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Crew Procedures and Retrofit Concepts for Microwave Landing System

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INTRODUCTION AND SUMMARY

This report presents the results of a Douglas Aircraft Company study in which crew workload was analyzed for microwave landing system (MLS) that could be retrofitted into existing commercial transport aircraft. The study was sponsored jointly by the FAA and NASA as part of NASA Advanced Transport Operating Systems (ATOPS) Technology Studies contract NAS1-18028. A previous workload study (Reference 1) evaluated an MLS receiver concept that was capable of angle-only operations and a concept that would interface with a flight management system. The flight management system would provide the guidance algorithm and waypoint data base for MLS operations. The present study evaluates two concepts that could be retrofitted into aircraft that do not have a flight management system but have more capability than angle-only operations.

Two equipment concepts were developed: a receiver capable of capturing the runway centerline based upon the capture concepts proposed by Erkelens (Reference 2), and a receiver capable of flying segmented approaches and storing multiple approach routes in the receiver's data base. Both of these concepts used a 3- by 5-inch control display unit for the MLS receiver that could be physically accommodated in the pedestal of a transport cockpit. The receiver interfaced with the digital flight guidance computer and the existing electromechanical flight displays. The aircraft would be capable of flying either in the instrument landing system (ILS) or the MLS mode.

An information-requirements analysis was performed to determine the crew interface requirements. The control and displays for the MLS functions were identified and conceptual designs were developed. Crew tasks were identified using these two equipment concepts. Approach scenarios were developed that would compare MLS operations using these equipment concepts against an ILS baseline scenario. Two scenarios were developed for the centerline capture concept and six scenarios were developed for the segmented path capture concept. The segmented path capture concept used three different methods to enter and verify the approach path. The three methods were: entry before the descent phase of flight; entry after approach control assigned the runway and the approach path, and manual entry of the waypoint data base after approach control assigned the runway and the approach path.

Workload comparisons between the approaches were made using a task-timeline analysis program that obtains workload indexes (i.e., the ratio of time required for the crew to perform the task to the time available). The results showed little workload variation between the ILS baseline and the two capture modes for the centerline capture concept. However, for the segmented path capture concept the differences in workload depended upon when the approach route was entered and verified. If the approach path is entered prior to descent, the workload is approximately the same as the ILS baseline. If it is entered and verified after runway assignment, the workload is significantly higher and head-down time is significantly longer than the ILS baseline. If the crew is required to manually enter the waypoints after runway assignment, it will not have enough time to complete the tasks.

One conclusion of the analyses is that the centerline capture concepts proposed by Erkelens have approximately the same workload or less compared to the ILS baseline. A lower workload is possible because of a reduction in the amount of radar vectoring required by the air traffic controller (ATC). Another benefit of these concepts is the possibility of flying simple segmented approaches consisting of a precision track to the centerline.

Based upon this analysis, segmented path capture concepts using a compact control display unit (CDU) do not appear to be feasible because of the time required to enter and verify the approach path. However, if the crew is not required to verify the approach path, the workload is approximately the same as for the ILS baseline.

These workload estimates are based upon operations with autopilot and autothrottles, and workload analysis does not include estimates for mental workload or compensate for errors in execution. Manual control with a flight director may produce an even higher workload with the MLS scenarios due to an increase in control activity to fly a segmented or curved track instead of a straight track. Although simulation studies have tested the pilot's ability to fly complex approaches manually (Reference 3), further studies are required to evaluate crew procedures and workload for path selection and verification in an operational environment.

BACKGROUND

Previous studies have developed guidance algorithms for flying segmented and curved approaches with the MLS guidance system (References 2-4). Several studies have performed piloted simulation to demonstrate the ability of pilots to fly segmented and curved approaches with a flight director (References 3 and 5). In Summers (Reference 1), crew procedures and workload were analyzed for different MLS equipment configurations and scenarios. One configuration was an MLS receiver capable of angle-only operations, a second consisted of a simple guidance computer built into the MLS receiver, and the third was an MLS receiver coupled to a flight management system (FMS). The FMS provided the guidance algorithms and waypoint data base for segmented and curved approaches. The results of this study showed that MLS operations using a receiver capable of angle-only operations or a receiver connected to an FMS would result in a small increase in crew workload.

The objective of the current study was to evaluate crew procedures and workload for MLS systems that could be retrofitted into existing aircraft. Two concepts were considered, both of which incorporated a microprocessor into the receiver. One used guidance algorithms for capturing the runway centerline based on Erkelens' study (Reference 2) while the other used guidance algorithms and stored waypoint data bases for segmented path approaches.

Four capture or path-interception modes, illustrated in Figure 1, were proposed by Erkelens. Two were based on the aircraft's own navigation: the first from any point and heading to a fixed (published) position on the approach path, and the second to an intercept point consistent with safely completing the approach that consumes the least fuel and time. The first mode is similar in nature to an ILS procedural turn where a base turn is made to the final approach path after crossing over a locator beacon; however, a direct intercept of the final approach path is made at the final approach fix or waypoint. The second approach mode is to a minimum intercept point for a safe straight-in leg. The only difference between these two modes is the location of the waypoint on the final approach path.

The other two capture modes are based on partial radar vectoring. The first mode provides precision guidance from the aircraft's current position and track to the interception of the runway centerline and on through to touchdown. This will relieve the ATC of any further vectoring, which will improve the workload for both ATC and crew. Another advantage is that approaches consisting of two segments could be flown because the aircraft is flying a precision track once the MLS mode is engaged. The limitations in using the track capture mode are that the track of the aircraft must intersect the runway centerline, and depending upon the aircraft's position relative to the runway centerline, the aircraft may overshoot the centerline.

The second mode, turning from present position and track to a fixed-angle intercept with the runway centerline, is useful when approaching from a downwind leg requiring a short turn into the final leg. If a 90-degree turn is made toward the runway heading, the aircraft will be on an intercept heading

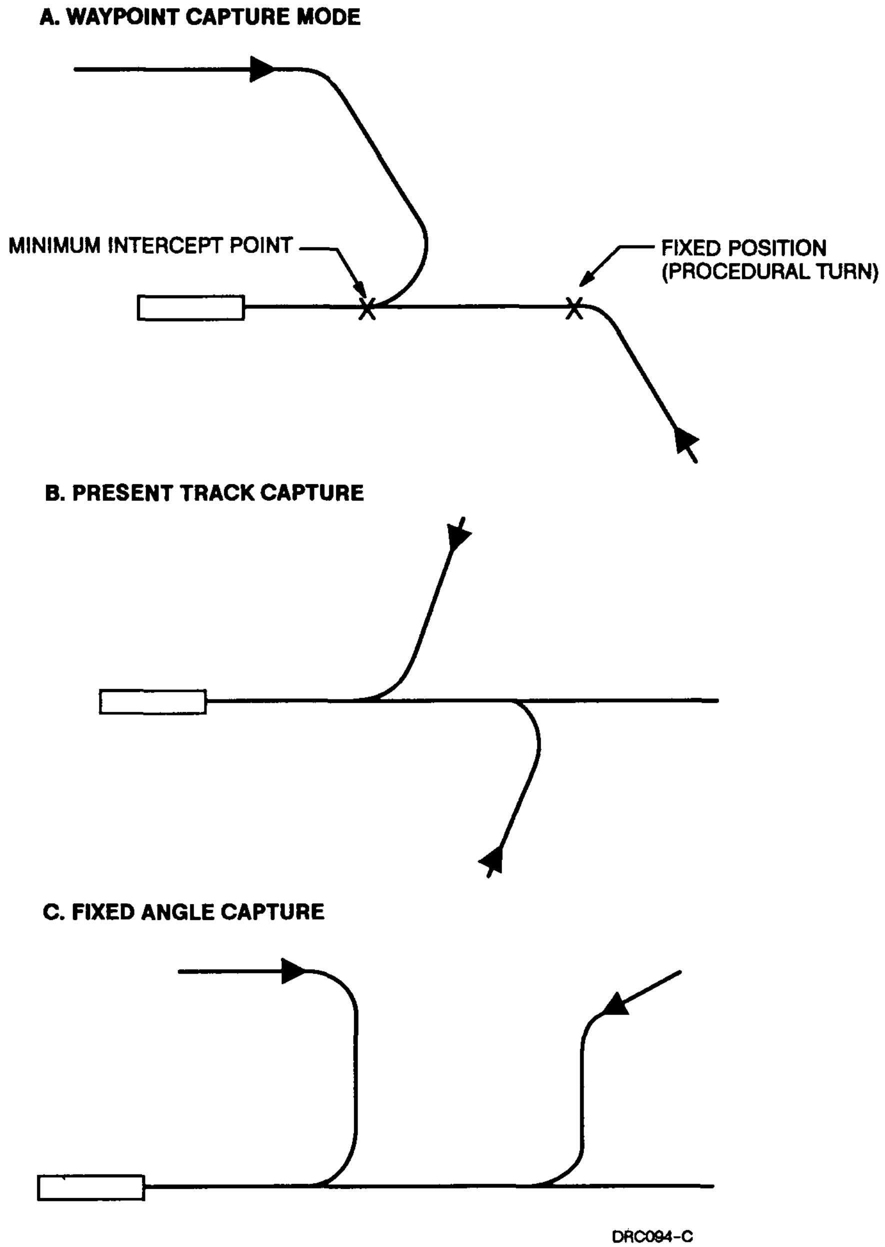

FIGURE 1. CENTERLINE PATH CAPTURE MODES

with the final approach path. Erkelens found that this capture mode was useful only with a downwind approach; otherwise, the resulting tracks were less predictable and required more maneuvering.

These four capture modes have several benefits: the track capture modes provide approach paths with two segments; they reduce the amount of vectoring required; they simplify crew interfaces for MLS operations, and the waypoint capture mode allows short straight-in finals.

The second concept for retrofit is to incorporate a waypoint data base into the receiver's microprocessor. This data base could contain numerous routes that the crew could call up. The waypoint data base would be programmed or reprogrammed on the ground, possibly by using memory modules that the ground crew could interchange. Also, the capability for in-flight programming could be provided. This concept would require a more complex crew interface for selecting and verifying the approach path. The basic design requirements are to minimize the crew's action and develop a CDU concept that could be retrofitted into a transport aircraft cockpit. This leads to the requirement for multilegend displays and multifunction controls. Also, because of space limitations, rotary control knobs were considered appropriate instead of a keyboard.

METHOD

The approach of this study was to develop MLS equipment concepts and use analytical techniques to estimate the crew workload. Two equipment concepts were developed. The first concept incorporates guidance algorithms that allow the aircraft to be guided from its present position and course to a straight-in final approach. The second concept incorporates guidance algorithms and a waypoint data base that allows the aircraft to be guided from its present position and course to a segmented approach path. The basic criteria in the development of these concepts were (1) to make the interfaces compatible with current aircraft systems and interfaces, (2) to keep the procedures as close as possible to ILS procedures, and (3) to minimize the crew actions required to maintain a satisfactory crew workload.

The equipment was configured for retrofit to an MD-80 aircraft that has a digital flight guidance system. This required developing a control display unit interface for the two concepts that could fit into a 3- by 5-inch space in either the forward or aft pedestal. Other requirements for the equipment included a switching unit for changing from ILS inputs to MLS inputs and modifying the flight guidance computer to accept the MLS guidance inputs.

An information-requirements analysis was performed to determine the crew interface requirements. On the basis of these requirements, the controls and displays for the MLS functions were identified and conceptual designs developed. These conceptual designs were reviewed by pilots from Douglas' Flight Operations Department and modifications were made based on their suggestions.

The approach scenario was based on an ILS approach with autothrottles and autopilot that was used for MD-80 certification (Reference 6). The aircraft configuration and airspeeds are listed in Table 1. The basic scenario was modified for MLS operations to allow comparisons between the ILS baseline and MLS scenarios.

TABLE 1
AIRCRAFT CONFIGURATION AND AIRSPEEDS

AIRCRAFT CONFIGURATION	
LANDING WEIGHT	132,000 LB
LANDING FLAPS	40 DEG
AIRSPEEDS	
MANEUVERING	236 KIAS
SLATS EXTENDED	184 KIAS
15-DEG FLAPS	158 KIAS
28-DEG FLAPS	147 KIAS
40-DEG FLAPS	142 KIAS
VREF (40 DEG)	133 KIAS

Crew tasks were identified for the MLS operations and substituted for the ILS procedures in the approach scenarios. The remaining crew tasks were approximately the same as the ILS scenario so that comparisons could be made between the approaches. All procedures for this study assumed autopilot and autothrottle operations, no deviations from the approach path by ATC, and no abnormal contingencies.

The workload analysis methodology was similar to that used in the previous study (Reference 1). This program uses a task-timeline analysis to quantify workload (Reference 7). Mission analysis is used to organize the flight into phases and segments. The segments are used as a framework to identify their respective tasks and subtasks.

These subtasks contain a store of data specific to a crew member and equipment. The data include the action required and the estimated time to complete the action for each of the body channels. The body channels are divided into left- and right-hand tasks, foot tasks, verbal/aural tasks, and internal visual tasks. The times required to complete the actions were derived from the American Institute for Research Index of Electronic Equipment Operability (Reference 8) and verified by in-flight studies (Reference 6). The time required for verbal communication tasks was based on the average time needed to speak the given phrase.

The times required to perform the subtasks were added serially to arrive at a total time required to complete a task. This is considered a conservative estimate of workload because the crew is capable of performing some tasks in parallel. The analysis does not consider any cognitive or mental activities; if the tasks differ significantly in mental activity (attention or memory demands), this methodology is insensitive to workload differences.

Workload indexes represent the ratio of the time required to perform the tasks within a flight segment, divided by the time available for the flight segment. The times available for the ILS baseline were based upon computer calculations using aircraft performance parameters. The same times were used for flight segments of the MLS scenarios that did not require any MLS guidance activity. Flight segments that used MLS guidance were based upon times computed in the MLS guidance study (Reference 9).

Availability for external vision tasks was also calculated. This represents the amount of time available to each crew member for viewing other aircraft traffic, the environment outside the cockpit, or the runway before landing. This is determined by subtracting the time needed during each segment to perform internal cockpit tasks that require vision from the total time available. The remainder is the time available for external vision.

MLS EQUIPMENT CONCEPTS

The equipment concepts were designed so the equipment could be retrofitted into existing aircraft with minimum modifications to other airborne equipment. The MD-80 series of aircraft was used as a model. The conceptual design was used only to identify the crew interface, procedures, and workload. It did not consider any of the requirements for installing MLS antennas and receivers, structural changes to the aircraft, or interfaces with other avionics equipment. Interfaces with the digital flight guidance and control system, the flight instruments, and the capability to switch from ILS to MLS operations would be required.

The two concepts used a microprocessor built into the MLS receiver to provide guidance algorithms for capturing the runway centerline or approach path. Figure 2 shows the system block diagram and interconnections with the other systems. The MLS receiver's CDU was the crew interface for selecting the channel, approach path, and capture mode, and for verifying the approach path. An ILS/MLS mode-select switch was located on the glareshield for selecting the MLS mode. The MLS was engaged by the same autopilot mode switches as the ILS. The receiver's output provided steering signals and mode annunciation to the digital flight guidance computer and flight instruments. Figure 3 shows the relationship of these various components in the MD-80 cockpit.

Concept 1 — Centerline Approach

The MLS receiver was assumed to have the following capabilities:

- The crew selects one of 200 MLS channels. When within coverage, the receiver decodes the data word and displays the three-letter ICAO (International Civil Aviation Organization) identification code and audio signal for the crew, as well as the station status.

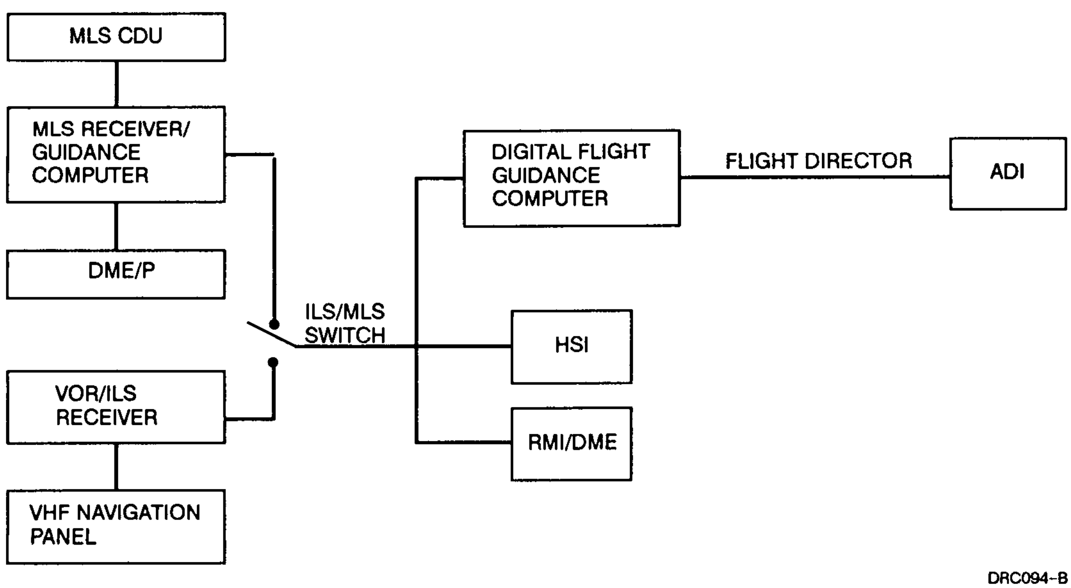

FIGURE 2. SYSTEM BLOCK DIAGRAM FOR MLS SYSTEM

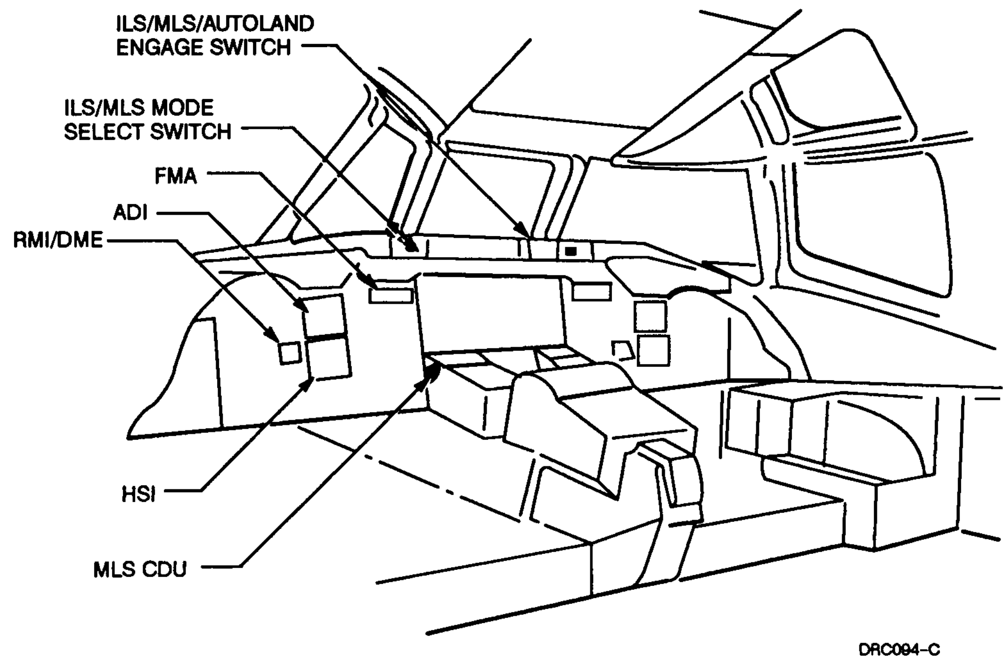

FIGURE 3. COCKPIT LAYOUT FOR MLS EQUIPMENT

- The crew selects the ILS or MLS mode. Signals driving the flight guidance computer and flight instruments are switched from ILS to MLS and vice versa. The VOR/LOC mode of the autopilot engages the lateral function of MLS. The ILS/MLS and AUTOLAND modes engage the vertical and lateral modes.
- The receiver performs built-in tests and displays the results to the crew.
- The crew selects the capture mode and verifies the azimuth and glide path alignment angles transmitted by the data word.
- For angle-only operations, the crew selects the azimuth and glide path angles using the MLS CDU.
- The back azimuth mode is armed when TOGA (takeoff and go-around) autothrottle is engaged, or upon nosewheel strut compression. When the back azimuth is armed and the MLS is engaged, the guidance function switches automatically to the back azimuth signal when the front azimuth coverage is lost. It reverts to forward azimuth armed mode when the MLS mode is disengaged.

More crew tasks are required for MLS operations than ILS operations. The crew must verify the azimuth alignment and minimum glide path angles, select the capture mode, select the range for the waypoint capture mode, and monitor the position of the aircraft when it is under MLS guidance. The task of entering the runway course has been eliminated.

As a backup mode, the MLS system is capable of flying angle-only operations. This is used if the guidance computer fails, or ATC assigns another azimuth or glide path angle. If ATC assigns an offset approach, a visual transition to the runway centerline is required. In addition to tuning the MLS receiver, verifying the station identification and verifying the equipment status, the crew is required to enter and verify the azimuth and glide path angles. The aircraft must be vectored to an intercept heading, similar to an ILS approach. The crew flies the aircraft with either the flight director or autopilot and performs a visual transition to the touchdown point or the runway centerline.

Information Requirement Analysis

Table 2 shows the crew functions, data sources, control inputs, and information feedback required to perform the functions. The sources of data are the approach plate, ATC verbal communications, the MLS azimuth and elevation angles, the precision distance measuring equipment (DME/P) range,

TABLE 2
INFORMATION REQUIREMENTS ANALYSIS FOR CENTERLINE CAPTURE CONCEPT, MLS CONTROL DISPLAY UNIT

FUNCTIONS	DATA SOURCE	CONTROL INPUT	INFORMATION FEEDBACK
CHANNEL SELECTION	APPROACH PLATE	MLS CDU – CHANNEL SELECT	MLS CDU – 3-DIGIT DISPLAY
STATION VERIFICATION	MLS DATA WORD/ RECEIVER AND AUDIO	–	ICAO ID ON MLS CDU AND AUDIO
STATION STATUS	MLS DATA WORD/ RECEIVER	–	MLS CDU, FMA, AND FLAGS
RECEIVER STATUS	BITE	–	MLS CDU, FMA, AND FLAGS
MODE SELECT	ATC	MLS CDU – MODE SELECT	MLS CDU – SWITCH POSITION
WAYPOINT RANGE SELECT	APPROACH PLATE OR ATC	MLS CDU – RANGE SELECT	MLS CDU – 3-DIGIT DISPLAY
AZ/BAZ ANGLE VERIFICATION OR SELECT	MLS DATA WORD/ RECEIVER, APPROACH PLATE OR ATC	MLS CDU – AZ/BAZ SELECT AZIMUTH ANGLE SELECT	MLS CDU – 3-DIGIT DISPLAY
GLIDE PATH ANGLE VERIFICATION OR SELECT	MLS DATA WORD/ RECEIVER, APPROACH PLATE OR ATC	MLS CDU – GLIDE PATH ANGLE SELECT	MLS CDU – 3-DIGIT DISPLAY
ILS/MLS MODE SELECT	ATC	GLARESHIELD – MODE SELECT	FLIGHT MODE ANNUNCIATOR
MLS ENGAGE	ATC	GLARESHIELD – AUTOPILOT MODE SELECT	FLIGHT MODE ANNUNCIATOR
STATUS	MLS RECEIVER	–	FLIGHT MODE ANNUNCIATOR, MLS CDU AND INSTRUMENT FLAGS
MONITOR FLIGHT DIRECTOR	DEVIATION SIGNALS – MLS RECEIVER – DIGITAL FLIGHT GUIDANCE SYSTEM	–	ATTITUDE DIRECTOR INDICATOR
MONITOR COURSE AND COURSE DEVIATION	DEVIATION SIGNALS – MLS RECEIVER	–	HORIZONTAL SITUATION INDICATOR
MONITOR GLIDE PATH DEVIATION	DEVIATION SIGNALS – MLS RECEIVER	–	COURSE DEVIATION INDICATOR
MONITOR ALONG TRACK DEVIATION	DEVIATION SIGNALS – MLS RECEIVER	–	HORIZONTAL SITUATION INDICATOR
MONITOR ORIENTATION AND DISTANCE TO THRESHOLD	DEVIATION SIGNALS – MLS RECEIVER	–	RADIO MAGNETIC INDICATOR/ DISTANCE MEASURING EQUIPMENT

the guidance commands, and the MLS data words. The control inputs are identified according to the control location and type. The information feedback is identified by the display location and type.

MLS Control Display Unit

Based on the above information requirement analysis, a control display unit was designed as shown in Figure 4. This unit could be located in the forward pedestal and fit into a 3- by 5-inch area. The display unit consisted of the following:

- Display Panel — A row of 0.30-inch characters consisted of three alphanumeric characters for channel number and the three-letter ICAO identification code, three numeric characters for azimuth magnetic bearing, three numeric characters for glide path angle, and three numeric characters for waypoint range. A row of 0.15-inch characters appeared above this row for labels. The AZ label for the bearing readout changed to BAZ when the back azimuth function was selected. Below the row of characters were fault annunciations on station and equipment status.

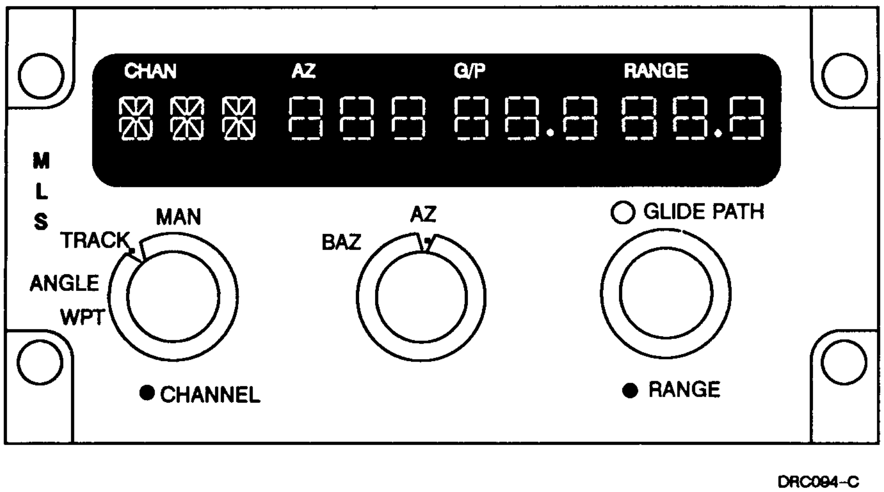

FIGURE 4. MLS CONTROL DISPLAY UNIT FOR CENTERLINE CAPTURE CONCEPT

- Controls — There were three concentric controls as follows:

  Left control

  The outer knob selected mode of operation:

  Manual — Angle-only operation.

  Track — Centerline capture from present track.

  Angle — Centerline capture from a fixed course angle.

  Waypoint — Centerline capture at a specific waypoint.

The inner knob was a two-position control for channel selection. The normal position selects channels at a slow rate, and the depressed position changes them at a fast rate.

Center Control

The outer knob was for selecting front or back azimuth on the display.

The inner knob was a two-position knob for slow/fast setting of the azimuth/back azimuth offset angle.

Right Control

The outer knob was for selecting the glide path angle,, and the inner knob is for selecting the waypoint range.

- Operation — The crew uses the MLS CDU to select the channel and operating mode, verify the azimuth and glide path angles, and, depending upon the mode selected, the azimuth, glide path, and range values.

Channel Selection

The crew selects one of 200 available channels using the channel number on the approach plate. The channel number appears on the display readout. When the aircraft is within the transmitter's coverage, the display changes to the ICAO three-letter identifier after a 3-second delay. The audio identification signal is received over the audio system.

Mode Selection

Manual — When in this mode, angle-only approaches are selected and the crew must enter the azimuth and glide path angles. Both the azimuth and glide path display values are blanked until values are selected with the azimuth and glide path control knobs.

Track — After the MLS is engaged, the aircraft remains on its current course until it captures the runway centerline. The azimuth offset angle of the runway and the minimum glide path angle are supplied by the data word and displayed in the azimuth and glide path readouts. The crew is only required to verify the readouts. The crew may also verify the back azimuth alignment by selecting the BAZ position with the AZ/BAZ selector.

Angle — In this mode the aircraft proceeds from present position to a fixed angle intercept with the runway centerline. Otherwise, it is the same as the track mode.

Waypoint — The aircraft flies from its present position to a waypoint on the runway centerline. The azimuth offset angle and the minimum glide path are provided by the data word and displayed. The range readout flashes until a range value is selected. (In the other modes the range readout is blank and no range can be entered.)

Flight Mode Annunciator

The current MD-80 flight mode annunciator (Figure 5) required modification as follows:

- An MLS annunciation was added next to the ILS annunciation. This is an amber light like that of the ILS and serves the same functions. It illuminates when the comparator detects a difference between the two receivers, and it flashes if a failure is detected or the condition does not permit centerline capture.
- The arm mode annunciation shows MLS when the MLS mode is armed for automatic capture of the MLS path.
- The lateral mode annunciation indicates MAZ CAP and MAZ TRK (MLS azimuth capture and track) when the MLS lateral path is being captured or tracked.
- The vertical mode annunciation indicates G/P CAP or TRK (glide path capture and track) when the MLS vertical path is being captured or tracked.

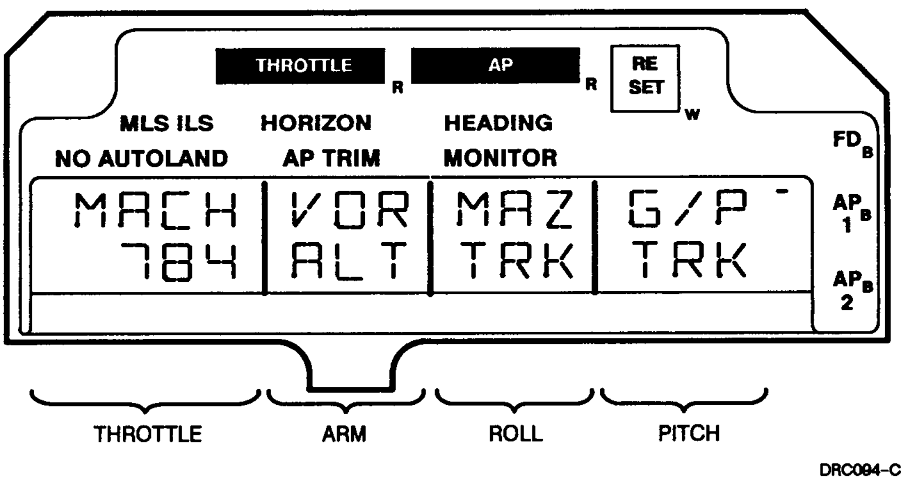

FIGURE 5. FLIGHT MODE ANNUNCIATOR

Attitude Director Indicator

The flight director provides MLS guidance signals via the digital flight guidance computer. The glide slope and localizer deviation indicators provide MLS deviation signals from the computed course and glide path.

Horizontal Situation Indicator

When operating in the MLS mode, the compass rose remains heading-oriented and the course pointer represents the course computed by the MLS algorithm. During a turn, the course pointer remains tangent to the computed curved path. The course deviation indicator and the vertical deviation indicator indicate aircraft deviations from the computed flight path. The DME readout indicates the along track DME. As illustrated in Figure 6, the ADF pointer was modified to indicate the course of the runway centerline.

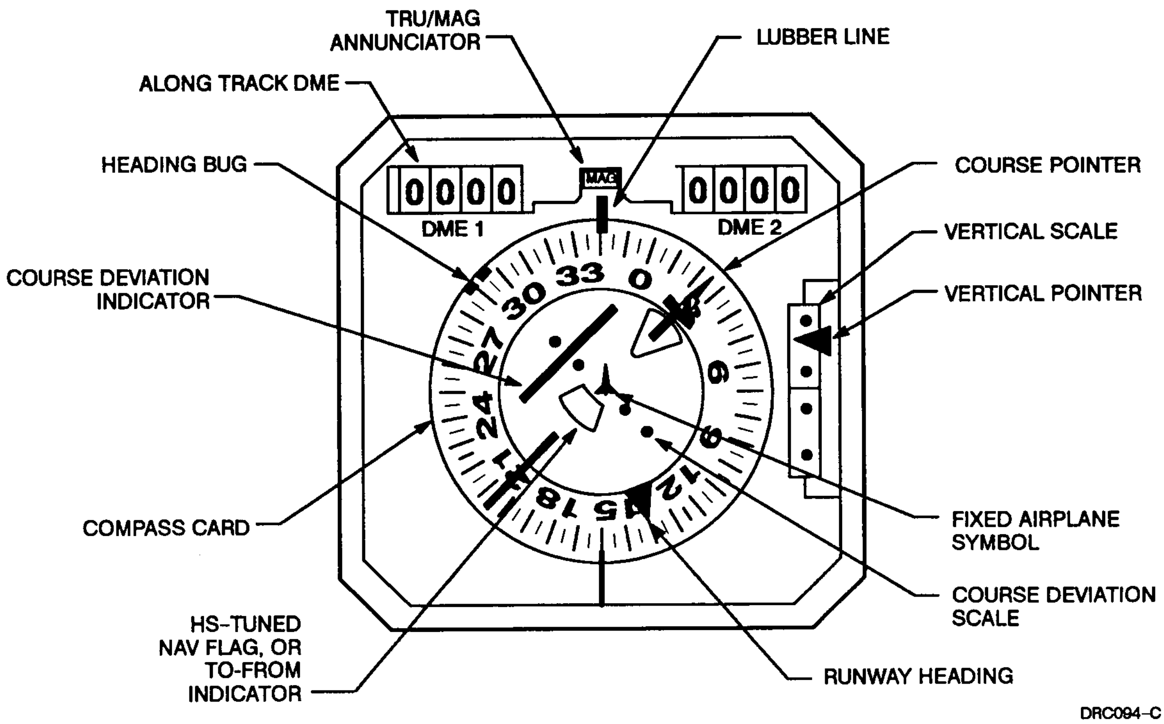

FIGURE 6. HORIZONTAL SITUATION INDICATOR FOR CENTERLINE CAPTURE CONCEPT

Orientation and Range to the MLS Datum Point

The radio magnetic indicator/distance measuring equipment (RMI/DME) readout was modified to indicate the bearing and distance to the MLS datum point from the two MLS receivers, as illustrated in Figure 7.

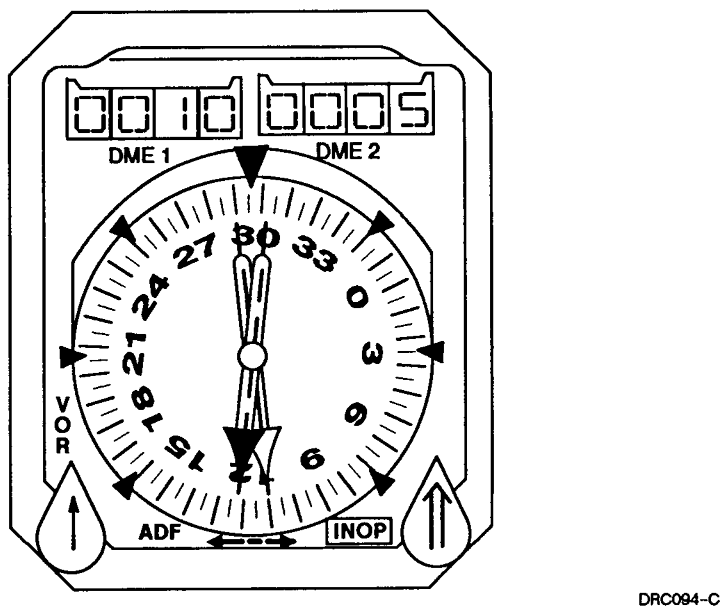

FIGURE 7. RMI/DME INDICATOR FOR DISTANCE AND BEARING TO THE MLS DATUM POINT

Concept 2 — Segmented Approach

The microprocessor for this concept provided smart capture algorithms, guidance on a segmented approach path, and the capability to store a number of approach paths consisting of multiple waypoints in memory. The receiver characteristics and functions are as follows:

- The receiver data base stores up to 100 approach paths. A small portion (approximately 10) was reprogrammable by the crew. The remainder was nonreprogrammable except by ground services. Each approach path was assigned a number from 0 to 99. This number is identified on the approach plate so that the crew can enter it into the CDU when tuning the receiver.
- Each route has a maximum of 10 to 12 waypoints, including the threshold waypoints and missed-approach or precision-departure waypoints. If the stored values for the threshold are not the same as those contained in the data word, a "threshold disagree" annunciation occurs on the MLS CDU.

  The waypoints are sequenced where the first waypoint is the first one encountered on the approach path and the last one (or largest-numbered waypoint) is the threshold waypoint. The missed-approach or departure waypoints are entered after the approach waypoints and are assigned negative numbers.

  The above assumes that the waypoints appear on the approach plate as shown in Figure 8. The data listed with each waypoint is the magnetic bearing to the MLS datum point, the range to the datum point, and the waypoints barometric altitude. For ten of the approach paths the crew may enter the waypoints through the MLS CDU. This is provided in case the aircraft landed at an unscheduled airport that is not in the data base. Also, the crew has the ability to select the manual mode that provides angle-only operations.

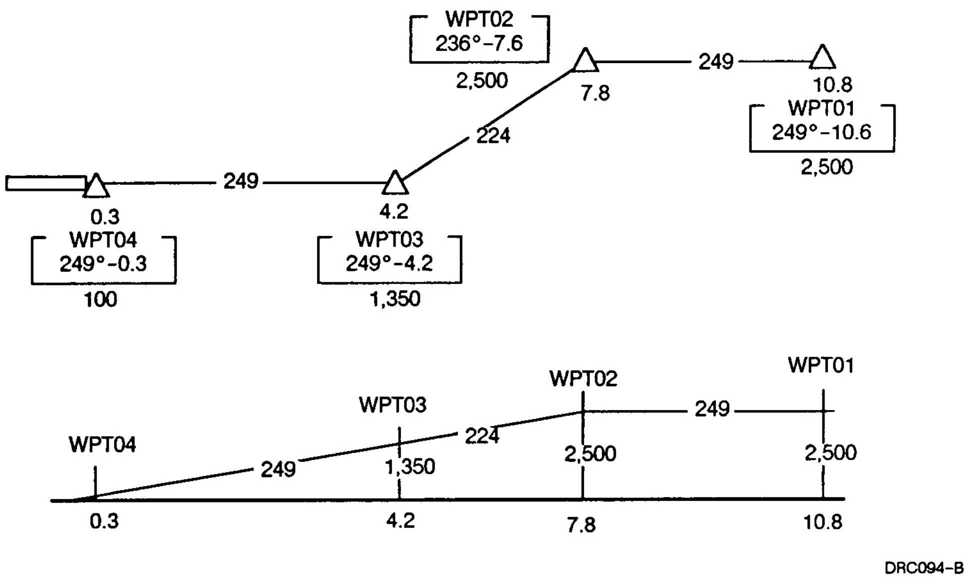

FIGURE 8. APPROACH PLATE FOR MLS SEGMENTED APPROACH PATH

- The crew selects one of 200 channels. When within coverage, the receiver decodes the data word and displays the three-letter ICAO identifier and audio signal to the crew. The receiver decodes the data word on station status and displays the results.
- The crew selects one of the three capture modes: track to leg capture, fixed angle capture of a leg, and waypoint flyover. For the waypoint flyover mode the crew must specify the waypoint.
- The receiver performs built-in tests and displays the results when a fault occurs.
- When the MLS mode is selected, signals driving the flight guidance computer and instruments will be switched from ILS to MLS and vice versa. The autopilot's VOR/LOC mode engages the lateral MLS function, and the ILS/MLS and AUTOLAND modes engage both the vertical and lateral modes.
- The back azimuth mode will be armed when the TOGA is engaged or upon nosewheel strut compression. When the aircraft is out of front azimuth coverage and the back azimuth signal is being received, guidance will be provided by the back azimuth signal and waypoints.

The crew's basic functions are to select the MLS mode, tune the receiver, select the route enter mode, enter the approach path number, select the capture mode, verify station identification and equipment status, verify the approach path waypoints against the approach plate, and engage the MLS. The crew monitors the progress as before with the flight director, course pointer, course and vertical deviation indicators, along track DME, and the relative position to the MLS datum point.

Differences between this concept and the ILS baseline are that the crew must enter the approach path number and verify the waypoints against the approach plate, enter the capture mode, and monitor the aircraft's position and course when it is using MLS guidance.

Information Requirement Analysis

Table 3 shows the crew functions, data sources, control inputs, and information feedback required to perform the functions. The sources of data are either the approach plate or ATC verbal communications, the MLS azimuth and elevation angles, the DME/P range, the guidance commands, and the MLS data words. The control inputs are identified according to location and type of control. Information feedback is identified by the location and type of display.

Control Display Unit

The conceptual design for this control display unit consists of a multifunction display and multifunction rotary control knobs. The size of the panel is 3 by 5 inches and would fit into the same space as the MLS CDU. The panel's layout is shown in Figure 9. The control display unit consists of the following:

TABLE 3
INFORMATION REQUIREMENTS ANALYSIS FOR SEGMENTED APPROACH

FUNCTIONS	DATA SOURCE	CONTROL INPUT	INFORMATION FEEDBACK
CHANNEL SELECTION	APPROACH PLATE	MLS CDU – CHANNEL SELECT	MLS CDU – 3-DIGIT DISPLAY
STATION VERIFICATION	MLS DATA WORD – RECEIVER AND AUDIO	–	ICAO ID ON MLS CDU AND AUDIO
STATION STATUS	MLS DATA WORD – RECEIVER	–	MLS CDU, FMA, AND FLAGS
RECEIVER STATUS	BITE	–	MLS CDU, FMA, AND FLAGS
MODE SELECTION	ATC	MLS CDU – MODE SELECT	MLS CDU – SWITCH POSITION
ROUTE ENTER MODE			
APPROACH PATH SELECTION	ATC OR APPROACH PLATE	MLS CDU – ENTER MODE AND MULTIFUNCTION CONTROL	MLS CDU – 2-DIGIT READOUT
APPROACH PATH VERIFICATION	APPROACH PLATE AND RECEIVER	MLS CDU – DISPLAY MODE AND MULTIFUNCTION CONTROL	MLS CDU – READOUTS FOR WAYPOINT, BEARING, RANGE AND ELEVATION
ROUTE PROGRAM MODE			
ENTER WAYPOINT, BEARING, RANGE AND ELEVATION FOR EACH WAYPOINT	APPROACH PLATE	MLS CDU – SELECT MODE AND MULTIFUNCTION CONTROL	MLS CDU – READOUTS FOR WAYPOINT, BEARING, RANGE AND ELEVATION
MANUAL MODE			
AZIMUTH AND GLIDE PATH ANGLE SELECTION	ATC OR APPROACH PLATE	MLS CDU – MANUAL MODE AND MULTIFUNCTION CONTROL	MLS CDU READOUTS FOR AZIMUTH AND GLIDE PATH
DISPLAY MODE			
WAYPOINT VERIFICATION	ATC OR APPROACH PLATE	MLS CDU – DISPLAY MODE AND MULTIFUNCTION CONTROL	
WAYPOINT SELECTION	ATC OR APPROACH PLATE	MLS CDU – DISPLAY MODE AND MULTIFUNCTION CONTROL	MLS CDU – 3-DIGIT DISPLAY
ILS/MLS MODE SELECTION	ATC	GLARESHIELD – MODE SELECT	FLIGHT MODE ANNUNCIATOR
MLS ENGAGE	ATC	GLARESHIELD – AUTOPILOT MODE SELECT	FLIGHT MODE ANNUNCIATOR
STATUS	MLS RECEIVER	–	FLIGHT MODE ANNUNCIATOR, MLS CDU AND INSTRUMENT FLAGS
MONITOR FLIGHT DIRECTOR	DEVIATION SIGNALS – MLS RECEIVER – DIGITAL FLIGHT GUIDANCE SYSTEM	–	ATTITUDE DIRECTOR INDICATOR
MONITOR COURSE AND COURSE DEVIATION	DEVIATION SIGNALS – MLS RECEIVER	–	HORIZONTAL SITUATION INDICATOR
MONITOR GLIDE PATH DEVIATION	DEVIATION SIGNALS – MLS RECEIVER	–	COURSE DEVIATION INDICATOR
MONITOR ALONG TRACK DEVIATION	DEVIATION SIGNALS – MLS RECEIVER	–	HORIZONTAL SITUATION INDICATOR
MONITOR ORIENTATION AND DISTANCE TO THRESHOLD	DEVIATION SIGNALS – MLS RECEIVER	–	RADIO MAGNETIC INDICATOR/ DISTANCE MEASURING EQUIPMENT

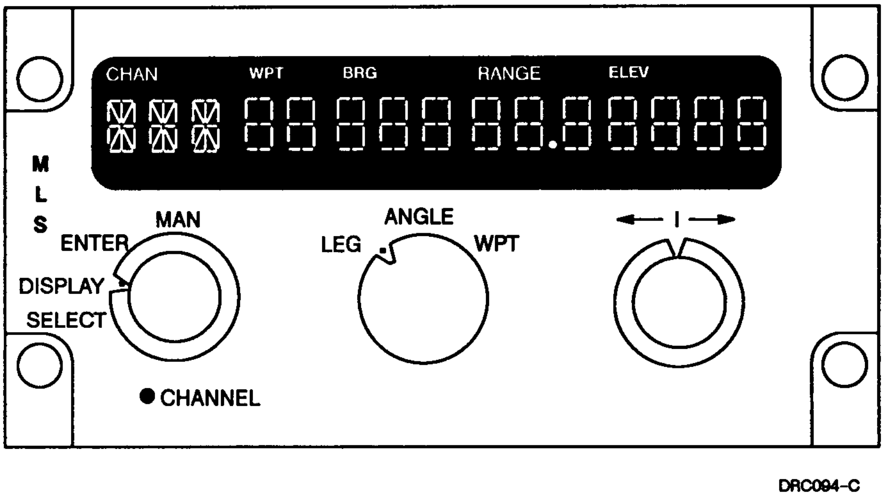

FIGURE 9. MLS CONTROL DISPLAY UNIT FOR SEGMENTED APPROACH

- Display Panel — The display unit is a flat panel display consisting of three rows: legends, parameter values, and annunciations. Legends are a row of 0.15-inch characters, parameter values are a row of 0.30-inch characters, annunciations are a row of 0.20-inch characters. The number of characters per row and their spacing depends upon the mode selected.
- Multifunction Controls — The left and right controls are concentric; the center control is a three-position switch. Their functions are as follows:

Left Control

The outer knob selects the mode of operation. Its modes are:

Manual — This is for angle-only operations. The multifunction display shows the channel number or the three-letter ICAO identifier, the azimuth angle and the glide path angle (Figure 10A). The crew can enter the channel number, azimuth angle, and glide path angle.

Enter — This is for selecting the channel number and approach route. The multifunction display shows the channel and approach-route numbers (Figure 10B), which can be entered by the crew.

Display — This mode is for displaying waypoint data. The display shows the approach route number, the waypoint number, bearing, range, and elevation (Figure 10C). The crew is only able to select the waypoint number. If the waypoint capture mode is selected, the waypoint being displayed is captured. During engagement, the active waypoint is displayed.

Program — This mode is for programming an approach path. The information displayed is the same as the display mode. The crew can select the waypoint number and enter the bearing, range, and elevation for each waypoint.

The inner knob is a two-position control for channel selection. The normal position is a slow rate, while the depressed position is a fast rate.

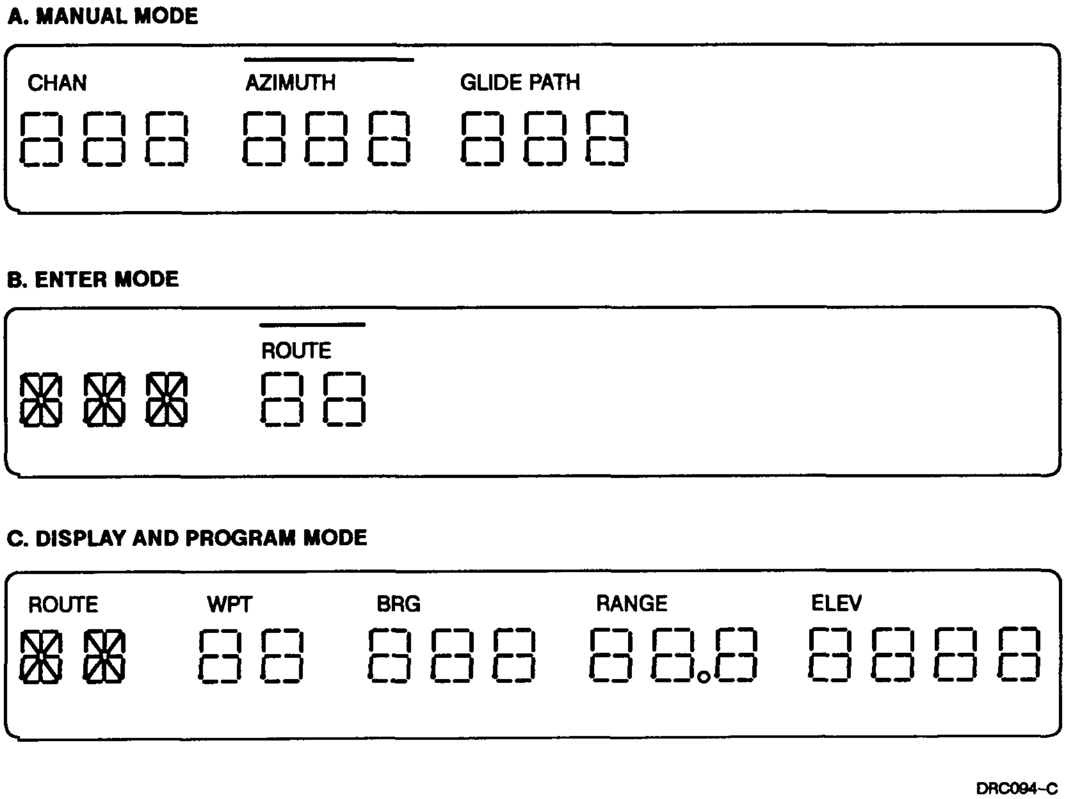

FIGURE 10. MLS CONTROL DISPLAY UNIT MULTIFUNCTION DISPLAY

Center Control

This is a three-position switch for capture mode selection. The capture modes are track (present position to leg, angle), present position to fixed-angle intercept of leg, and waypoint (present position to a specified waypoint).

Right Control

The outer knob is a two-way spring-loaded momentary switch. This knob moves the cursor position on the display and is used to select the parameter to be changed by the inner knob. The cursor position is indicated by a horizontal bar that appears above the legend of the displayed parameter, as shown in Figure 10. The inner control is a two-position rotary knob — normal (slow) and pushed-in (fast) — for selecting the value of the parameter.

- Operation — The CDU is used to select the MLS channel, the approach path stored in the receiver's data base, and the capture mode. In addition, it is used to verify the approach path and monitor the waypoint legs during approach. It allows the crew to enter an alternate approach path into the data base, and can fly angle-only approaches.

Channel Selection

The crew selects one of 200 available channels using the channel number on the approach plate. The channel number appears on the display readout. When the aircraft is within coverage, the display changes to the three-letter ICAO identifier after a 3-second delay.

Mode Selection

Normal Operation — When the enter mode is selected the channel and approach-route numbers are displayed, as shown in Figure 10B. The inner right-hand knob is used to select the route number, which will be on the approach plate. The display mode is selected, which changes the display panel to the configuration shown in Figure 10C. The crew can confirm the displayed approach path against the waypoints on the approach plate by rotating through the waypoints with the inner right-hand knob. After verification the crew selects the capture mode with the center knob, and if they select the waypoint capture mode, they must also select the waypoint to be captured while in the display mode. After the MLS is engaged, the display mode shows the waypoint currently being tracked.

Route Programming — The crew selects the enter mode and selects one of the route numbers that can be programmed. The program mode is selected and the display panel appears as in the display mode, except the cursor position is shown. All entries are blanked until the crew enters the values obtained from an approach plate. The crew positions the cursor to the waypoint readout and enters the waypoint number with the inner right-hand knob. This sequence is repeated for the bearing, range, and elevation of the waypoint. The whole sequence is repeated for each waypoint. After entry, the crew can verify the route by selecting the display mode and rotating through each waypoint, as described in the normal operation.

Manual Operation — The crew selects the manual mode and the display shows the azimuth offset angle and the glide path angle with the cursor position indicator. The crew uses the right-hand control to enter the azimuth and the glide path angle. When in this mode, both the azimuth and glide path angles are blanked until values are entered.

Flight Mode Annunciator

The flight mode annunciator previously described is used for this concept.

Attitude Director Indicator

The flight director provides MLS guidance signals via the digital flight guidance computer. The glide slope and localizer deviation indicators provide MLS deviation signals from the computed course and glide path.

Horizontal Situation Indicator

When operating in the MLS mode, the compass rose remains magnetic-heading oriented and the course pointer represents the course computed by the MLS algorithm. During a turn, the course pointer remains tangent to the computed curved path. The course deviation indicator and the vertical deviation indicator indicate aircraft deviations from the computed flight path. The DME readout indicates the along track DME. The ADF pointer, as modified, indicates the course of the next leg. An alert annunciator comes on to provide a 15-second warning before the start of a turn to the next leg and goes off when the HSI indicates the start of a turn (Figure 11).

Orientation and Range to the MLS Datum Point

As in Concept 1 the RMI/DME readout is modified to indicate the bearing and distance to the MLS datum point from the two MLS receivers.

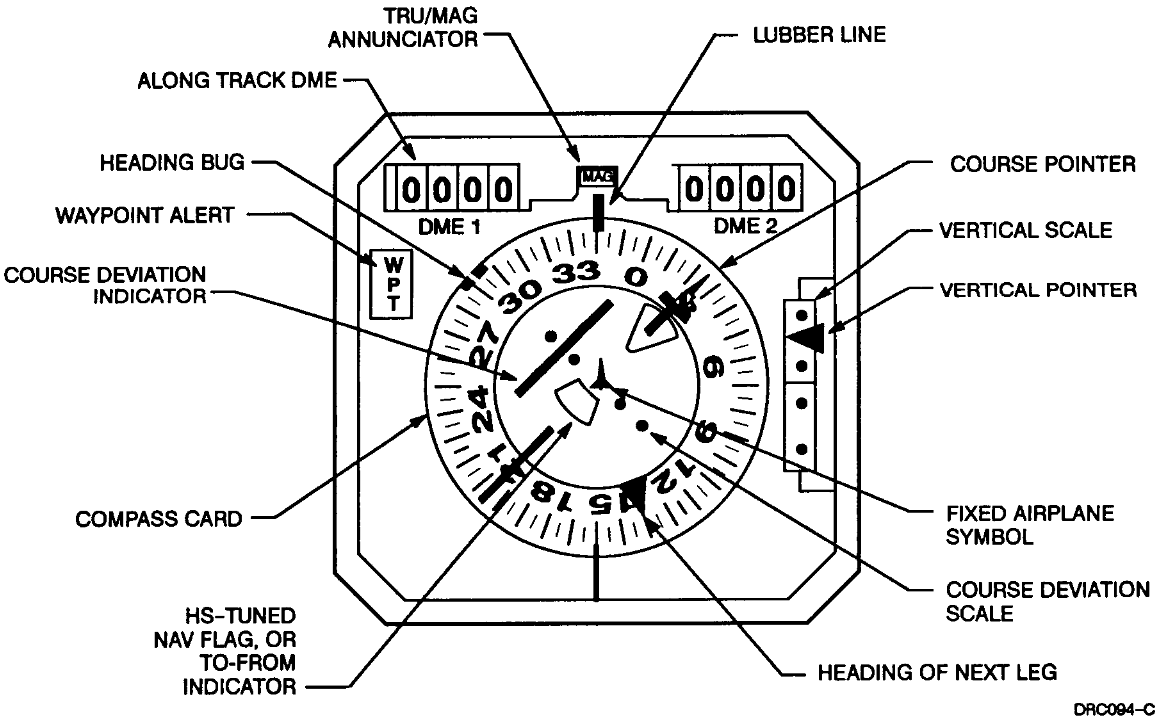

FIGURE 11. HORIZONTAL SITUATION INDICATOR FOR SEGMENTED APPROACH

APPROACH SCENARIOS

The MLS approach scenarios were selected so that they could be compared to the ILS baseline originally developed for MD-80 certification (Reference 6). This scenario used an arrival to Runway 24 at Los Angeles International Airport. This baseline was recently updated for the MD-82 certification because of changes in route and arrival procedures for the MD-82 certification.

The scenario used the Avenal transition to Runway 24/25 (Figure 12). This descent requires the aircraft to cross the Fillmore VOR at 10,000 feet, turn to a heading of 148 and a speed of 250 knots. The aircraft descends to 5,000 feet after Fillmore and turns to a heading of 081. At Santa Monica the aircraft turns to a heading of 068. At 16 DME it is vectored to a heading of 225, descends to a final approach altitude of 2,200 feet and slows to 200 knots. Once at 225 it is cleared for approach. Figure 13 shows the plan view of this approach.

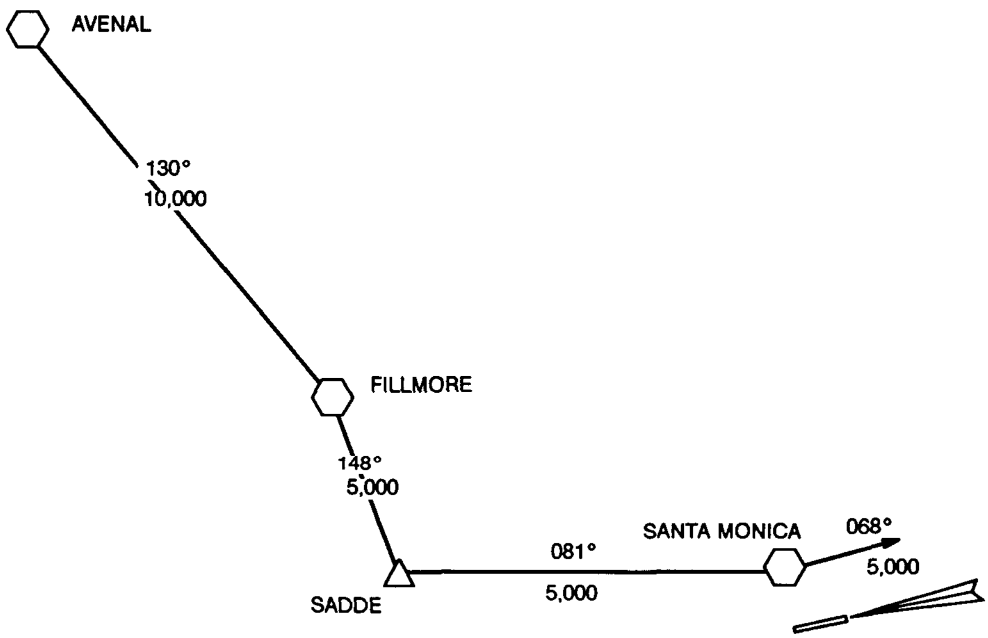

FIGURE 12. AVENAL TRANSITION TO LOS ANGELES RUNWAY 24/25

All the flight scenarios utilized autopilot and autothrottle operations. ATC traffic advisories were scattered throughout the scenario and the crew monitored nonpertinent radio communications. The original flight procedures were developed jointly by pilots and human factors engineers. The flight tasks were simulated in mockups to ensure that the flight scenario was accurate. The original task-timeline analysis was validated by analysis of in-flight video recordings of the cockpit activities and voice-communication recordings (Reference 6).

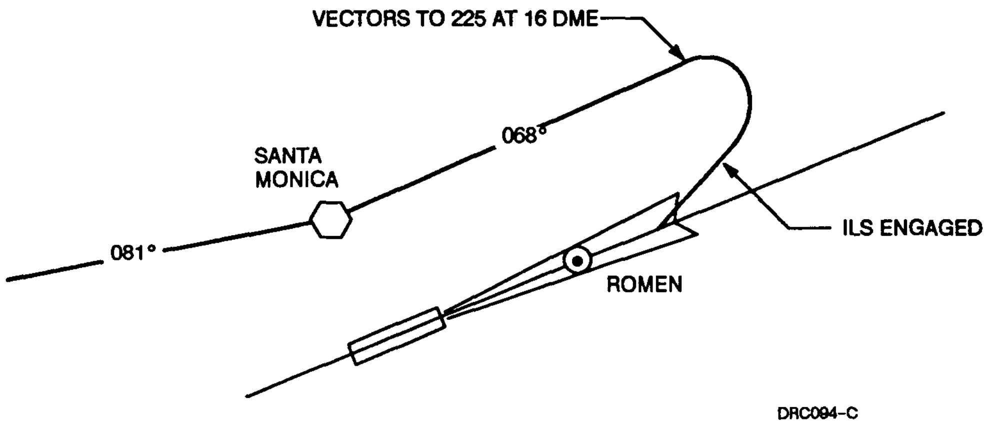

FIGURE 13. ILS BASELINE APPROACH

Poor arrival weather was assumed in order to require a Category II approach. The weather was defined as a 300-foot ceiling topping out at 4,000 feet, 3-mile visibility, no winds, daytime, and a temperature of 59 degrees Fahrenheit.

Although approaches to Los Angeles do not require MLS operations to avoid terrain or noise-sensitive areas, a similar approach profile was used so that a direct comparison could be made between the MLS and ILS workloads. This required minimum modifications to the flight profile so that the flight times for each task segment were relatively comparable. Crew procedures, except for the MLS guidance activity, remained the same.

Two scenarios were developed for runway centerline capture: (1) the track capture mode, where the aircraft turns to a heading of 061 at the Santa Monica VOR, and at 9.8 DME the ATC vectors the aircraft to 173 before clearing for final approach, and (2) waypoint capture, where ATC clears the aircraft for final approach at 9.5 DME on the 061 heading. These approach paths are illustrated in Figure 14. In the track capture mode the precision track would be known once the aircraft reaches a heading of 173. For the waypoint capture mode the precision track would not be known until the aircraft passes over the waypoint. however, less vectoring of the aircraft is required.

Figure 15 shows two scenarios were developed for the segmented path approaches. For the leg capture mode, the ATC would vector the aircraft from the 061 heading to an intercept heading. Once the MLS is engaged, the aircraft is on a precision track. As for the waypoint capture mode, no ATC vectoring is required but the precision track would not be known until the aircraft passes over the waypoint.

Task analyses were prepared for the following scenarios:

- ILS Baseline — This task analysis was basically the same as the one prepared for the MD-82 certification. The crew tasks for ILS guidance are listed in Table 4.

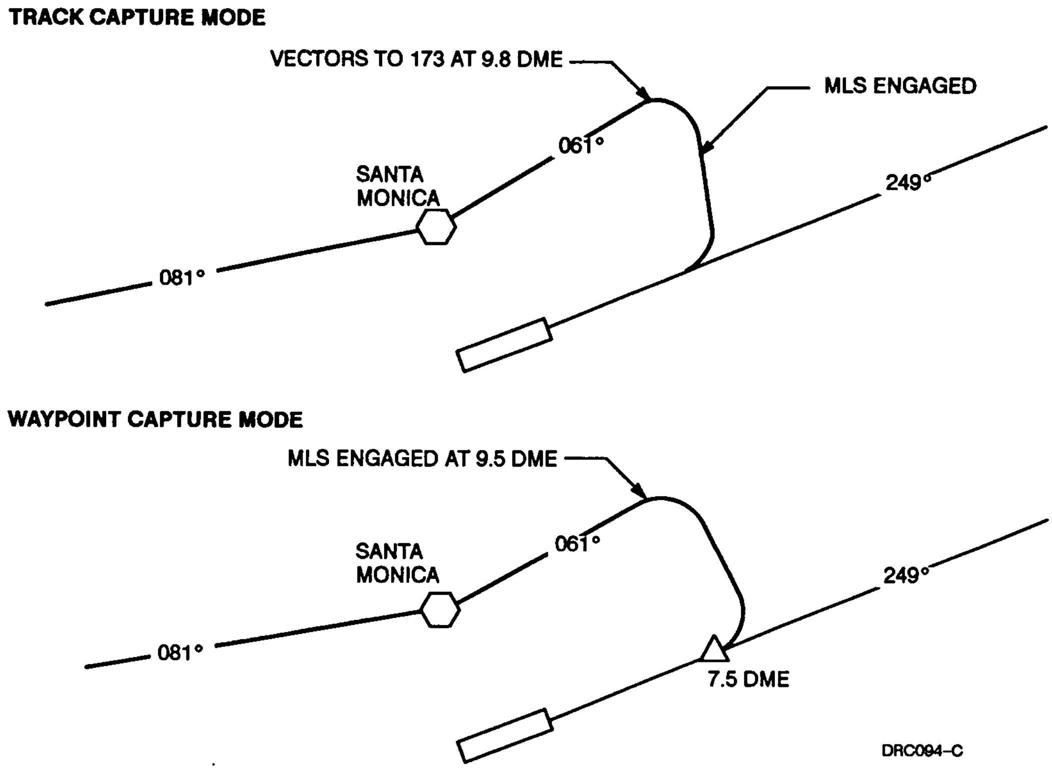

FIGURE 14. CENTERLINE CAPTURE APPROACH PATHS

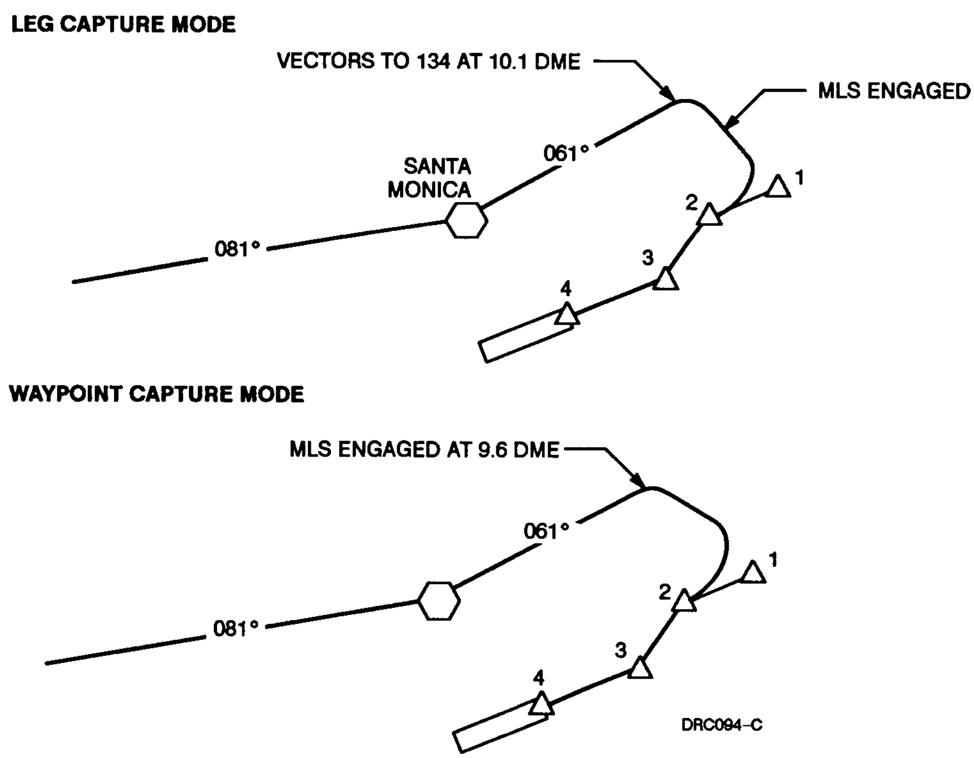

FIGURE 15. SEGMENTED APPROACH PATHS

TABLE 4
CREW GUIDANCE AND CONTROL TASKS FOR ILS BASELINE APPROACH

FLIGHT SEGMENT	CREW GUIDANCE AND CONTROL FUNCTION
ARRIVE AT APPROACH ALTITUDE	APPROACH CONTROL ASSIGNS RUNWAY AND APPROACH PATH. CREW READS THE ILS FREQUENCY AND THE RUNWAY COURSE AND ENTERS THEM INTO THE VOR/ILS CDU ON THE GLARESHIELD.
VERIFY OVER SANTA MONICA VOR	CREW VERIFIES THE STATION IDENTIFICATION VIA THE AUDIO PANEL. CREW SCANS THE FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS.
TURN	APPROACH CONTROL VECTORS THE AIRCRAFT TO AN INTERCEPT HEADING. CREW TURNS THE AIRCRAFT TO THE VECTORED HEADING.
ARRIVE AT 2,200 FEET	APPROACH CONTROL CLEARS THE AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES THE ILS OR AUTOLAND. CREW FLIES OR MONITORS THE FLIGHT OF THE AIRCRAFT WITH THE FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS AND THE MARKER BEACONS.

- Concept 1, Centerline Approach — This would use an approach path similar to the ones shown in Figure 14. The procedures are different, depending upon the capture mode. Table 5 lists the tasks for both the track capture mode and the waypoint capture mode.
- Concept 2, Segmented Approach Capture — The approach paths that can be flown by this equipment are shown in Figure 15. The procedures using Concept 2 may vary depending upon how and when the crew selects and verifies the approach path. For this study three methods were selected:

  1) The route is entered and verified before descent. In this case the crew would have to know the approach route before approach control assigns the runway and approach path.
  2) The route is entered and verified after approach control assigns the runway and approach path. This is the scenario most likely to occur.
  3) The approach path is manually entered and verified after approach control assigns the approach path. This scenario would occur if the approach path was not stored in the computer and the crew had no prior knowledge of which approach path would be selected. The scenario is not likely to occur but was used for the analysis to determine the effect on workload.

These scenarios were selected to determine the differences in workload. The most likely scenario is the second one. The first could occur if the flight crew knows which runway and approach path will be assigned. It was assumed that the crew would have enough time to enter and verify the approach path during the cruise phase of flight so that it would not affect normal workload. The last scenario was selected to determine whether it is feasible for the crew to enter an approach scenario into the data base during the initial approach. The guidance functions involved in these scenarios are listed in Table 6.

TABLE 5
CREW GUIDANCE AND CONTROL TASKS FOR CONCEPT 1, CENTERLINE APPROACH

FLIGHT SEGMENT	CREW GUIDANCE AND CONTROL FUNCTIONS	
	TRACK CAPTURE MODE	WAYPOINT CAPTURE MODE
ARRIVE AT APPROACH ALTITUDE	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM APPROACH PLATE AND ENTERS IT VIA MLS CDU. CREW SELECTS ENTER MODE AND APPROACH PATH USING THE NUMBER ON THE APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES WAYPOINTS AGAINST APPROACH PLATE BY ROTATING THROUGH WAYPOINTS ON THE MLS CDU.	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM APPROACH PLATE AND ENTERS IT VIA MLS CDU. CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS WAYPOINT CAPTURE MODE AND RANGE ON MLS CDU AND MLS MODE ON GLARESHIELD.
VERIFY OVER SANTA MONICA VOR	CREW VERIFIES THE STATION IDENTIFICATION VIA THE MLS CDU OR AUDIO PANEL. CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS. APPROACH CONTROL VECTORS AIRCRAFT TO AN INTERCEPT HEADING. CREW TURNS TO VECTORED HEADING. APPROACH CONTROL CLEARS AIRCRAFT FOR FINAL APPROACH.	CREW VERIFIES PUBLISHED AZIMUTH OFFSET ANGLE AND GLIDE PATH ANGLE ON MLS CDU. CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS. APPROACH CONTROL CLEARS AIRCRAFT FOR FINAL APPROACH.
TURN	CREW ENGAGES ILS/MLS OR AUTOLAND. CREW FLIES OR MONITORS AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW AND ALONG TRACK DME.	CREW ENGAGES ILS/MLS OR AUTOLAND. CREW FLIES OR MONITORS AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW AND ALONG TRACK DME.

TABLE 6
CREW GUIDANCE AND CONTROL TASKS FOR CONCEPT 2, SEGMENTED APPROACH CAPTURE

APPROACH PATH ENTERED PRIOR TO DESCENT		
	CREW GUIDANCE AND CONTROL FUNCTIONS	
FLIGHT SEGMENT	TRACK CAPTURE MODE	WAYPOINT CAPTURE MODE
CRUISE	FLIGHT CREW SELECTS ENTER MODE ON MLS CDU AND ENTERS ROUTE NUMBER OBTAINED FROM APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES EACH WAYPOINT ENTRY BY ROTATING THROUGH WAYPOINTS AND CHECKING BEARING, RANGE AND ALTITUDE OF EACH WAYPOINT AGAINST APPROACH PLATE.	FLIGHT CREW SELECTS ENTER MODE ON MLS CDU AND ENTERS ROUTE NUMBER OBTAINED FROM APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES EACH WAYPOINT ENTRY BY ROTATING THROUGH WAYPOINTS AND CHECKING BEARING, RANGE AND ALTITUDE OF EACH WAYPOINT AGAINST APPROACH PLATE.
ARRIVE AT APPROACH ALTITUDE	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY, AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM APPROACH PLATE AND ENTERS IT VIA MLS CDU.	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY, AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM APPROACH PLATE AND ENTERS IT VIA MLS CDU.
VERIFY OVER SANTA MONICA VOR	CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS TRACK CAPTURE MODE ON MLS CDU, AND MLS MODE ON THE GLARESHIELD. CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS.	CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS WAYPOINT CAPTURE MODE AND RANGE ON MLS CDU, AND MLS MODE ON THE GLARESHIELD. CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS.
TURN	APPROACH CONTROL VECTORS AIRCRAFT TO AN INTERCEPT HEADING. CREW TURNS TO VECTORED HEADING. APPROACH CONTROL CLEARS AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES ILS/MLS OR AUTOLAND.	APPROACH CONTROL CLEARS THE AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES ILS/MLS OR AUTOLAND.
ARRIVE AT 2,000 FT	CREW FLIES OR MONITORS AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW AND ALONG TRACK DME.	CREW FLIES OR MONITORS AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW AND ALONG TRACK DME.

TABLE 6

CREW GUIDANCE AND CONTROL TASKS FOR CONCEPT 2, SEGMENTED APPROACH CAPTURE (CONTINUED)

MANUAL ENTRY OF APPROACH PATH AFTER APPROACH CONTROL ASSIGNS APPROACH PATH AND RUNWAY		
	CREW GUIDANCE AND CONTROL FUNCTIONS	
FLIGHT SEGMENT	TRACK CAPTURE MODE	WAYPOINT CAPTURE MODE
ARRIVE AT APPROACH ALTITUDE	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY, AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM THE APPROACH PLATE AND ENTERS IT VIA MLS CDU. CREW SELECTS ENTER MODE AND A ROUTE NUMBER CAPABLE OF BEING PROGRAMMED. CREW SELECTS PROGRAM MODE AND ENTERS BEARING, RANGE, AND ALTITUDE FOR EACH WAYPOINT ON THE APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES WAYPOINTS AGAINST THE APPROACH PLATE BY ROTATING THROUGH THE WAYPOINTS ON THE MLS CDU.	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY, AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM THE APPROACH PLATE AND ENTERS IT VIA MLS CDU. CREW SELECTS ENTER MODE AND A ROUTE NUMBER CAPABLE OF BEING PROGRAMMED. CREW SELECTS PROGRAM MODE AND ENTERS BEARING, RANGE, AND ALTITUDE FOR EACH WAYPOINT ON THE APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES WAYPOINTS AGAINST THE APPROACH PLATE BY ROTATING THROUGH THE WAYPOINTS ON THE MLS CDU.
VERIFY OVER SANTA MONICA VOR	CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS WAYPOINT CAPTURE MODE AND RANGE ON THE MLS CDU, AND MLS MODE ON THE GLARESHIELD.	CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS WAYPOINT CAPTURE MODE AND RANGE ON THE MLS CDU, AND MLS MODE ON THE GLARESHIELD.
TURN	CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS. APPROACH CONTROL CLEARS AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES ILS/MLS OR AUTOLAND.	CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS. APPROACH CONTROL CLEARS AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES ILS/MLS OR AUTOLAND.
ARRIVE AT 2,000 FT	CREW FLIES OR MONITORS THE AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW, AND ALONG TRACK DME.	CREW FLIES OR MONITORS THE AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW, AND ALONG TRACK DME.

TABLE 6
CREW GUIDANCE AND CONTROL TASKS FOR CONCEPT 2, SEGMENTED APPROACH CAPTURE (CONTINUED)

APPROACH PATH ENTERED AFTER APPROACH CONTROL ASSIGNS APPROACH PATH AND RUNWAY		
	CREW GUIDANCE AND CONTROL FUNCTIONS	
FLIGHT SEGMENT	TRACK CAPTURE MODE	WAYPOINT CAPTURE MODE
ARRIVE AT APPROACH ALTITUDE	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY, AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM APPROACH PLATE AND ENTERS IT VIA MLS CDU. CREW SELECTS ENTER MODE AND APPROACH PATH USING THE NUMBER ON THE APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES WAYPOINTS AGAINST THE APPROACH PLATE BY ROTATING THROUGH WAYPOINTS ON THE MLS CDU.	APPROACH CONTROL ASSIGNS APPROACH PATH, RUNWAY, AND CAPTURE MODE. CREW READS MLS CHANNEL NUMBER FROM APPROACH PLATE AND ENTERS IT VIA MLS CDU. CREW SELECTS ENTER MODE AND APPROACH PATH USING THE NUMBER ON THE APPROACH PLATE. CREW SELECTS DISPLAY MODE AND VERIFIES WAYPOINTS AGAINST THE APPROACH PLATE BY ROTATING THROUGH WAYPOINTS ON THE MLS CDU.
VERIFY OVER SANTA MONICA VOR	CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS WAYPOINT CAPTURE MODE AND RANGE ON THE MLS CDU AND MLS MODE ON THE GLARESHIELD.	CREW VERIFIES STATION IDENTIFICATION VIA MLS CDU OR AUDIO PANEL. CREW SELECTS WAYPOINT CAPTURE MODE AND RANGE ON THE MLS CDU AND MLS MODE ON THE GLARESHIELD.
TURN	CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS. APPROACH CONTROL CLEARS THE AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES ILS/MLS OR AUTOLAND.	CREW SCANS FLIGHT MODE ANNUNCIATOR FOR OPERATIONAL STATUS. APPROACH CONTROL CLEARS THE AIRCRAFT FOR FINAL APPROACH. CREW ENGAGES ILS/MLS OR AUTOLAND.
ARRIVE AT 2,000 FT	CREW FLIES OR MONITORS THE AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW AND ALONG TRACK DME.	CREW FLIES OR MONITORS THE AIRCRAFT WITH FLIGHT DIRECTOR, COURSE DEVIATION INDICATORS, COURSE ARROW AND ALONG TRACK DME.

RESULTS

Since the ground tracks vary for the baseline, centerline-capture, and segmented approach scenarios, it is difficult to compare the workload indexes on the same time scale. Therefore, instead of using a time base, the workload indexes were compared for each flight segment. This gives a better comparison of workload differences between the MLS and ILS scenarios. However, this type of presentation makes each flight segment appear equivalent in time, when some are actually ten times longer than others. This also makes workload comparisons difficult because the workload indexes are averaged over time. Therefore, short segments will vary more than long ones.

Table 7 shows the differences in segment flight time for each of the scenarios. The differences occur between arrival at approach altitude and through to threshold. The ILS baseline has the longest time, 14.72 minutes, and the track capture mode of the centerline scenario has the shortest time, 12.54 minutes. The other MLS scenarios have approximately the same time, ranging from 12.58 to 13.17 minutes.

TABLE 7
COMPARISON OF FLIGHT TIMES FOR THE SCENARIOS*

		CENTERLINE CAPTURE		SEGMENTED APPROACH	
FLIGHT SEGMENT	ILS BASELINE	TRACK	WAYPOINT	LEG	WAYPOINT
ARRIVAL AVENAL	3.20	3.20	3.20	3.20	3.20
DESCEND TO 10,000	13.33	13.33	13.33	13.33	13.33
VERIFY FILLMORE	4.25	4.25	4.25	4.25	4.25
ARRIVE SADDE	0.57	0.57	0.57	0.57	0.57
ARRIVE APPROACH ALTITUDE	2.83	3.49	3.49	3.49	3.49
VERIFY SANTA MONICA	4.67	3.67	3.56	3.79	3.58
TURN	1.70	1.76	2.98	0.74	2.27
ARRIVE AT 2,200	2.95	0.70	0.27	2.21	0.40
FLY TO THRESHOLD	2.57	2.92	2.87	2.84	2.84
TOUCHDOWN	0.14	0.14	0.14	0.14	0.14
ROLLOUT	0.80	0.80	0.80	0.80	0.80
TOTAL	37.01	34.83	35.46	35.36	34.87

*ALL TIMES IN MINUTES

Concept 1 — Centerline Approach

Figure 16 presents the comparison of the workload indexes for the track and waypoint capture modes with the ILS baseline for both the captain and first officer. Differences between the results are minor for both crew members. The MLS scenarios show a slight increase in workload after approach control assigns the approach path. This increase is due to the shorter time for this flight segment in the MLS

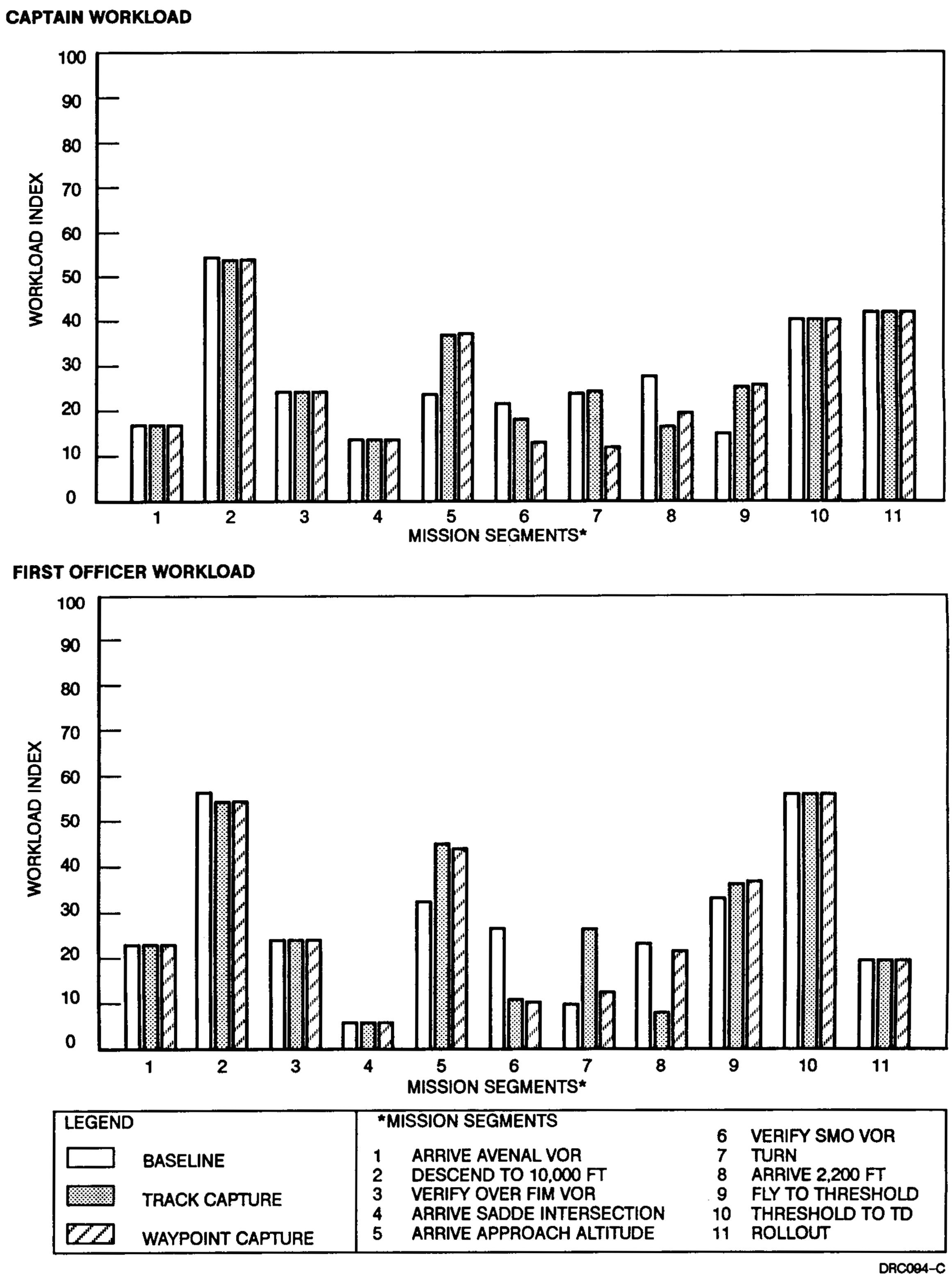

FIGURE 16. CENTERLINE APPROACH WORKLOAD

scenario and the crew actions required to set up the CDU. In the MLS scenarios there are workload savings for the captain at the turn to the intercept heading. This is most notable in the waypoint capture mode and is due to the absence of ATC vectoring. There is little difference between the scenarios for external vision availability, as shown in Figure 17. If anything, there is more time available in the MLS scenarios.

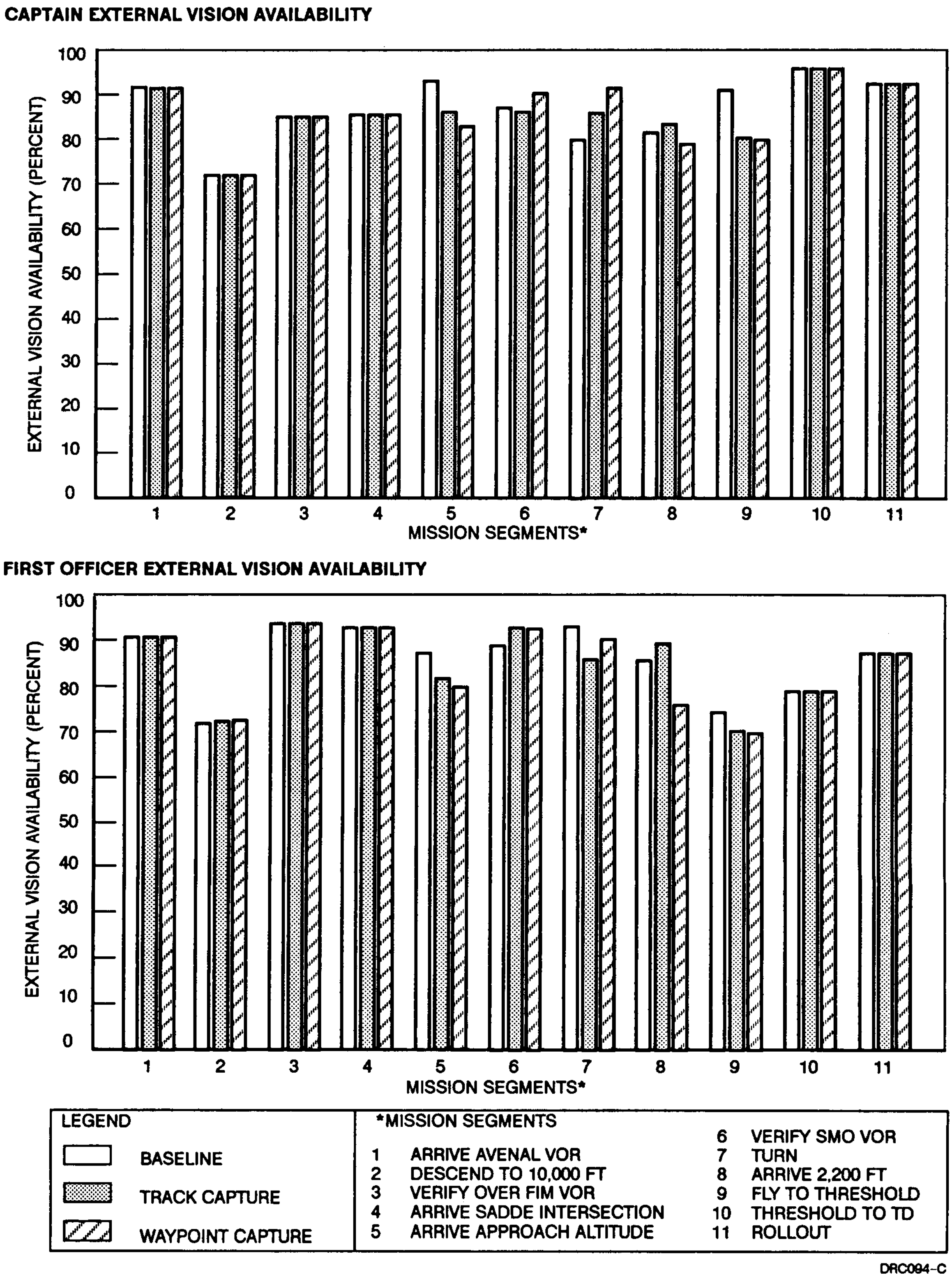

FIGURE 17. EXTERNAL VISION AVAILABILITY FOR CENTERLINE APPROACH

Concept 2 — Segmented Approach

For these scenarios the increase in workload is due to the selection and verification of the approach paths. As described earlier, three scenarios were evaluated: (1) entering and verifying the approach path before descent, (2) entering and verifying a prestored path after approach control assigns the runway and approach path, and (3) manually entering and verifying the waypoints after approach control assigns the runway and approach path. The workloads vary depending on the time in which these tasks are completed.

Figure 18 presents the workload indexes for the captain and first officer when the approach path is entered before the descent phase. The workload indexes are similar to the centerline capture modes and there appear to be few workload differences between the MLS scenarios and the ILS scenario. Again there is a workload savings for the captain at the turn to intercept heading, due to less vectoring. Head-down time is approximately the same for all these scenarios, as indicated by the external vision availability in Figure 19.

Figure 20 presents the workload indexes for entering the approach path and its verification after approach control assigns the runway and approach path. The figure shows a notable workload increase, compared to the ILS baseline, for the flight segment where approach control assigns the runway and the crew enters and verifies the approach route ("Arrive at Approach Altitude"). The captain's workload increases from 25 to 60 percent, and from 33 to 65 percent for the first officer. Head-down time increases from 8 percent to about 40 percent for both the captain and first officer, as indicated by the external vision availability in Figure 21.

Figure 22 shows the workload indexes for manually entering of the waypoints after approach control assigns the runway and approach path. This figure shows that the captain's and first officer's workload is greater than the time available. This is due to the time required to enter the waypoints one at a time and to verify the entries. However, it is possible that part of this activity could carry over to the next flight segment. Figure 23 shows that the time required for these tasks is head-down time and less than 5 percent of the time is available for external vision.

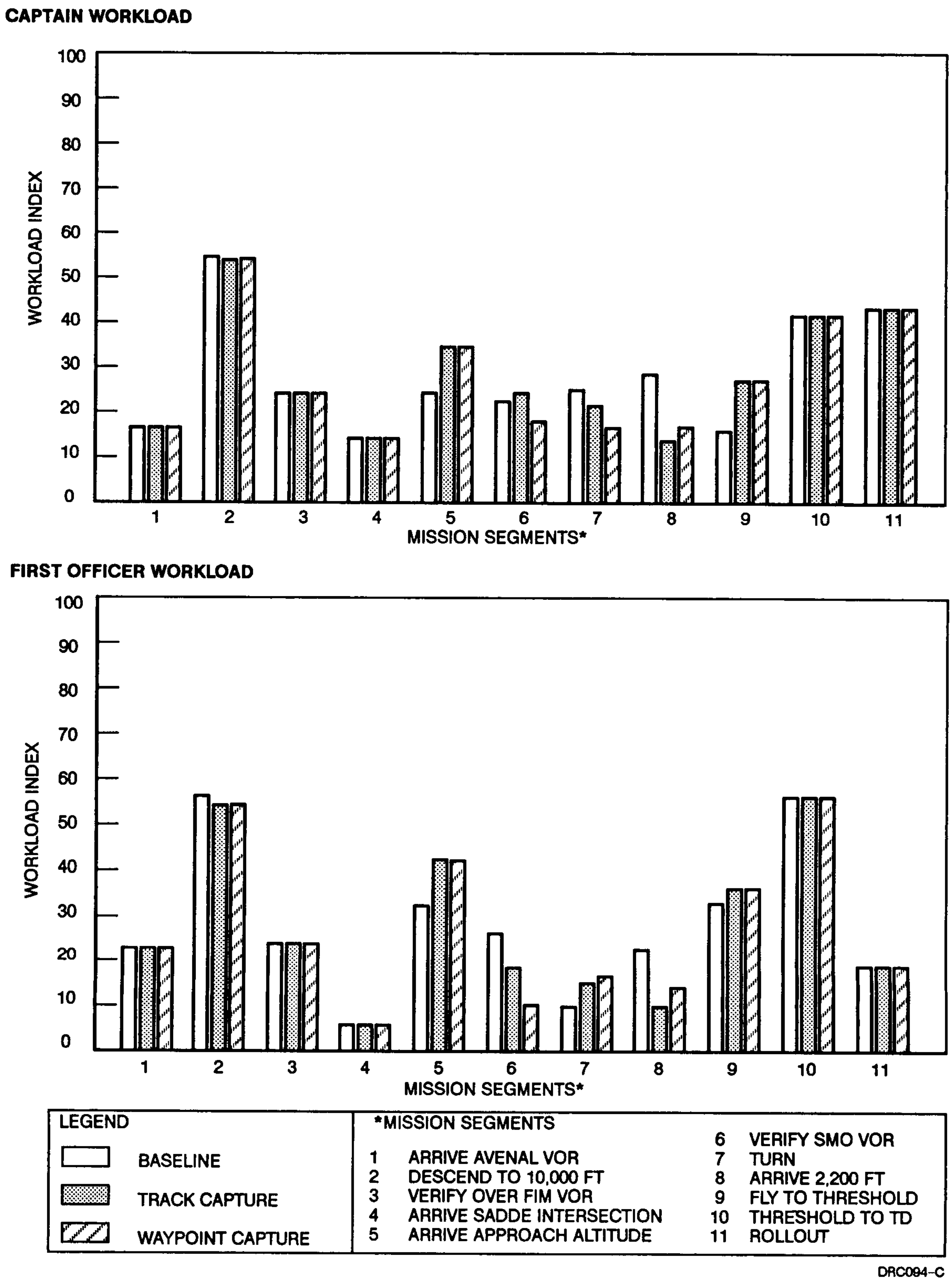

FIGURE 18. SEGMENTED APPROACH WORKLOAD WHEN ROUTE IS ENTERED PRIOR TO DESCENT

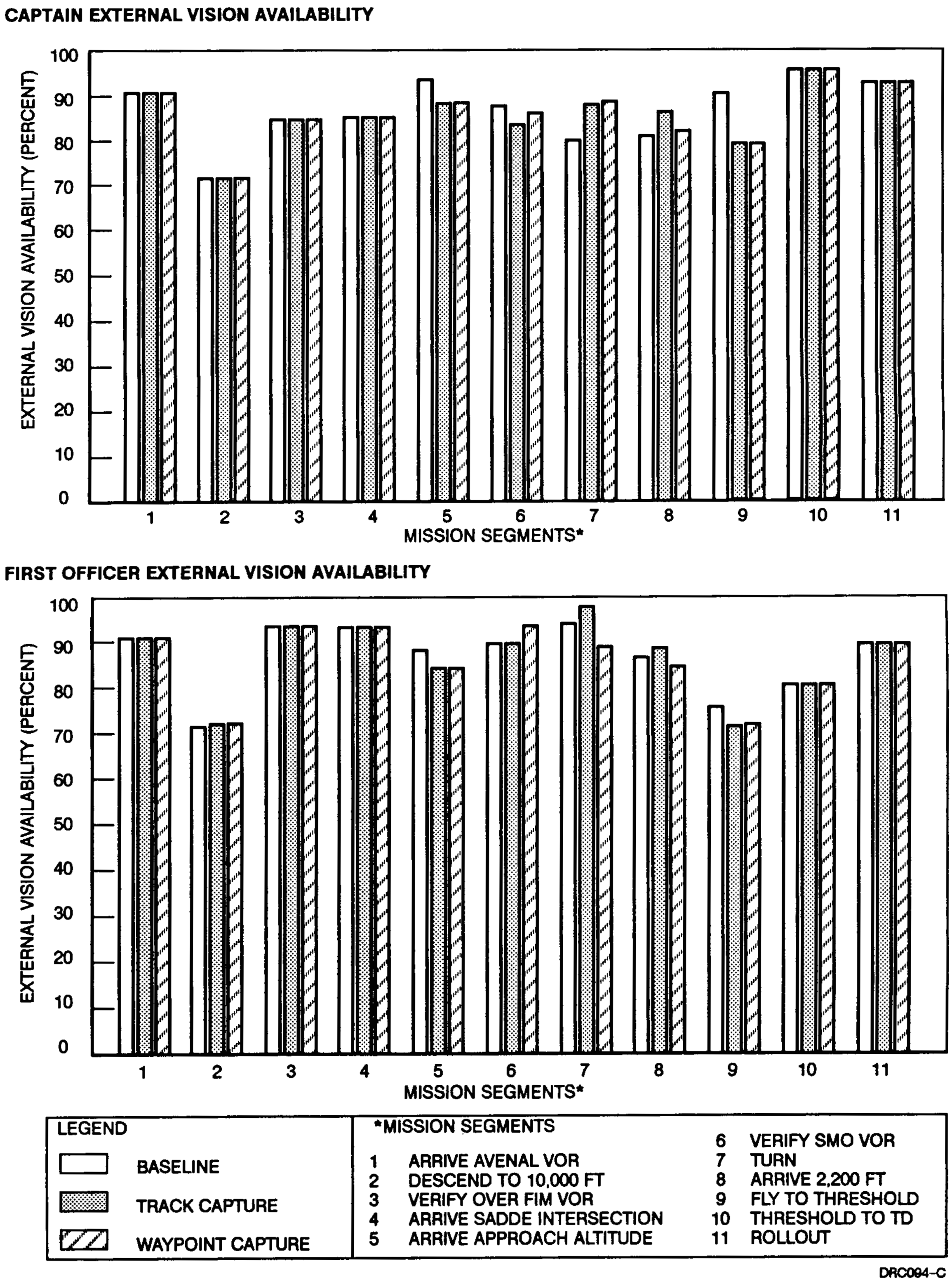

FIGURE 19. EXTERNAL VISION AVAILABILITY FOR SEGMENTED APPROACH WHEN ROUTE IS ENTERED PRIOR TO DESCENT

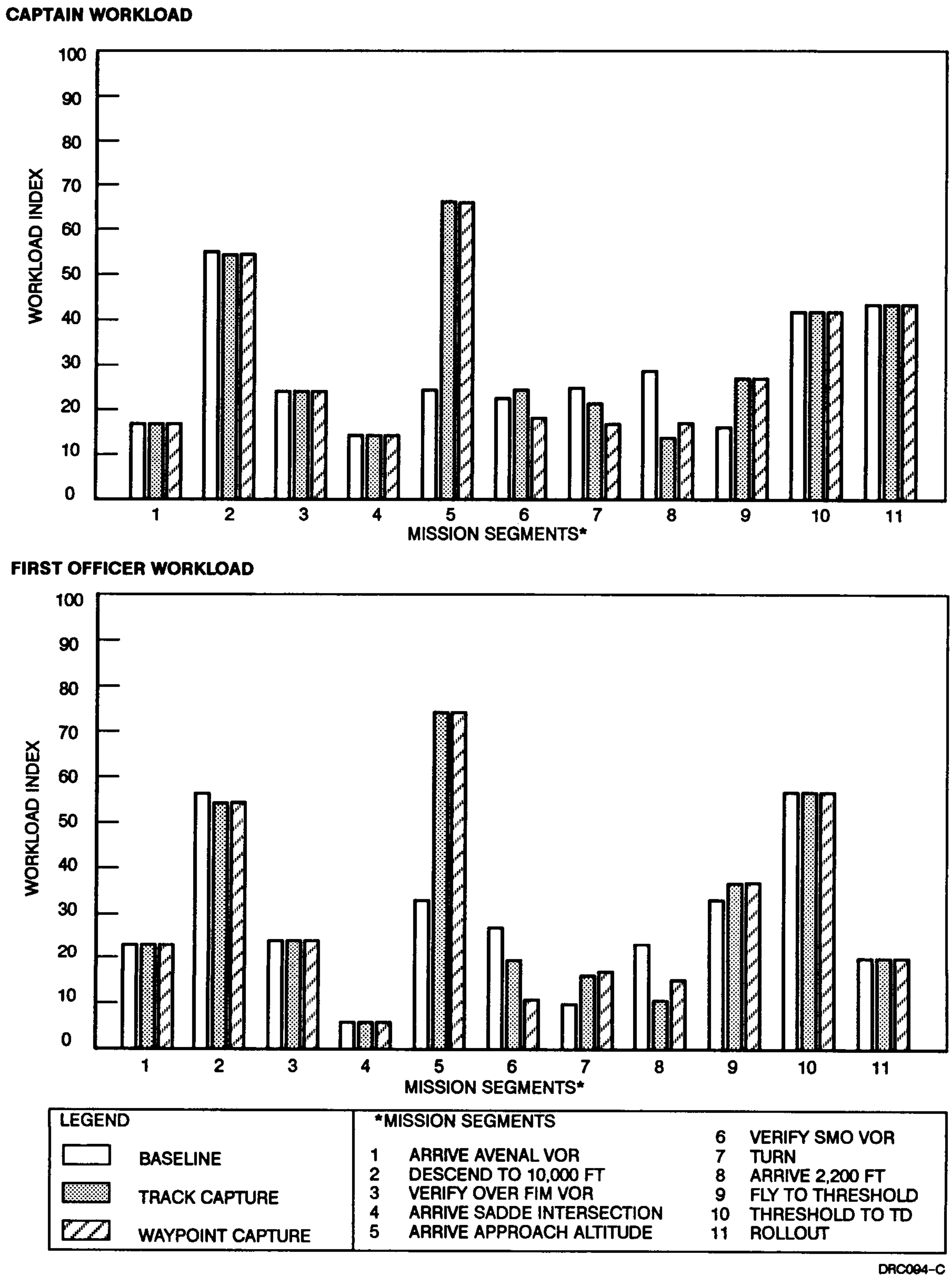

FIGURE 20. SEGMENTED APPROACH WORKLOAD WHEN ROUTE IS ENTERED AFTER APPROACH CONTROL ASSIGNS RUNWAY

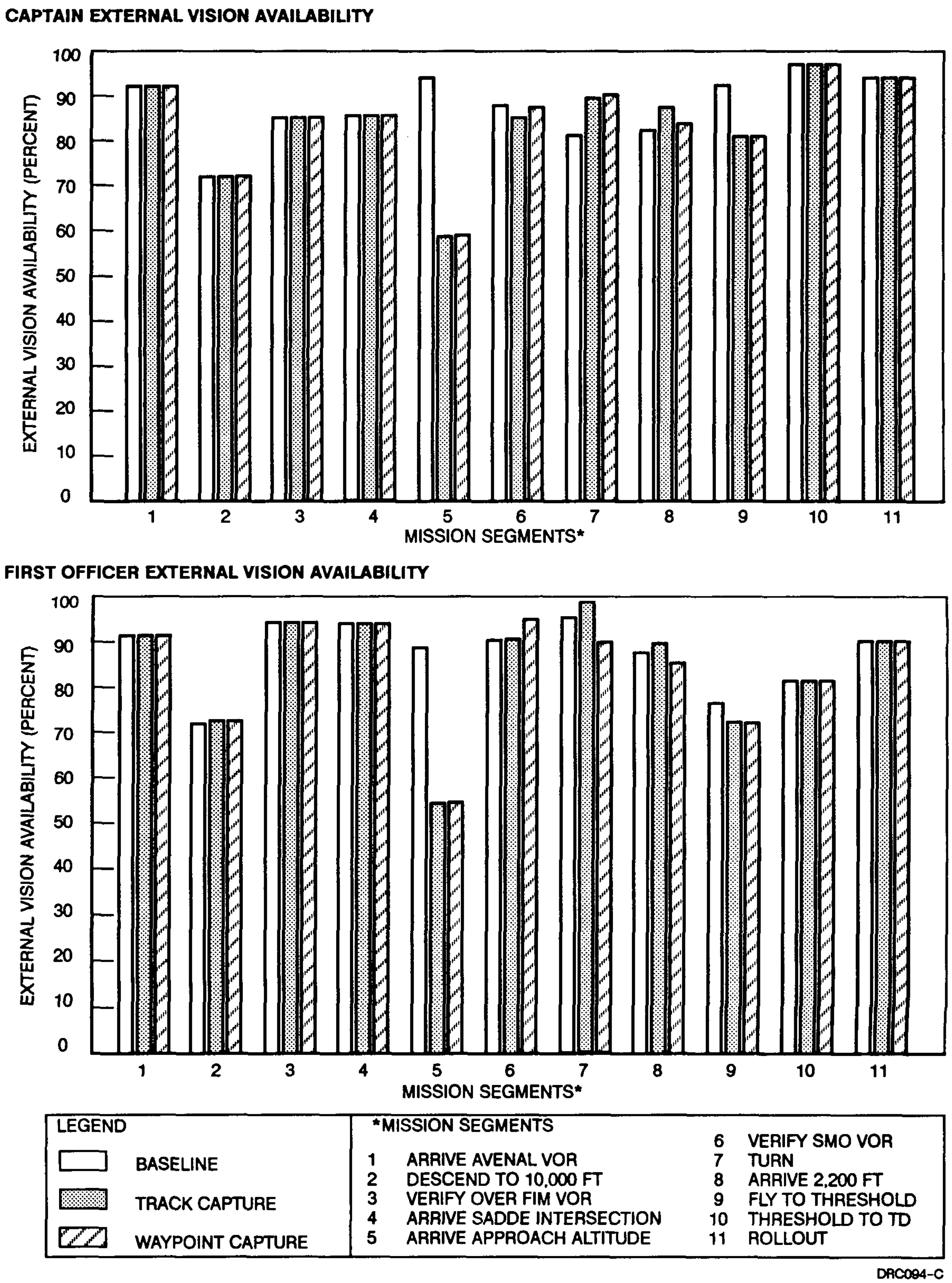

FIGURE 21. EXTERNAL VISION AVAILABILITY FOR SEGMENTED APPROACH WHEN ROUTE IS ENTERED AFTER APPROACH CONTROL ASSIGNS RUNWAY

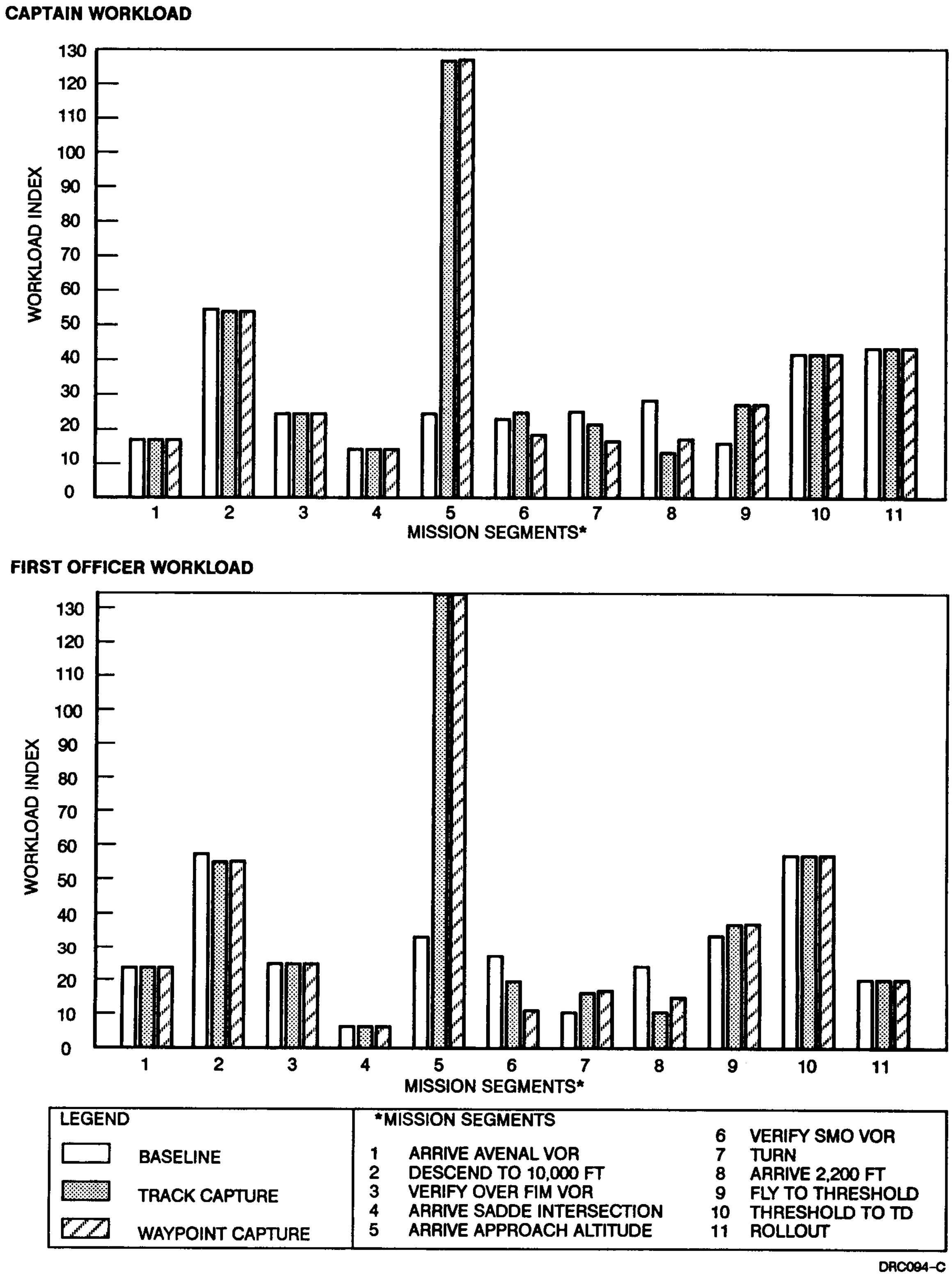

FIGURE 22. SEGMENTED APPROACH WORKLOAD WHEN ROUTE IS PROGRAMMED AFTER APPROACH CONTROL ASSIGNS RUNWAY

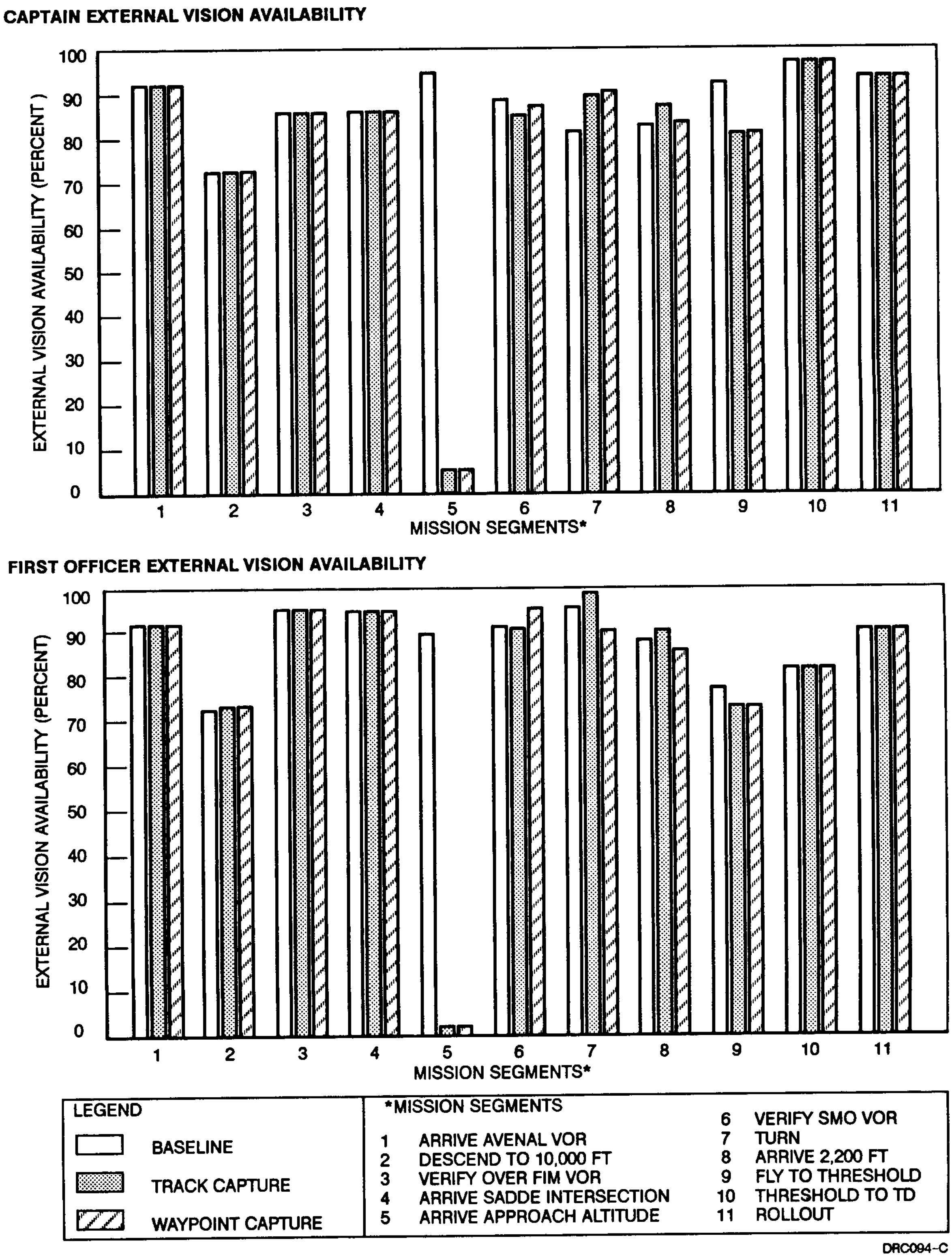

FIGURE 23. EXTERNAL VISION AVAILABILITY FOR SEGMENTED APPROACH WHEN ROUTE IS PROGRAMMED AFTER APPROACH CONTROL ASSIGNS RUNWAY

DISCUSSION

Depending on the equipment concept, the workload for MLS operations may be significantly higher than the ILS baseline. For Concept 1, centerline capture approaches, the only significant increase in workload is for path selection and verification. This requires more head-down time when the aircraft reaches approach altitude. The workload is reduced for the remaining flight segments until centerline capture, primarily because less radar vectoring is required by approach control.

For Concept 2, segmented path capture, the workload is notably higher depending on the time the approach path is selected and verified. Normally the path is selected after approach control assigns the runway. This requires a significant, 40-percent increase in crew activity and 30-percent increase in head-down time. This activity occurs after the aircraft has descended to the approach altitude and is in a high-traffic area. The crew's primary activity should be heads-up, so that they are aware of traffic and their flight path. For the crew to manually enter the approach path during this phase, more time is required for both body actions and head-down activity than is feasible. The only scenario where path selection or path entry does not significantly affect workload is when it occurs before final descent.

If the crew is not required to verify the approach path, the activity for route entry is reduced and it would be approximately the same as for the centerline approaches. In the previous study (Reference 1) the MLS receiver was coupled to the flight management system and a complete approach page was displayed on the flight management system CDU. This reduced the time the crew needed to scan and verify the approach route.

In the current study, the crew workload for the centerline approach mode increased from 30 to 40 percent for the flight segment where the crew was required to select and verify the approach path. Since the workload was not greater than 50 percent, it is considered within acceptable limits. The capture modes proposed by Erkelens have other benefits compared to the ILS baseline, such as reducing the amount of radar vectoring and providing the capability to fly precision approaches consisting of two legs. On the other hand, the segmented approach mode using a small multifunction control unit required a notable increase in crew activity and is not considered feasible.

Although this analysis considers the increase in activity for monitoring the flight instruments while under MLS guidance, it does not take into account the mental activity that occurs with this monitoring activity. Also, this analysis considers only the autopilot mode of operation and there would be a significant workload increase for the crew to manually fly the aircraft with the flight director. This increase would be greater for the MLS scenarios than for the ILS scenario due to the changes in course.

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16. Abstract

The objective of the study was to evaluate crew procedures and workload for MLS systems that could be retrofitted into existing transport aircraft. Two MLS receiver concepts were developed. One is capable of capturing a runway centerline and the other is capable of capturing a segmented approach path. Crew procedures were identified and crew task analyses were performed using each concept. Crew workload comparisons were made between the MLS concepts and an ILS baseline using a task-timeline workload model. Workload indexes were obtained for each scenario. The results showed that workload was comparable to the ILS baseline for the MLS centerline capture concept, but significantly higher for the segmented path capture concept.

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