aircraft would start the missed approach by accelerating and turning left toward GOLET, but it would level at 700 feet rather than climbing to 5000 feet. At first, to the pilots, the aircraft would feel like it was performing the missed approach properly; the aircraft would stop descending and the throttles would move forward. However, the aircraft would not begin climbing. The problem from the crew's perspective is one of timely recognition, especially with obstacles and high terrain nearby. The pilots expect the aircraft to halt the descent and accelerate, and at first these expectations are not violated. They might even feel as though they are climbing as they accelerate. To recognize the problem in time when in the clouds, the pilots would have to carefully observe the vertical speed indicator, altimeters, and PFD pitch angle.

#### Altitude Capture while Setting Missed Approach Altitude

While spinning the MCP altitude dial to set the missed approach altitude, it is possible that the aircraft could enter Altitude Capture mode. That is, if there is a pause or slowing while spinning the dial, the aircraft may capture an altitude between the DA and the MA altitude settings, which is not what the pilots intend. In the RNAV approach example (Figure 4), while the aircraft is descending from 1800 feet and the crew tries to reset the MCP from the 700-foot DA to the 5000-foot missed approach altitude, the aircraft might capture an altitude of 1500, for example. If this occurs, the autopilot will switch to Altitude Hold mode upon reaching 1500 feet MSL and fly level at that altitude. The flight mode annunciators will switch to Alt Capture then to Alt Hold and the altitude hold light on the MCP will illuminate. Per procedures, if VNAV PATH is lost during this final descent and if the pilots do not see the runway, they must execute a missed approach.

#### **4.6. Information Requirements and Situational Awareness**

Naturally, professional pilots seek to avoid problems and errors. Therefore, they spend a large portion of their time during flight maintaining and updating an accurate mental picture of where the aircraft is, how the flight is progressing relative to the plan, and predicting how changes will affect the flight plan in the future. It is this situation awareness that forms the basis for decision-making during flight. The airline industry recognizes that pilot SA is an important component of flight safety, and has expended great effort to train and teach SA and decision making skills as a part of introductory and recurrent pilot training. In addition, a number of studies have focused on SA and the information requirements of commercial pilots during flight. We examined three such studies in reference to the baseline and SVS approach task analyses.

The first two studies (Ververs, 1998 and Schvaneveldt, 2000) both focus on the relative importance of information during different phases of flight. In both cases, pilots were provided with a survey that included a list of common information available during flight. The subject pilots ranked the relative importance of each piece of information across different phases of flight. Both studies included the approach and landing phases and both studies presented similar results in terms of what pilots thought were the most important cues.

The third study (Endsley, 1998) created an exhaustive list of every type of information desired by pilots to generate complete and accurate SA throughout an entire flight. The information requirements were based on the goals and decisions that pilots make throughout each phase of flight. The result is a highly detailed list of SA information requirements for each of the three levels of SA – perception, comprehension and projection – included in Endsley's taxonomy of situational awareness. She generated this list to help future cockpit designers, and noted that some of the information desired by pilots is not currently provided by cockpit systems. Also, the study

recognized that some SA information elements are more important than others during different phases of flight. However, Endsley did not prioritize this information as was done in the other two studies.

The combined knowledge from these three studies indicates that SVS has the potential to improve pilot SA by presenting information that is not currently displayed in commercial aircraft, and by emphasizing information that pilots judge to be most important, especially during approaches.

#### **4.7. SVS Approach Benefits**

The use of SVS is mainly notional at this point since there are no FAA-approved procedures for such systems. The concept of operations information (Section 3.3.2.1) provides ideas and goals for what the system will do and how it should be designed, but does not discuss how pilots will actually use it down at the level of individual task steps. Likewise, simulations and test flights using SVS have focused on specific research issues related to the design or use of the system, independent of other flight concerns. Given these limitations, we have not attempted a task decomposition for SVS approaches. We do, however, discuss some tasks that probably will not change with SVS use. Following that, we discuss how SVS may change the cues that are available to pilots.

The procedures for aircraft stabilization during approach are unlikely to change due to the use of SVS. The speeds and flap settings used to slow and stabilize the aircraft, the required callouts between pilots, the use of checklists to verify the completion of required tasks, and radio calls to ATC will all still occur during the approach sequence. One change that may occur relates to the timing of the configuration steps. In poor visibility conditions, configuration steps are usually completed earlier in an approach than during good visibility conditions. The use of SVS may allow pilots to delay some configuration steps during poor visibility, as if they were flying in good visibility conditions. Delaying some configuration steps saves fuel.

##### **4.7.1. Situation Awareness with and without SVS**

This section focuses on the differences in cues available from SVS versus the cues available in the standard B757 instrumentation during poor visibility conditions. Since the most significant benefit of SVS touted by an SVS test pilot was the improved SA, it is important to compare the cues from SVS with standard B757 instrumentation to identify how SVS impacts SA. To give this discussion more context, though, it is worthwhile to first present Endsley's (1999) decomposition of the three levels of SA:

- **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 pilots need to accurately perceive information about their aircraft and its systems (airspeed, position, altitude, route, direction of flight, etc.), as well as the 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 pilots' goals. Based upon knowledge of Level 1 elements, particularly when put together to form patterns with the other elements, a holistic picture of the environment is formed, including a comprehension of the significance of information and events. The pilots need to mentally combine disparate bits of data to determine, for example, the impact of a system malfunction on another system, or deviations in aircraft state from expected or allowable values. Novice pilots might be capable of achieving the same Level 1

SA as more experienced pilots, but may not integrate various data elements along with pertinent goals to comprehend the situation as well as more expert pilots.

- **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 level 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, pilots must not only comprehend that a thunderstorm – given its position, movement and intensity – is likely to create a hazardous situation within a certain time period, but they must also determine what airspace will be available for route diversions, must ascertain where other potential conflicts may develop, must plan appropriate path changes, and must request changes from ATC. This level of SA enables pilots to decide on the most favorable course of action.

When comparing SVS to standard B757 instrumentation, the above descriptions of the three levels of SA highlights a very significant strength of SVS; that is, SVS provides Level 2 and 3 SA directly to the pilots. For example, consider a missed approach at an airport surrounded by steep terrain (Figure 4). If the velocity vector is above the terrain profile on the SVS display, the pilots know that the projected location of the aircraft will ensure flying clear of the terrain (assuming, of course, that the aircraft performance does not change significantly, for example, due to wind shear or a loss of thrust). Even if the missed approach is performed by the autopilot and auto-throttles rather than manually, the pilots gain confidence in the automation and missed approach execution when they see the velocity vector rise above the terrain.

In contrast, for a non-SVS-equipped B757, the pilots would have to integrate Level 1 SA from different sources to have a similar level of confidence. The elevation of the terrain comes from the approach charts; aircraft heading comes from the navigation display; vertical speed comes from the vertical speed indicator; and, distance to the terrain comes from mentally overlaying the terrain information on the navigation display. Granted one of the primary reasons for requiring pilots to follow missed approach procedures is so that they do *not* have to integrate all this information to ensure terrain clearance. But the point here is if the pilots do not precisely follow the MA procedure or if the aircraft is not where the pilots think it is (for whatever reason – distractions from cockpit alerts, ATC communication, etc.), then ensuring terrain clearance becomes workload intensive, exacerbating an already unusual situation. With SVS, terrain awareness is quickly acquired from a single display. Furthermore, the feedback provided by the velocity vector relative to the terrain image gives a prediction of what is needed (in terms of control inputs) for terrain clearance. In contrast, an awareness of terrain clearance is very difficult to achieve with current B757 instrumentation.

SVS also provides the pilots with the ability to crosscheck displays that receive data from different sources, therefore increasing confidence in total system accuracy, or revealing a malfunction sooner than might otherwise be possible. The SVS display uses GPS position to present the aircraft's position relative to the terrain. On the other hand, runways equipped with ILS transmitters have a localizer and glide slope that are independent of GPS. If the pilots are flying an ILS approach in poor visibility, they can crosscheck the PFD's ILS guidance with the SVS display. If the PFD's flight director is aligned with the localizer and glide slope, then the pilots should see that the SVS display also shows proper runway alignment. If both displays agree, then the pilots have added confidence in the information. If the displays disagree, the pilots can execute a missed approach and then investigate the source of the problem in a more controlled and safer environment. Pilots routinely crosscheck their altitude readings among independent altimeters, for example. SVS enables crosschecking other critical flight information, as well.



Even though it seems obvious that SVS should enhance pilots SA, Stark (2001) reported that the use of tunnel navigation did not increase the pilots' situation awareness during the approach phase as was expected. Stark suggests that the ease of using the tunnel navigation to maintain the approach path may somehow reduce the amount of information the pilots gather as they fly an approach. It is also possible that the environment of the test, which limited the tasks and decisions required of the pilots, contributed to a lowered sense of, or need for, SA. Stark's results suggest that it is worth further investigating pilot interactions with SVS and its impact on SA.

#### **4.7.2. Pilot Interaction with SVS**

An interview with one of the few pilots who has flown tests with an SVS compared the use of SVS to what many pilots experience when using a "hood" with an instructor pilot during instrument procedure practice. The hood blocks a pilot's view out the window, forcing him or her to rely solely on the flight instruments – an excellent practice method. However, hoods are not perfect vision obstructions, and so pilots will sometimes peek around the hood out the window, especially during a difficult approach. SVS provides a constant "peek out the window," according to the SVS test pilot. The idea is that no matter how much pilots trust their instruments, they are aware that interpreting the instrument indications has the potential for error, and that a "peek at the runway" provides an immeasurable sense of confidence. The SVS test pilot described his interaction with SVS in such phrases as, "increased comfort level," "reduced worry," and "increased confidence in the approach."

Given these statements, it is tempting to characterize the use of SVS as the same as flying during good visibility daylight conditions. However, the SVS test pilot rejected this notion indicating that the cues provided by SVS create an interaction that falls somewhere between scans of the instruments and the out-the-window view during good visibility. With this understanding in mind, we next define the differences between the cues provided by SVS and what a pilot sees or does during good visibility daylight conditions. The following section focuses on those differences. We find that the SVS cues are highly dependent on the implementation of the system and, as such, use variations in the NASA and Rockwell Collins concepts (as shown in Figure 11) to present the pilot-SVS interaction.

##### **4.7.2.1. Closure and Crossing Rate Interpretation**

Pilots have learned to interpret the position and alignment of the aircraft as a function of the cues provided by the change in the view of the terrain outside the cockpit. Closure and crossing rates are interpreted by the perceived rate of change of the size of features ahead of, and around, the aircraft. The SVS terrain map provides closure and crossing rate cues similar to those available during good visibility daylight conditions. However, the value of the cues seems to decrease with the level of fidelity of the view of the terrain. The SVS test pilot indicated that while the generic texturing of the Rockwell Collins concept provided more of such cues than did ILS instrumentation, the detail provided by the photo texturing of the NASA concept was easier to interpret compared to the Rockwell Collins concept.

There are also two issues related to the field of view provided by SVS. The cockpit windows provide a much greater usable field of view than is provided by the SVS display (Figure 12). Being able to see terrain features to the side of the aircraft during good visibility daylight conditions increases the available cues used for closing and crossing rate interpretation. The SVS concepts limit the pilot to the terrain cues that are ahead of the aircraft. This limitation is particularly pronounced while turning the aircraft. During good visibility daylight conditions, pilots look out a side window or move their

heads forward to obtain terrain cues during a turn. The current SVS display does not support looking into a turn the way the cockpit windows do.

Also, in a crosswind, pilots orient the nose of the aircraft to counteract the effect of the crosswind. The result is that the nose of the aircraft is angled relative to the actual direction of travel. In this situation pilots do not look over the aircraft nose, rather they look in the direction of travel by turning their heads in that direction. In this way the closure and crossing rate interpretation remains stable relative to the terrain and direction of travel. The SVS display limits the terrain view to the direction that the aircraft nose is pointing. As such, the perception of closure and crossing rates can be disrupted in a crosswind situation.

Instrument approach procedures are designed to aid pilots during poor visibility and to help them fly the aircraft below the cloud deck to a point where visual sighting of the runway and a normal landing are possible. The SVS test pilot indicated that when first breaking out below the clouds there is an adjustment period between using the ILS instruments and becoming oriented based on the visual out-the-window scene. The difficulty making this adjustment may relate to identifying terrain features and correlating those features to the aircraft position. He indicated that using SVS might aid that transition as the pilots should have a better idea of the terrain features and their orientation prior to breaking out below the clouds.

#### **4.7.2.2. Tunnel Navigation**

The tunnel navigation component of the SVS display (Figure 11) provides navigation cues beyond what are available to pilots during good visibility daylight conditions. The tunnel can be thought of as a combination of the glide slope and localizer guidance cues because the bottom, top and sides of the tunnel help the pilots to keep the aircraft within a defined approach corridor. However, the tunnel exceeds localizer and glide slope guidance because it presents approaches with altitude steps, or circling approaches that require the pilot to align with the runway after an arcing and descending turn. The tunnel allows pilots to follow a different visual representation of the approach rather than relying on their interpretation of separate lateral and vertical path cues to maintain the approach profile. The lateral and vertical guidance of ILS and RNAV approaches are each 2D representations of the approach. Whereas the tunnel is more of a 4D representation in that it gives a 3D combination of lateral and vertical guidance, plus a depiction of the desired path into the future (3D + time = 4D).

The different graphical implementations of the tunnel represent different levels of cue availability. The Rockwell Collins tunnel shows a continuous connected path that may make it easier to see the extended tunnel ahead of the aircraft allowing the pilots to anticipate changes in the flight path. The NASA implementation does not enclose the tunnel or connect the individual tunnel pieces. The NASA concept may make it more difficult to see the tunnel as it extends ahead of the aircraft, thus limiting the ability of the pilots to anticipate flight path changes. However, there is a trade-off in terms of screen clutter. The Rockwell Collins tunnel uses more graphics overlaid on the terrain image. This clutter could, for example, make it difficult to distinguish between the line for the artificial horizon and lines from the tunnel, especially during turns, thus making undesirable attitude changes more likely.

Both SVS concepts use an aid to help the pilots maintain position within the tunnel. The NASA concept uses the ghost aircraft to lead the pilots along the path. The task involves keeping the velocity vector aligned with the tail of the ghost aircraft. The Rockwell Collins concept uses a magenta colored box that borders the tunnel and leads the aircraft along it. The pilots keep the velocity vector within the magenta box as it travels ahead of the aircraft. While the idea of traveling along the tunnel is

highly intuitive and the idea of following something along it makes the task easier, there are some issues related to cue differences and performance between the magenta box and ghost aircraft implementations. The magenta box of the Rockwell Collins concept predicts the aircraft position along the tunnel 5 seconds into the future (if the pilots make no control changes). If the velocity vector is within the box, the aircraft will fly within the box position 5 seconds from the current time. However, the task of positioning the velocity vector on the ghost aircraft in the NASA concept may require the PF to make constant small control changes because the size of the ghost is relatively small compared with the movements of the velocity vector. In contrast, the task of keeping the velocity vector within the Rockwell Collins' magenta box requires a lower level of workload because the box presents a much greater target area on the SVS screen, which creates the impression that the PF has larger maneuver tolerances than with the ghost aircraft. The SVS test pilot indicated that the difference in workload was not so much with control manipulations as it was in the attention required to perform the task.

Another issue relates to convention violations within the representations. The first concerns the predictive nature of the magenta box versus the standard use of the velocity vector. The velocity vector has traditionally represented the flight path of the aircraft based on control inputs at the current time. The task of positioning it within the magenta box that represents a position 5 seconds into the future violates that convention. The second issue involves the implementation of the ghost aircraft. Pilots with military formation flying experience (many commercial pilots have military backgrounds), who follow an aircraft, know that they need to turn inside a lead aircraft's turn to maintain a fixed distance from that lead aircraft. While the ghost aircraft resembles such a lead aircraft, it violates the convention in two ways. First, the ghost aircraft cues a turn by yawing rather than banking, which makes it difficult to notice when the turn begins. Second, the task of following the ghost aircraft involves keeping the velocity vector on the ghost, rather than ahead of it during a turn, as formation flying practices dictate. It is impossible to know what the effects of these convention violations will be, but it is anticipated that, with training and increased use, the differences from convention may not present insurmountable problems.

## **5. Future Work**

Human performance modeling leverages systems engineering resources for new systems by identifying issues early in the design and development stages (while changes can still be made relatively easily, compared to engineering changes after fielding a system). HPM also reveals human-system integration issues that otherwise might not be discovered until prototype testing or usability analyses. While it seems logical that SVS will help pilots fly more precise approaches, with better SA and fewer errors, this is a testable hypothesis. The next steps in the ongoing NASA AvSP HPM research are to build pilot performance models and to begin testing the hypothesis. Modeling teams supporting the Human Performance Modeling Element will next develop pilot performance models based upon the task analyses and run digital experiments looking for pilot performance, workload, or related issues to show the tangible benefits of SVS compared to baseline conditions.

## **6. Suggested Reading**

**Fundamentals of Air Traffic Control** by M. Nolan. Provides an excellent description of ILS, instrument approach procedures, runway lighting, and ATC communication phraseology.

**An Exploration of Function Analysis and Function Allocation in the Commercial Flight Domain**, by J. McGuire et al. of Douglas Aircraft (over 300 pages). Provides a very detailed functional analysis for a flight from LA to NY. Excellent source for event timeline information.

**Key Cognitive Issues in the Design of Electronic Displays of Instrument Approach Procedure Charts** by Monterey Technologies. The main document doesn't apply specifically to HPM of the approach, but it has a very interesting 34-page appendix, which actually includes a Conceptual Graph Structure of the ILS approach. Also contains a high-level task analysis.

**The Boeing 757/767 Simulator and Checkride Procedures Manual** by M. Ray. This unofficial manual provides excellent insight into recovering from off-nominal events or conditions, and highlights the key items to remember to stay out of trouble in the first place.

**The Pilot's Guide to the Modern Airline Cockpit** by S. Casner. This "technical, but doesn't read that way" book very clearly explains the new generation flight deck with an emphasis on the FMS and guidance modes.

**Situation Awareness Requirements for Commercial Airline Pilots** by M. Endsley et al. This paper breaks SA requirements down by phase of flight.

**Priority and Organization of Information Accessed by Pilots in Various Phases of Flight** by Schvaneveldt et al. Provides insight into what information is most important to pilots, decomposed by flight phase.

**Understanding a Pilot's Tasks** by P. Ververs. Similar to the above, with a slightly different emphasis.

**NASA's Aviation Safety Program web site** ([http://avsp.larc.nasa.gov/images\\_svs.html](http://avsp.larc.nasa.gov/images_svs.html)) contains information related to the entire SVS project, including history, concept descriptions, and simulator and flight test documentation.

**Flight Test Evaluation of Tactical Synthetic Vision Display Concepts in a Terrain-Challenged Operating Environment** by Bailey et al. This is the first report documenting the results of the Eagle County Regional Airport flight test. It includes results relating to terrain awareness, workload, and SA.

**Preliminary Examinations of Situational Awareness and Pilot Performance in a Synthetic Vision Environment** by Stark et al. This paper reports results of an early SVS simulator-based test.

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## **9. Acronyms and Abbreviations**

2D	two-dimensional
3D	three-dimensional
4D	four-dimensional
AGL	(altitude) above ground level
Alt	altitude
A/P	autopilot
APP	approach
ARPT	airport
A/T	auto-throttles
ATC	air traffic control
AvSP	(NASA's) Aviation Safety Program
B727	Boeing 727 aircraft (a medium-sized, tri-jet, 1960s-vintage airliner that carries about 150-180 people depending on configuration)
B757	Boeing 757 aircraft (a medium-sized, twin-engine, 1980s-vintage airliner that carries 200-280 people depending on configuration)
CMD	command
DA	decision altitude
DH	decision height
FAA	Federal Aviation Administration
FAF	final approach fix
FD, F/D	flight director
FL CH	flight level change
FMA	flight mode annunciator
FMS	flight management system
FO	first officer (also known as copilot)

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FY	fiscal year (The federal government's fiscal year runs from October 1 <sup>st</sup> to September 30 <sup>th</sup> . So FY02, for example, goes from 10/01/2001 to 9/30/2002.)
GPS	global positioning system
G S	glide slope
GS	ground speed
GSIA	glide slope intercept altitude
HDG	heading
HPM	human performance model (or modeling)
HUD	head up display
IAF	initial approach fix
IAS	indicated airspeed
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological conditions
LA	Los Angeles
LAX	Los Angeles International Airport
LNAV	lateral navigation
LOC	localizer
MA	missed approach
MA&D	Micro Analysis and Design (a human factors and human performance modeling small company; see <a href="http://www.maad.com">www.maad.com</a> for more information)
MCP	mode control panel
mic	microphone
MSL	(above) mean sea level
NASA	National Aeronautics and Space Administration
NAVAID	navigational aid
ND	navigation display
NM or nm	nautical miles (1 nm = 6076.115 feet)
NY	New York
OM	outer marker (usually also the final approach fix)
PF	pilot flying
PFD	primary flight display
PNF	pilot not flying
RNAV	area navigation (usually using inertial reference systems and global positioning satellite signals)
SA	situation awareness
SBA	Santa Barbara Municipal Airport
SPD	speed
SVS	synthetic vision system
TCAS	traffic alert and collision avoidance system
TFC	traffic
US	United States
VASI	visual approach slope indicator
VERT SPD	vertical speed (climb or descent at a set rate in feet per minute)
VFR	visual flight rules
VMC	visual meteorological conditions
VNAV	vertical navigation
VORTAC	a type of NAVAID