ACES
Aircraft Command in Emergency Situations

Federal Aviation Administration
Contract No. DTFA03-89-C-00061

Presented to
Wichita State University
Institute of Aviation Research

Aircraft Interiors 1990 Conference
April 24-25, 1990

Presented by
Thomas L. Reynolds, Sr.
Program Manager
(206) 234-4394

Boeing Commercial Airplane Group
P.O. Box 3707
Seattle, Washington 98124

Aircraft Command In Emergency Situations (ACES)

Current Status and Findings

Thomas L. Reynolds, Sr.
Program Manager
Boeing Commercial Airplane Group

The purpose of this paper is to describe a technical study, currently under contract with the FAA Technical Center, which will define two advanced inflight smoke/fire detection systems for commercial jet aircraft. The objective of this study is to identify the system criteria that will provide for accurate, timely, and complete guidance to the flight crew for their use in responding to possible and/or actual inflight smoke and fire events within the pressurized fuselage.

Introduction

The motivation for this work is the computerization of the modern commercial jet aircraft flight deck, the evolution toward the two-man flight crew, and the documented times taken to locate and implement the appropriate emergency procedures once the emergency has been determined. The primary objective of the ACES system is to provide the capability to reduce the time required for the flight deck crew to make a decision to land the aircraft.

Contract Study

The approach to developing this study is to: review aircraft requirements and previous studies; develop the necessary database on existing and new sensors and detectors, i.e., sensor and detector performance capabilities and availability; develop the "concept" requirements for each of the proposed detection approaches; identify the necessary flight deck interface requirements for both sensor system status inputs and communications. These data are being generated with the Boeing 757 being used as the study baseline model because of its advanced flight deck, Class C cargo compartments, and passenger cabin (lavatory) smoke and fire detection capability.

In developing the requirements for the two systems (Concepts "A" and "B"), the two types of smoke/fire alerts were addressed: those where the corrective action was initiated by the flight deck, and those initiated by the cabin crew. Several particular parameters were identified as absolutes for configuring the detection and communication systems. These were:

Sensing – To provide for earlier detection of smoke, fire, and hot spots, and to minimize false alarms by trend monitoring and concurrence of other sensors.

Alerting – To improve the quality of information to the flight deck by providing definitive information on the nature of the alert, a more precise location of the problem, and the type of problem, i.e., smoke, flame, or heat.

Crew Response – Minimize the crew response time by automating the emergency procedures checklist and the verification process, and implement an inflight planner which would automatically provide diagnostic capability and rerouting to alternate airports.

Decision Making – Establish a high level of system reliability which will foster crew confidence and contribute to maximizing the time available to the flight deck for decision making.

The ACES system concepts have been defined to address major inflight fires resulting in the loss of life and aircraft, concealed and "hidden" smoke and fire sources, cabin smoke and fire events, and false alarms–a problem source which contributes to aborted flight plans, irate passengers, and damage to the carrier's reputation. Fires which originate in the engines, APUs, or wheelwells are not part of this study.

Sensor and detector technology reviewed during the course of this study has included, but has not been limited to, equipment currently available commercially, the locations where sensors are currently installed in the aircraft, where additional detection can be beneficial, and new advanced technology sensors.

Current Technology Sensors

Sensor technology currently in use in the commercial aviation industry and considered for this study consists primarily of ionization and photoelectric particle and smoke detectors. Several other types of detectors, such as thermal, optical, and gas detectors, were also being considered, but were excluded because of application considerations.

Photoelectric detectors, Figure 1, operate on the principal of reflected light, whereby smoke particles entering the detector cause a beam of light to be scattered and detected by a photoelectric cell, thereby initiating an alarm. The ionization detector, Figure 2, utilizes an alpha particle source to ionize two chambers. The influx of particles into one chamber causes a bias with the reference voltage and initiates an alarm.

Current Usage

The predominant locations for the photoelectric and ionization detectors within the pressurized areas of the aircraft are in the lavatories and cargo bays. For some aircraft, detectors are also installed in the lower electronic (E/E) bays.

The Boeing 757-200 aircraft utilizes a five-port sampling tube to collect air samples in the Class C cargo bays and passes the air through two photoelectric smoke detectors coupled with "and" logic, Figure 3. Ionization detectors are installed in the lavatories, and photoelectric detectors in the forward E/E bays. Detectors in the Class C cargo bays and E/E bays are linked to the flight deck Master Caution and Warning System, Figure 4. A dual-bottle Halon fire suppression system is installed for the lower cargo bays. The passenger cabin smoke/fire detectors located in each lavatory are standalone, "home type," and are not connected to the flight deck data bus. A customer option which provides for interfacing each of the detectors to the aircraft crew warning system, attendant call lights, and in some instances, to the Engine Indicating and Crew Alerting System (EICAS) displays, is offered on each of the Boeing aircraft.

The Airbus A320 also has the smoke detection system for the lavatory detectors connected to the flight deck warning system and provides an alert to the cabin attendants.

Advanced Sensors

New sensor and detector technologies are being investigated for application in the ACES system include the Acoustic Wire Temperature Sensor (Schlumberger), Fiber Optic Distributed Temperature Sensing (York), Thermal Imaging Module (HTL), and Multiple Pulse Coincidence Circuits (Gamwell).

Acoustic wire detectors, Figure 5, utilize an ultrasonic transducer to transmit an acoustic pulse down a steel wire. The temperature of the wire affects the speed of the returned acoustic signal, hence, through signal processing, the temperature can be ascertained to within 1°F. "Zones" are created by placing crimped rings on the wire at selected intervals, creating distinguishable nodal points. The temperatures in the zones can be determined, again by processing the returned signal from each of the zones. This type of system has very rugged operational characteristics and high temperature capability.

Fiber-optic distributed temperature sensors, Figure 6, utilize the scattering properties of a pulse of light from a laser diode passing through an optical fiber to determine temperature. As light passes through the fiber cable, Raleigh scattering occurs, a process by which light is reflected equally in all directions, some of which returns via an optical coupler, to an optical time domain reflectometry-type detector. By modulating the scattering loss coefficient and temperature, the Raman component (anti-Stokes) can be used to determine the temperature along the fiber because of its sensitivity to temperature changes. Fiber losses are negated by transmitting the lased pulse from each end of the fiber and canceling the noise components of the signal.

Thermal Imaging Module (TIM), Figure 7, is a rotating and scanning sensor which operates in dual infrared (IR) bands with thermal sensing capability. TIMs have a constant 90-deg field of view over a 24 foot diameter. The primary output indicates that the optical overheat IR threshold has been exceeded. The secondary output warns of the presence of flame signature. The tertiary output indicates that the body temperature has exceeded 85°C.

Multiple pulse coincidence circuit detectors (photoelectric) do not initiate a smoke warning until four consecutive pulses have been received over an 8-second interval. The alarm signal can be connected through an "and" gate and displayed on the lower EICAS panel. This sensor should significantly reduce the false alarm incidents commonly associated with photoelectric and ionization detectors.

Smoke/Fire Incidents

To determine where to best position smoke and fire detectors, a comprehensive review of incident and accident data files was undertaken. During the period from January 1974 through September 1989, there were 822 smoke and fire incidents (both ground and inflight) aboard commercial jet aircraft which resulted in 6 accidents involving the loss of life. These incidents were further analyzed to determine which were inflight incidents only, and what was the origin of the smoke and fire. There were 558 inflight incidents of smoke and/or fire during this 15-year period. Of these 558 inflight incidents, the majority originated in the galley, followed by those in the lavatory, and lastly, those in the passenger cabin. Cargo bay fires were the source of the three fatal accidents.

Put into proper perspective, during this same period of time, the airlines of the free world recorded 158-million departures, a remarkable safety record. However, analysis of these grim statistics is often necessary in order to provide some of the insight necessary to determine how to best design more capable and reliable smoke and fire detection systems.

Boeing Study Aircraft

The Boeing 757-200 was selected by our ACES proposal team to be the baseline aircraft for the purposes of this study. The general arrangement and interior features of this aircraft are shown in Figures 8, 9, and 10.

The 757 utilizes a centralized Environmental Control System (ECS) which receives engine bleed air and cooled outside ram air to maintain cabin and flight deck temperatures. The forward and aft passenger cabins are fed separately from the flight deck and lower E/E bays, Figure 11. Lavatory and galley vents are routed to an aft pressurized compartment which discharges overboard through an outflow valve. Flight deck and cabin air is used to cool the E/E bay and cargo compartments, then returned to the mix manifold to be reconditioned with fresh conditioned air, Figure 12. Recirculation systems such as this can contribute to the problem of trying to diagnose the source of a smoke event once the smoke enters the ECS. For instance, smoke entering the cabin could be coming from contaminated bleed air from one of the engines. Current procedures to determine which air pack or engines is the source of the smoke are time consuming and experimental. Our study has found that relatively simple modifications to existing designs could be incorporated on new aircraft that would eliminate the experimentation currently required.

In addition, a self-calibrating smoke detector that would mount in the compartment of the outflow valve (discharge) is under consideration. This unit would sense smoke emanating from any of the lavatory, galley, or equipment bay vents that would subsequently pass through the outflow valve.

Concept "A"

The ACES Concept "A," Figure 13, is an enhanced detection capabilities version of the existing 757-200. Two types of alerts are addressed: those that would be addressed by the flight deck, including cargo smoke/fire, forward E/E bay smoke, air-conditioning smoke from the air packs, and attic smoke/overheat. The cabin crew would address smoke/fire events associated with the lavatories, galleys, and open cabin.

Three principal changes have been proposed which would improve the smoke/fire detection capability of the ACES baseline aircraft. These are: the addition of (6) Gamwell RT7 Multiple Pulse Coincidence Circuit photoelectric detectors in the ceiling to provide additional coverage, and two each in the cargo compartments, (Figure 14); installation of Jamco PU90-461R3 ionization detectors in the ceiling and close to the wastepaper bin in the lavatory to provide additional detection capability, Figure 15; installation of Geamatic air-conditioning duct smoke detectors upstream of the air packs; installation of master attendants panels at the crew stations; and interface of all smoke and fire detectors to the Engine Indication and Crew Alerting System (EICAS) data bus and Master Caution and Warning Panel on the flight deck.

Attendants Panel

The function of the attendants fire control panel, Figure 16, is to indicate which of the detectors have been activated, and to provide an immediate notice to the flight deck and to the cabin crew. The attendants panels interface with the EICAS data bus and provide the capability for both verbal and nonverbal communications with the flight deck.

Nonverbal communication with the flight deck can be accomplished while the cabin crew is investigating the problem by pressing the flashing light/button on the cabin attendants panel, changing it from a flashing to a steady-state light in the cabin and on the flight deck. This will serve to notify the flight deck that the problem is being investigated. Upon initiation of the detector warning, the EICAS will display the warning on the Master Caution and Warning Panel and lower EICAS display. The automated emergency procedure can be selected from the EICAS display while the cabin crew is assessing the nature and severity of the problem, and be in place for activation should it be required. Automation of the emergency procedures manual (QRH) will reduce the long documented time required to locate the proper response and initiate the proper procedure.

Concept "B"

The ACES Concept "B," Figure 17, incorporates all the features and capabilities of Concept "A" but, in addition, has several other expanded advanced technology detection features that have the potential to enhance thermal and flame detection capability and status monitoring as well.

Two advanced technology detectors under study include the acoustic wire and fiber-optic cable detectors, both previously described. These types of sensors are being considered for application in hidden areas of the aircraft, such as behind sidewalls and cargo liners, above ceiling panels, and below cargo bay flooring. The fiber-optic cabling can also be imbedded in high-current power distribution harnesses for detection of overload (heating) conditions. Current fiber-optic technology limits zone resolution to approximately 7 meters due to the pulse repetition frequency of the laser. Higher PRF rates, i.e., shorter pulse durations, will increase resolution. Currently, the technique for "spot" temperature measurements is coiling lengths of the cable on a spool. One significant advantage of the fiber cable over the solid wire is its lower susceptibility to damage. The fiber cable can be cut and still provide temperature data since the signal is fed from both ends, whereas the solid cable loses all data beyond the point of the break. Fiber-optic cables can be repaired with a connector with minimal signal loss; the solid cable cannot be repaired. Replacement, if necessary, is significantly easier with the fiber cable than with the solid wire.

The implementation of a thermal monitoring system, in conjunction with the smoke/fire detectors, will provide for a redundant capability and afford the opportunity for the system to check itself. If smoke is detected by one of the detectors, the thermal sensor will measure the heat buildup or possibly confirm if it is a false alarm. Being able to monitor inaccessible and hidden areas is a particular interest, as a fire originating in these areas can become catastrophic if it remains undetected.

Undetected smoke/fire events are of particular concern in combi-type aircraft where passengers and cargo are both located on the main deck. How to properly address this issue and the requirements for a corrective regulation are currently the subjects of frank discussions between the regulatory agencies and industry.

Several approaches are currently being considered, including installation of more and newer types of sensors, a roving "firefighter," and converting the combi Class B compartments to Class C. (Note: Class B compartments have detection but not suppression capability; Class C has both capabilities.) Whatever the final results, there are two major considerations: detect the smoke/fire earlier (60-second rule) and respond accordingly, either by extinguishing (install a Halon system in a Class C compartment) or send in the roving firefighter if the compartment remains Class B. In either event, good reliable communications are required from both the aircraft systems to alert the flight deck to the nature and severity of the problem, and with the cabin crew for proper action and communications on their part.

Concept "B" sensors will interface with the EICAS system and the Master Caution and Warning Panel to provide timely alerts. Automation of the emergency procedures will further enhance the flight crew's response time and their ability to make decisions earlier.

Flight Deck Design Philosophy

Automation is often viewed as the answer to the problems on the flight deck. Human errors, cockpit work overloads, and lack of operator dependability are problems that warrant automation approaches. Improper judgment of a situation is often the major cause of accidents. According to *Flight International Magazine*, January 17-23, 1990 issue, human error contributed to 66% of the "total loss" accidents between 1986-1988, and for 60% of all fatal airline accidents during the previous decade.

Avionics and flight control systems are being implemented by which the system operates and the human monitors. However, the human has proven not to be an effective monitor, or in some cases has chosen to delay responding until a second source of confirmation is found. There has been some justification for this in the case of smoke detectors which have had a tendency to produce false alarms.

The basic philosophical approach to the design of the ACES system is that the equipment is on board to assist the pilot to do his/her job. The equipment is not there as the ultimate decision maker, but rather, is subordinate to the pilot's discretion and legal responsibility. One of the first considerations is to decide what automation should do to help the pilot, not what it can do. The second consideration is to decide how the needed information can best be displayed. Flight deck improvements should be toward development of an error-tolerant system in which alerting algorithms or automated systems provide a protective "envelope" around crew actions.

ACES Flight Deck Features

The existing 757-200 flight deck alerts and displays are used on the ACES system for both Concepts "A" and "B" and are shown in Figure 18. Warning, caution, and advisory messages are displayed on the upper EICAS display panel.

The ACES Concept "B" system will provide an electronic checklist to replace the Quick Reference Handbook. An inflight planner and synoptic display graphics will be presented in the lower EICAS panel. Enhanced cabin attendant/flight deck communications will be provided with the addition of the cabin attendants fire control panel previously discussed. The existing master caution and warning lights and the aural speakers are retained to gain the flight crew's attention, Figure 19.

Electronic Checklist Demonstration

The pilots Quick Reference Handbook, which provides emergency procedures, will be automated to provide an electronic checklist that will be displayed on the lower EICAS display panel, Figure 20. The electronic checklist will be customized to the event, location, and flight phase; prioritized for the proper sequence of checklist items; and used to track completed, remaining, and intransit steps in each of the procedures. The checklist can also be integrated with other active alerts, be closed loop in design to provide feedback when an event is complete, and provide for enhancements afforded with the implementation of an expert system.

Synoptic Display–Layout

The menu selectable synoptic display currently being studied for the ACES Concept "B" is shown in Figure 21. This system has the capability to display information useful in assessing the progress of the emergency. Features such as the location of the event, type of detector activated, previous history or trend, and feedback on the effects of extinguishing actions can be displayed. It should be emphasized here that these are R&D development tools and that there is no intention for the flight deck crew to conduct exhaustive diagnostics of an emergency warning before responding to the alert, but rather it is, and shall be, their primary function to fly the airplane to the nearest suitable airport.

Synoptic Display–Sensor Signatures

For demonstration purposes, assume that a smoke/fire warning is detected in the lower aft cargo bay, Figure 22. The current procedure requires firing the Halon bottle (Class C bay), then waiting 80 minutes or upon landing approach to fire the second bottle. Diversion to an alternate airport is the pilot's option. If the aircraft is on an overwater flight, then the flight deck crew may want to have more information available to verify the conditions within the aircraft after the initial checklist has been performed.

Synoptic Display–Extinguisher Feedback

The heat/smoke history of the detector can be displayed on the lower EICAS display and monitored to provide trend data to the crew, Figure 23. This may be useful in eliminating the uncertainty regarding the possibility of false alarms. Under conditions of a smoke/fire warning, if the Halon bottle is discharged, the ambient temperature can be monitored to determine the effectiveness of the extinguisher or if the second bottle should be immediately fired.

The Inflight Planning Assistant

The Inflight Planning Assistant, Figure 24, is a decision aid tool being developed as an expert system on Boeing IR&D. It has the capability to provide a list of options to the flight deck crew. Based on embedded expertise, information such as alternate airports, heading and flying time, weather conditions, and emergency equipment available at each of the prospective landing sites would be immediately available to aid the flight deck crew in selecting an airport in which to divert. The use of the inflight planning tool allows the pilots to concentrate on the critical factors required to make timely and accurate decisions.

Cabin Water Spray Disbenefits Study

Transport Canada Aviation Group
Technical Development Center
Montreal, Quebec, Canada

In June 1989, Boeing Commercial Airplane Group responded to a request for proposal from Transport Canada Aviation Group for a "Study of the Disbenefits Created by the Installation of Water Spray Systems for the Protection of Aircraft Cabins." This study was to address the potential "disbenefits" of both commanded and uncommanded operation of a "SAVE" Ltd. cabin water spray system when installed in a commercial jet passenger aircraft, Figure 25.

The 10-month study is designed to be a broad wide-ranging investigation of water spray systems–their effect on the aircraft systems and emergency evacuation of the aircrafts, in both commanded and uncommanded operation of this system.

Specific areas of interest include:

Ground activation

- Activation of the system in the presence of a severe fire external to the aircraft.
- Inadvertent or uncommanded operation of the system when the aircraft is on the ground but in a takeoff roll.

Airborne activation

- Inadvertent activation of the system while the aircraft is in level flight and in a landing approach.

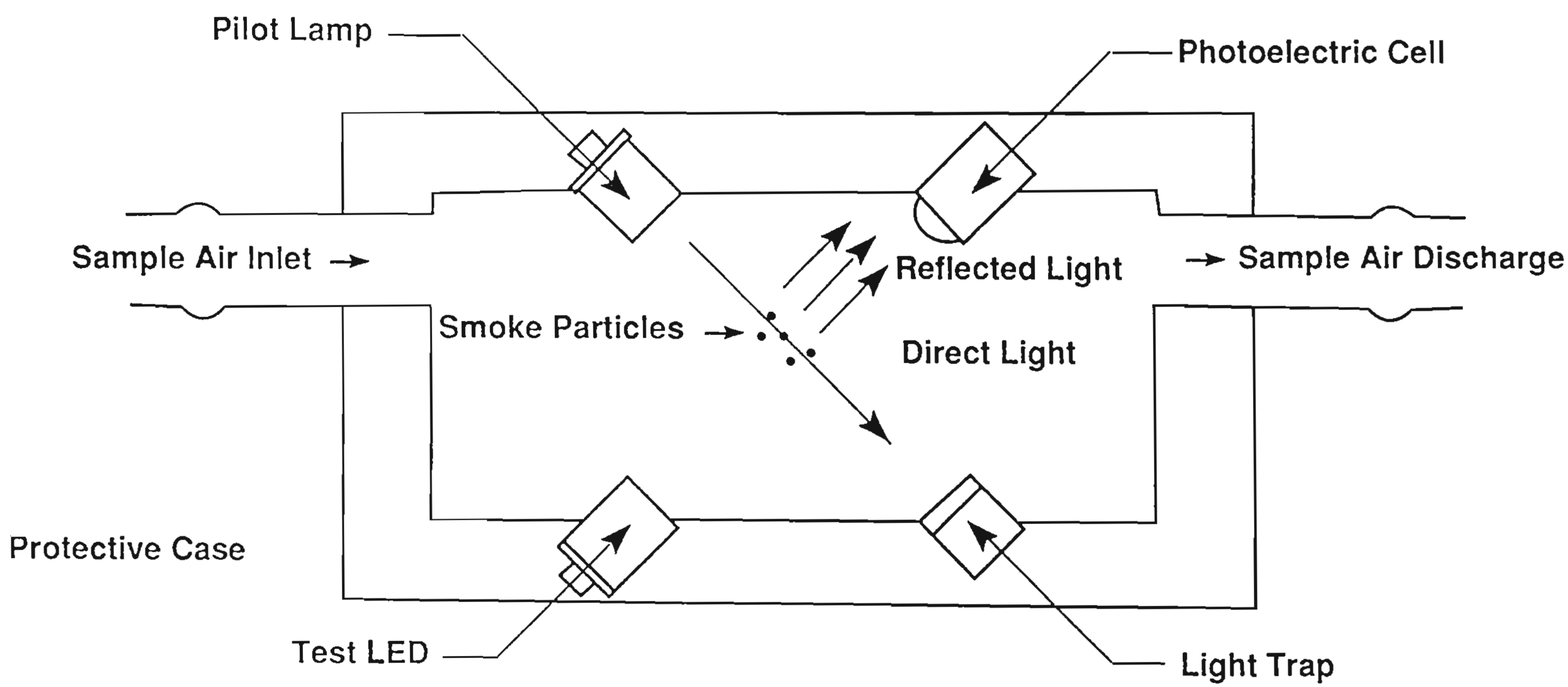
Return to service

- The costs of returning the aircraft to service following the precautionary use or uncommanded activation of the cabin water spray system in the circumstance where the aircraft has not been damaged by fire.

The cabin water spray disbenefits study is part of a collaborative study effort being conducted by the regulatory agencies to determine a benefit analysis prior to making a decision which could lead to a regulation.

To date, this has been an active but unfunded contract.

ACES
Photoelectric Detector



Functional Diagram for Photoelectric Smoke Detector

Figure 1

ACES
Ionization Detector

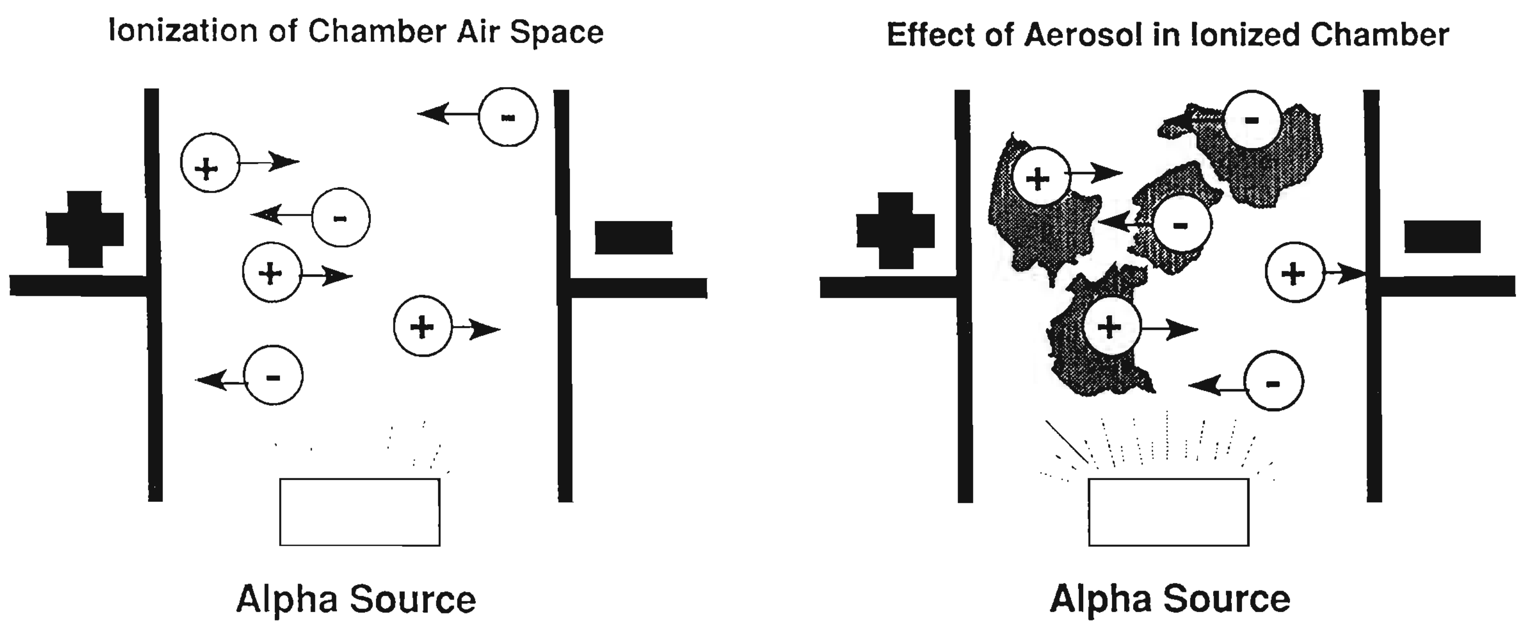


Figure 2

ACES

757 -200 – Cargo Compartment Smoke Detection System

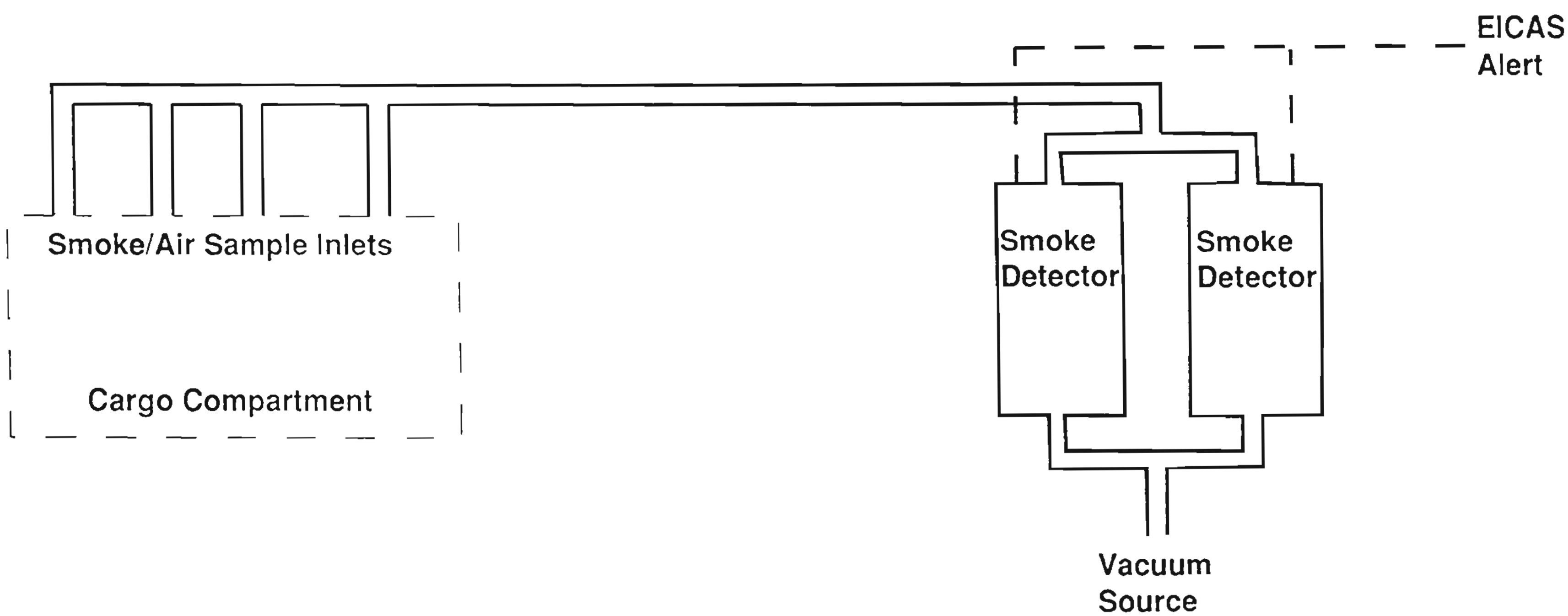
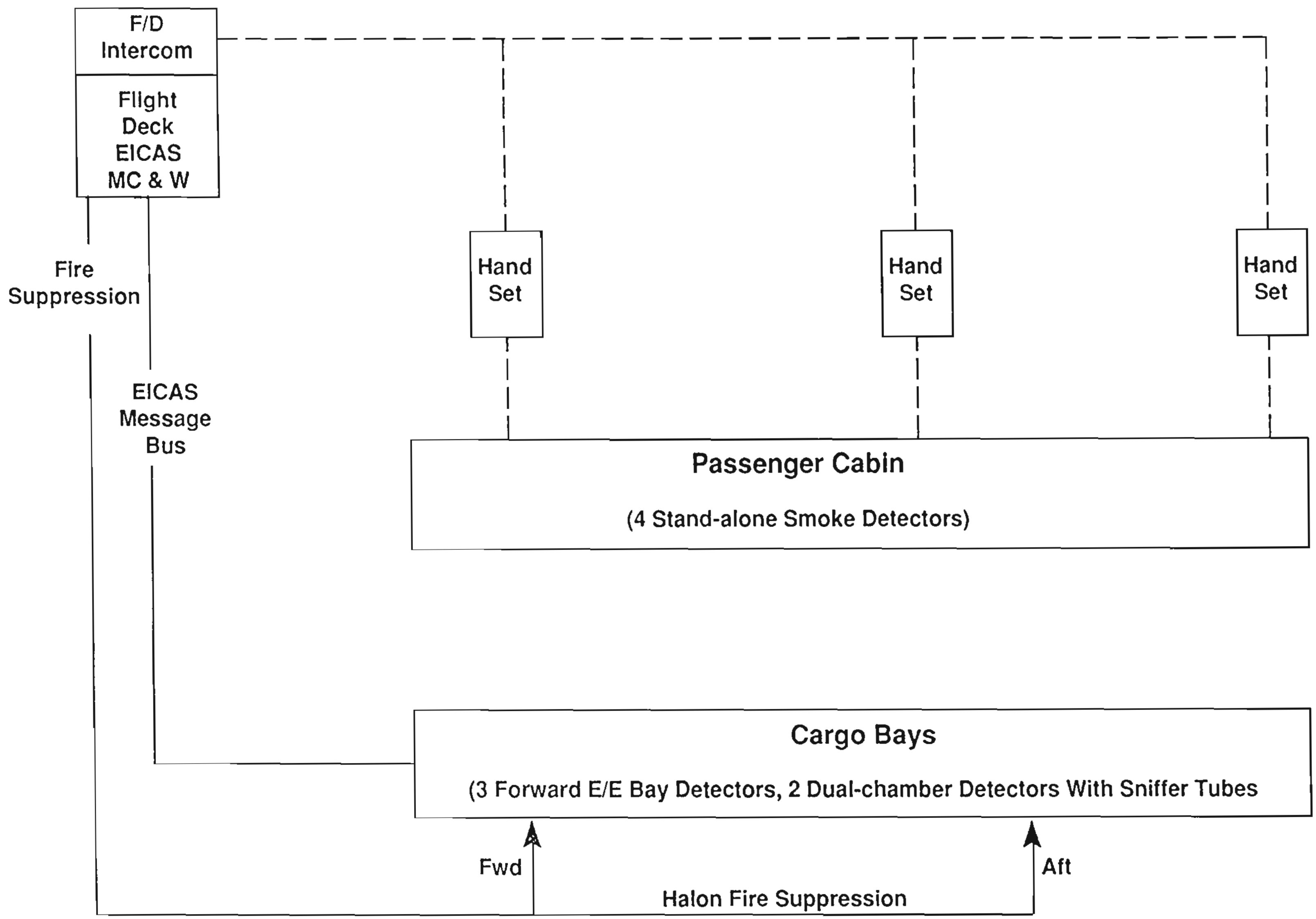


Figure 3

ACES

Existing 757-200

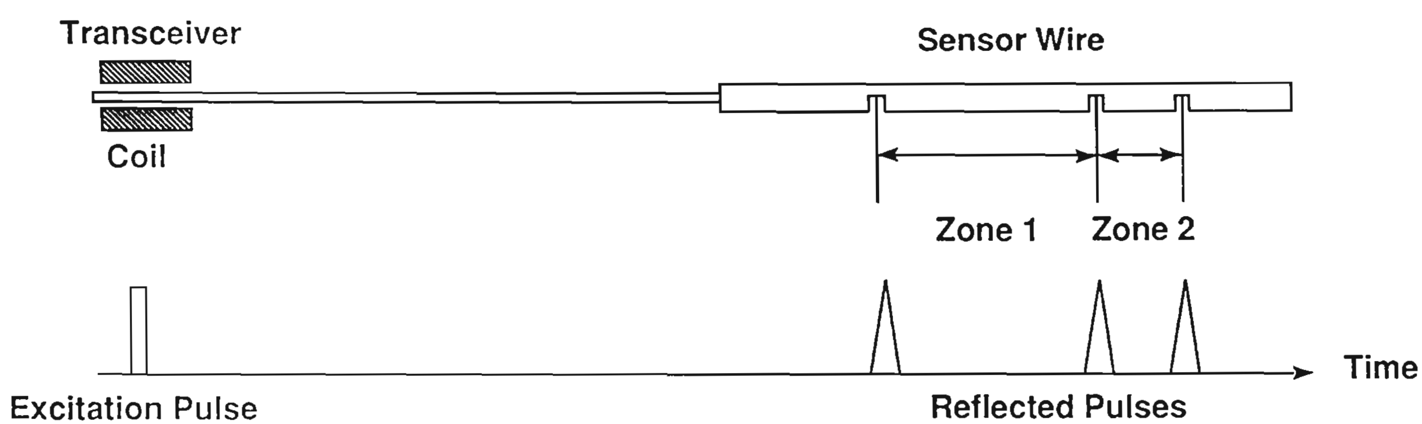


757-200 Capability Without ACES

Figure 4

ACES
Acoustic Detector

Ultrasonic Thermometry

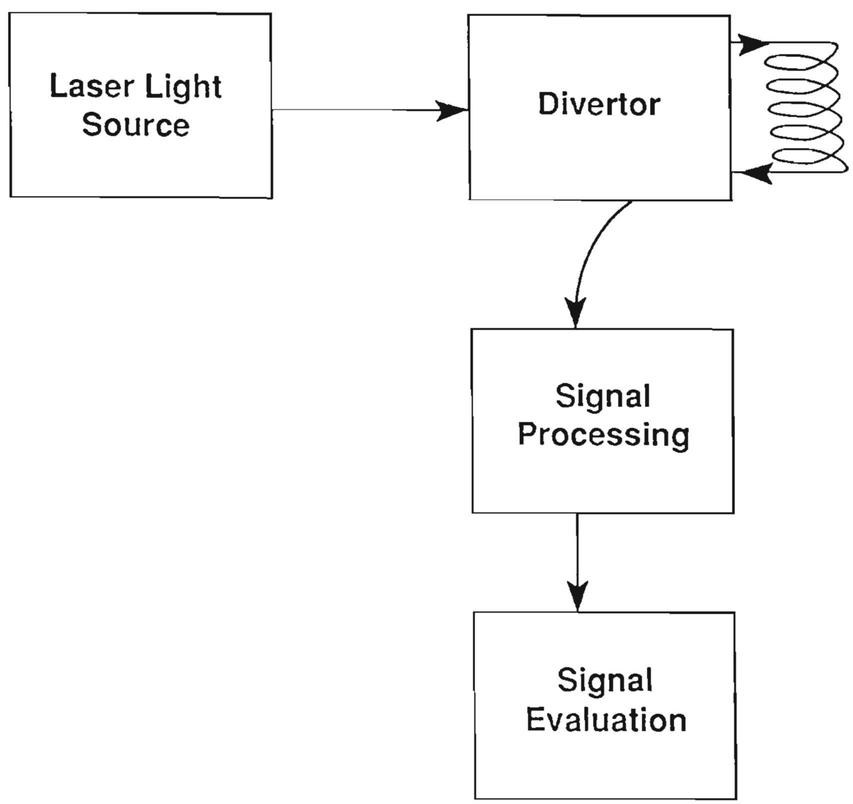


$$\text{Velocity of Sound} = \sqrt{\frac{\text{Young's Modulus}}{\text{Density}}}$$

Figure 5

ACES

Fiber Optic Distributed Temperature Sensor



Measurement time: 12 seconds/loop

Maximum number of loops: 4

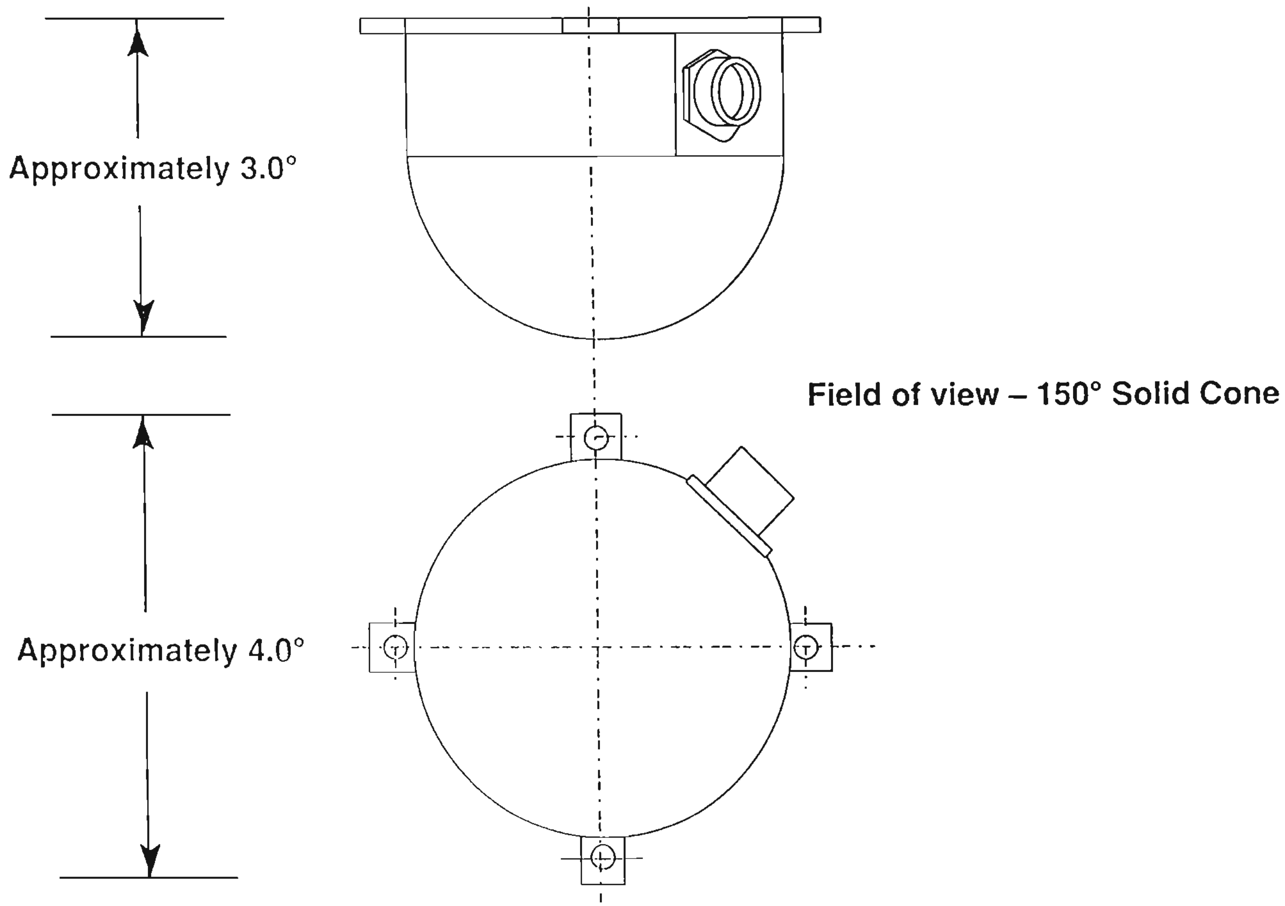
Temperature resolution: ± 1°C

Loop length: 2 km

Figure 6

ACES

Thermal Imaging Module (TIM)



Combi Cargo Bay Fire Protection System

Figure 7

757-200 General Arrangement

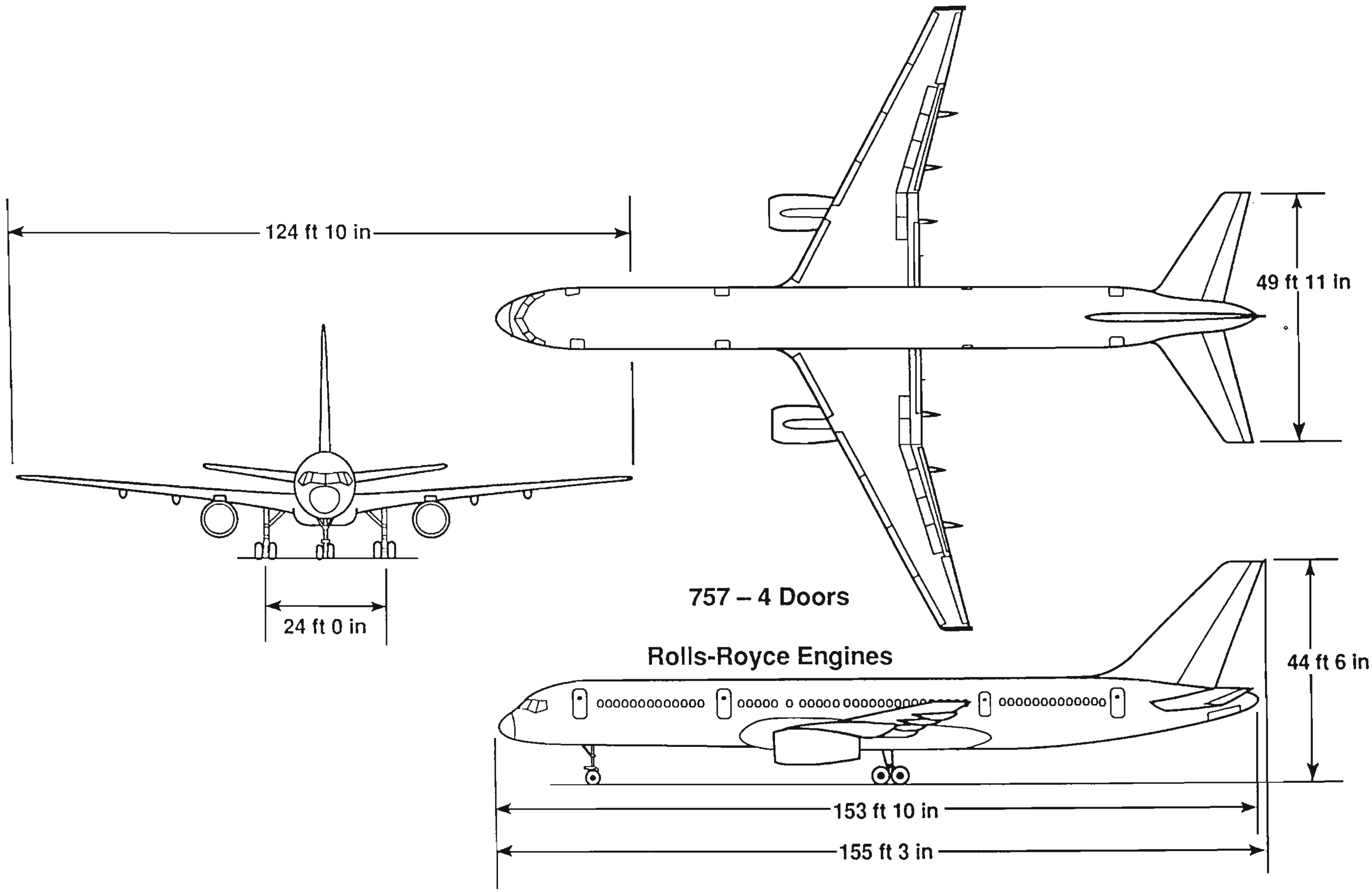


Figure 8

Body Cross Section

757-200, Basic Airplane

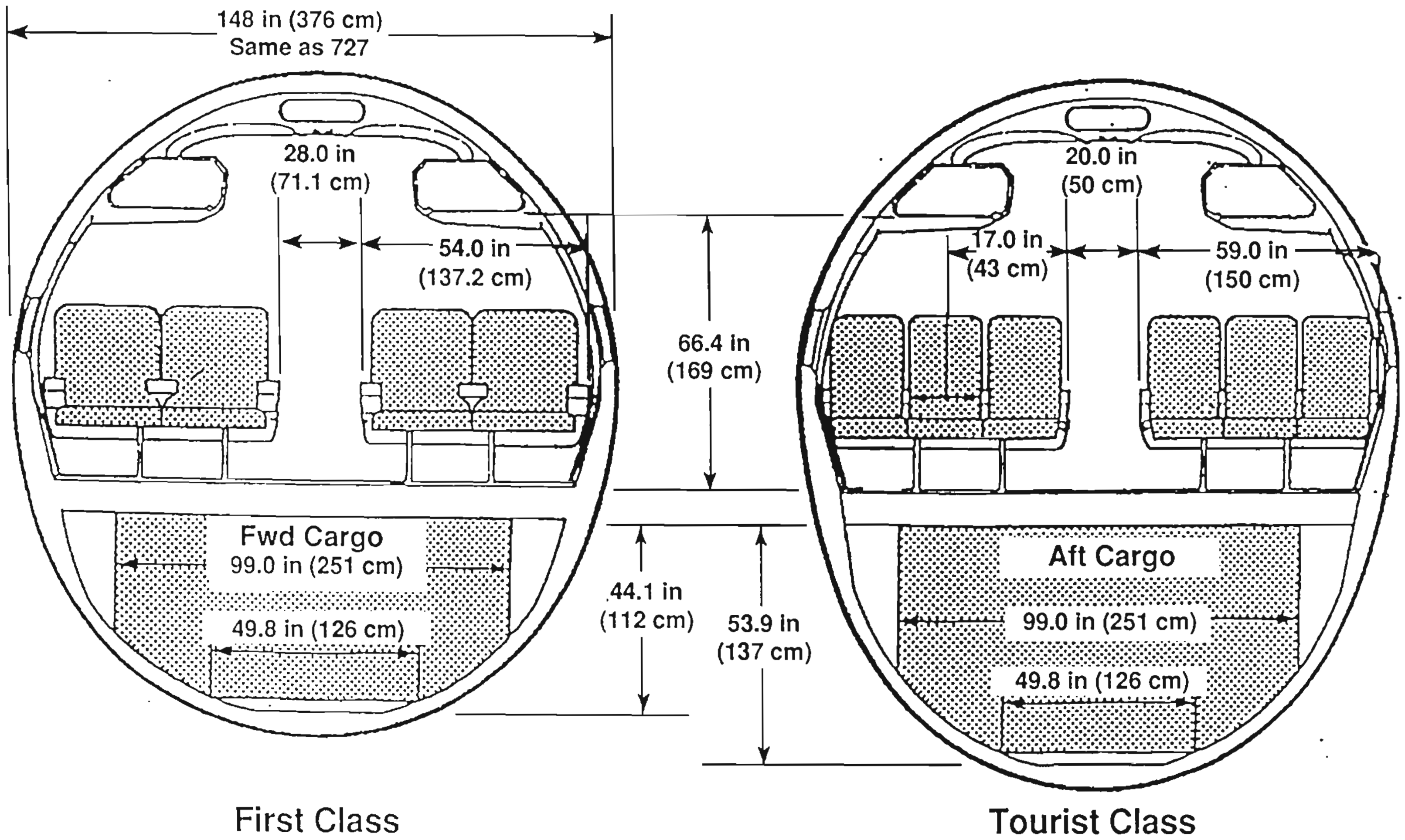


Figure 9

Lower Cargo Compartments

757-200

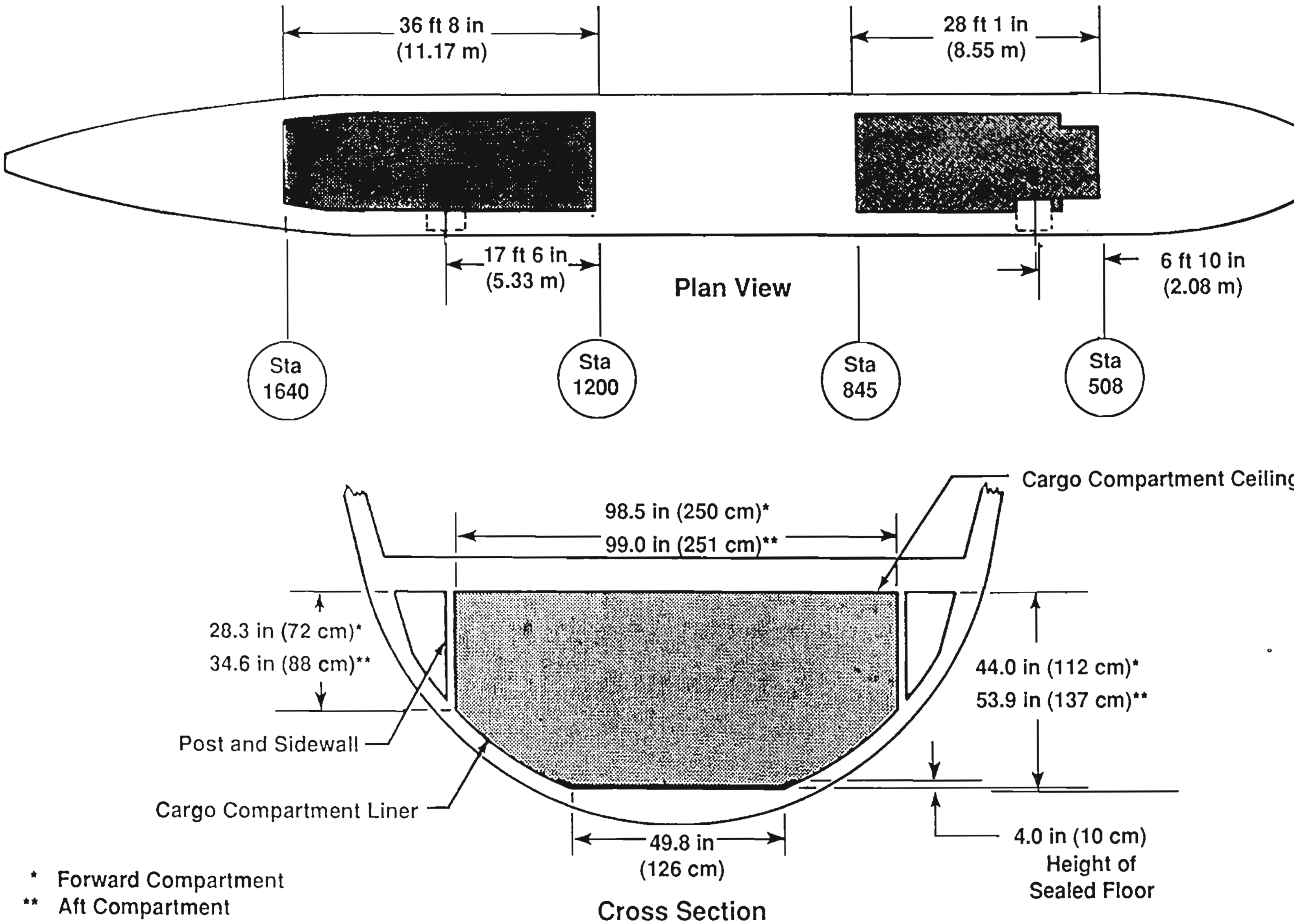
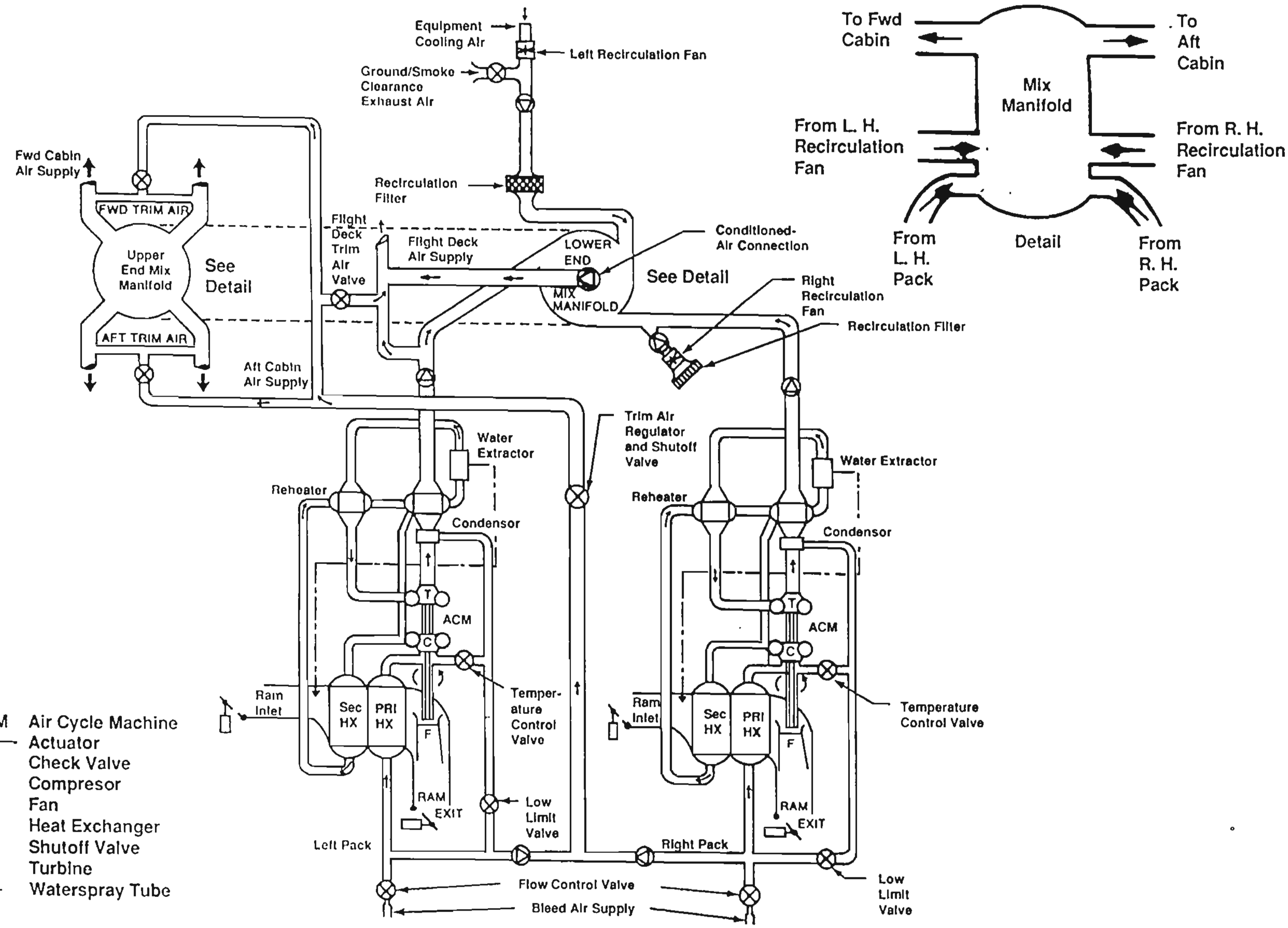


Figure 10

ACES

Air-Conditioning System



ACM	Air Cycle Machine
(symbol)	Actuator
(symbol)	Check Valve
C	Compresor
F	Fan
HX	Heat Exchanger
⊗	Shutoff Valve
T	Turbine
—·—	Waterspray Tube

Figure 11

ACES Equipment Cooling and Ventilation Systems

757-200 and 757-200PF

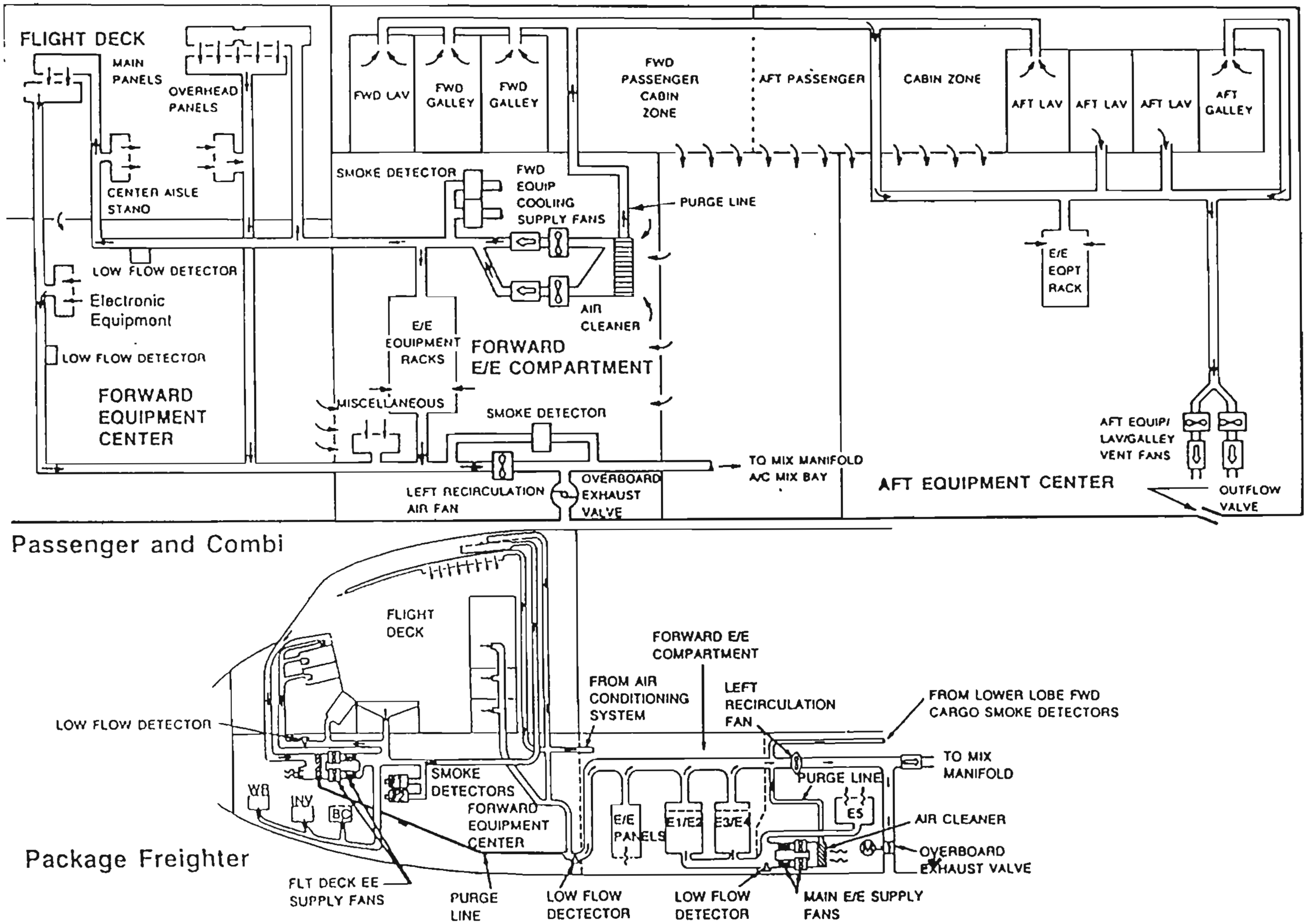
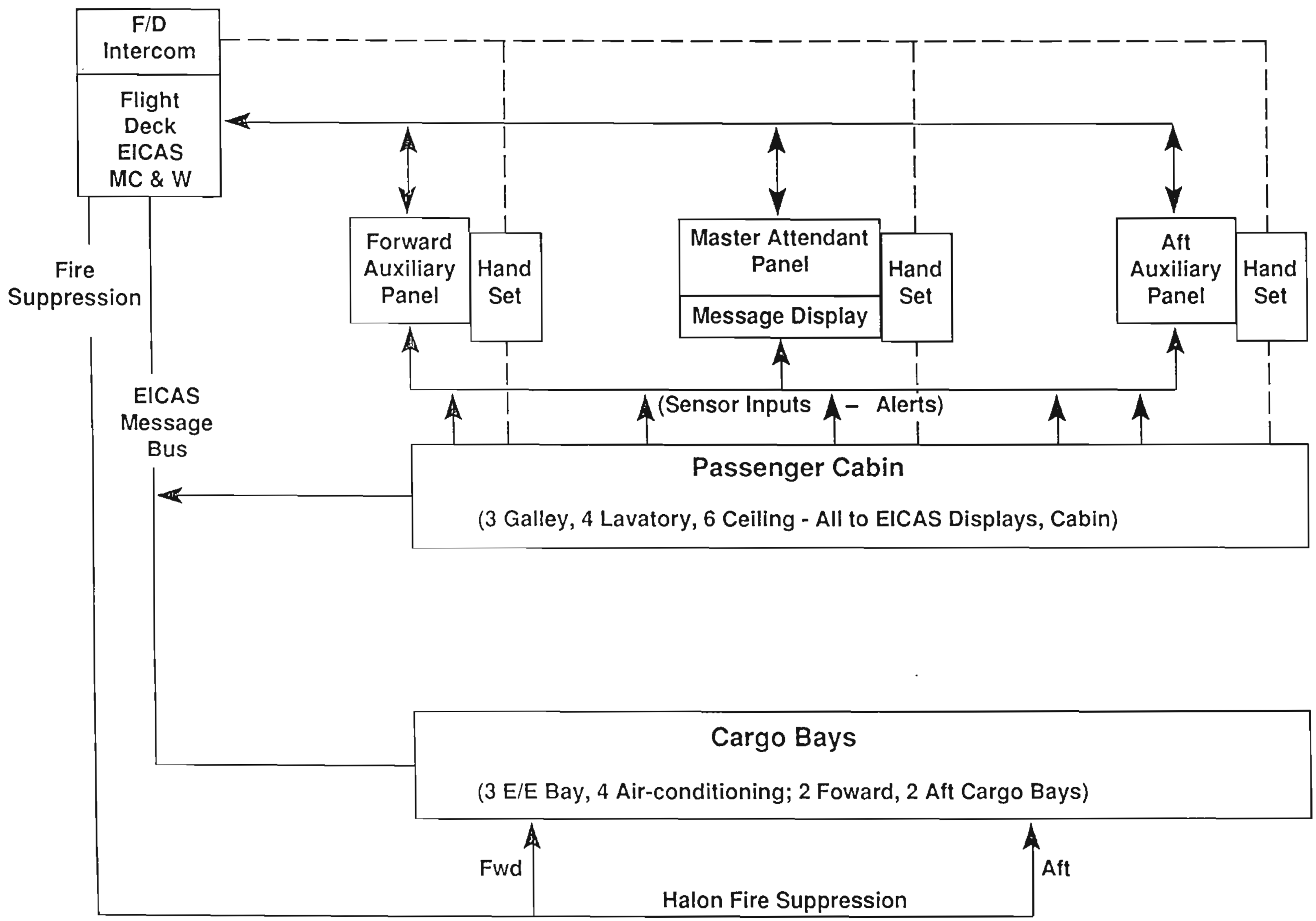


Figure 12

ACES

Concept "A"



757-200 Capability With ACES

Figure 13

ACES

Concept "A" Detector Location

Location	Incidents	Current	Addition	Total	Type (suggested)
Cargo	15				
Forward (Note 1)		2	0	2	Photoelectric - Gamewell
Aft (Note 1)		2	0	2	Photoelectric - Gamewell
Lavatory	147				
Ceiling		4	0	4	Ionization - Jamco
Under Counter		0	4	4	Ionization - Jamco
E/E Bays	2				
Forward		3	0	3	Photoelectric - Autronics
Galley	214				
Exhaust Vent		0	3	3	Photoelectric - Geamatic
Passenger Area	126				
Attic		0	6	6	Photoelectric - Gamewell
Air-conditioning (Note 1, 2)		0	4	4	Photoelectric - Geamatic
Total	504	11	17	28	

Suggested priority for sensors in new locations:

1) Air-conditioning 4
2) Attic – galley 3
3) Attic – passenger area 6 (This would include ceiling video equipment)
4) Lavatory – under counter 4

Note 1: Installed as pairs with "AND" logic

Note 2: Conditioned air into the mix manifold

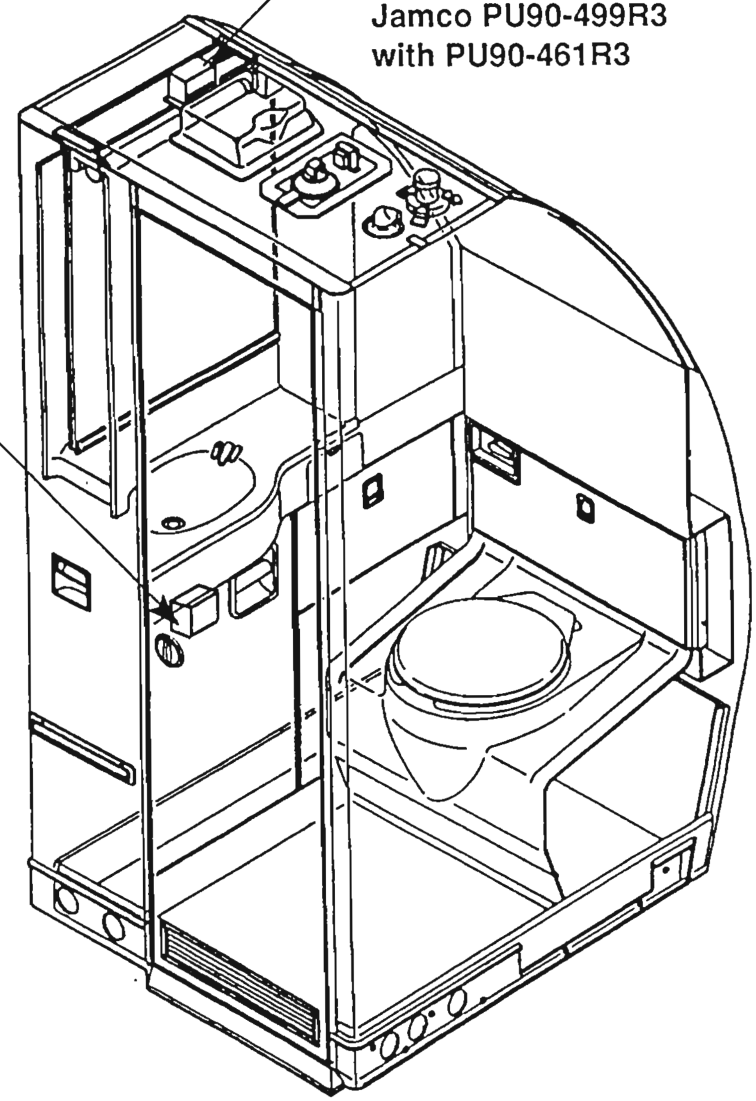
Incident numbers are for inflight fire/smoke events only, from D. Anderson data of 11/20/89

Figure 14

ACES

Concept "A" Modifications – Lavatory Features

- Modular construction
- Single-piece floor pan
- Hardpoint mounted above floor – no tracks
- Easy access to toilet assembly
- Self-contained recirculating toilet

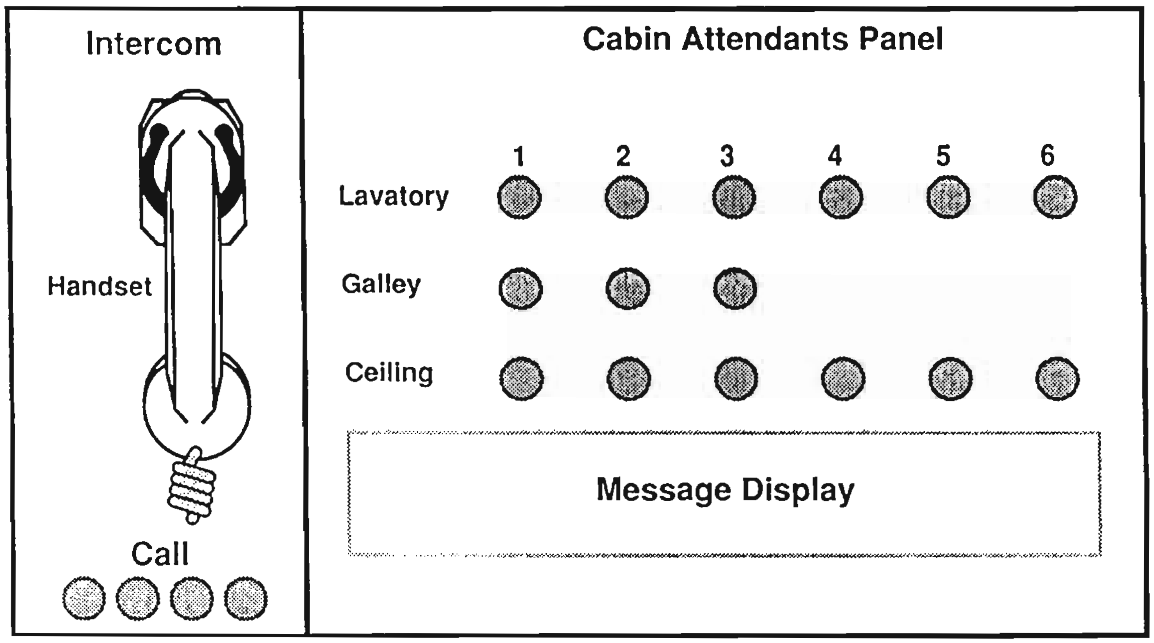


Note: Lavatory wiring will be revised to accommodate additional smoke detectors

Figure 15

ACES

Intercom Panel



Master Cabin Attendants Panel

Interfaces with Master Cabin Attendants Panel

Interfaces with Flight Deck Intercom

Interfaces with EICAS

Interfaces with Master Caution and Warning System

Figure 16

ACES

Concept "B"

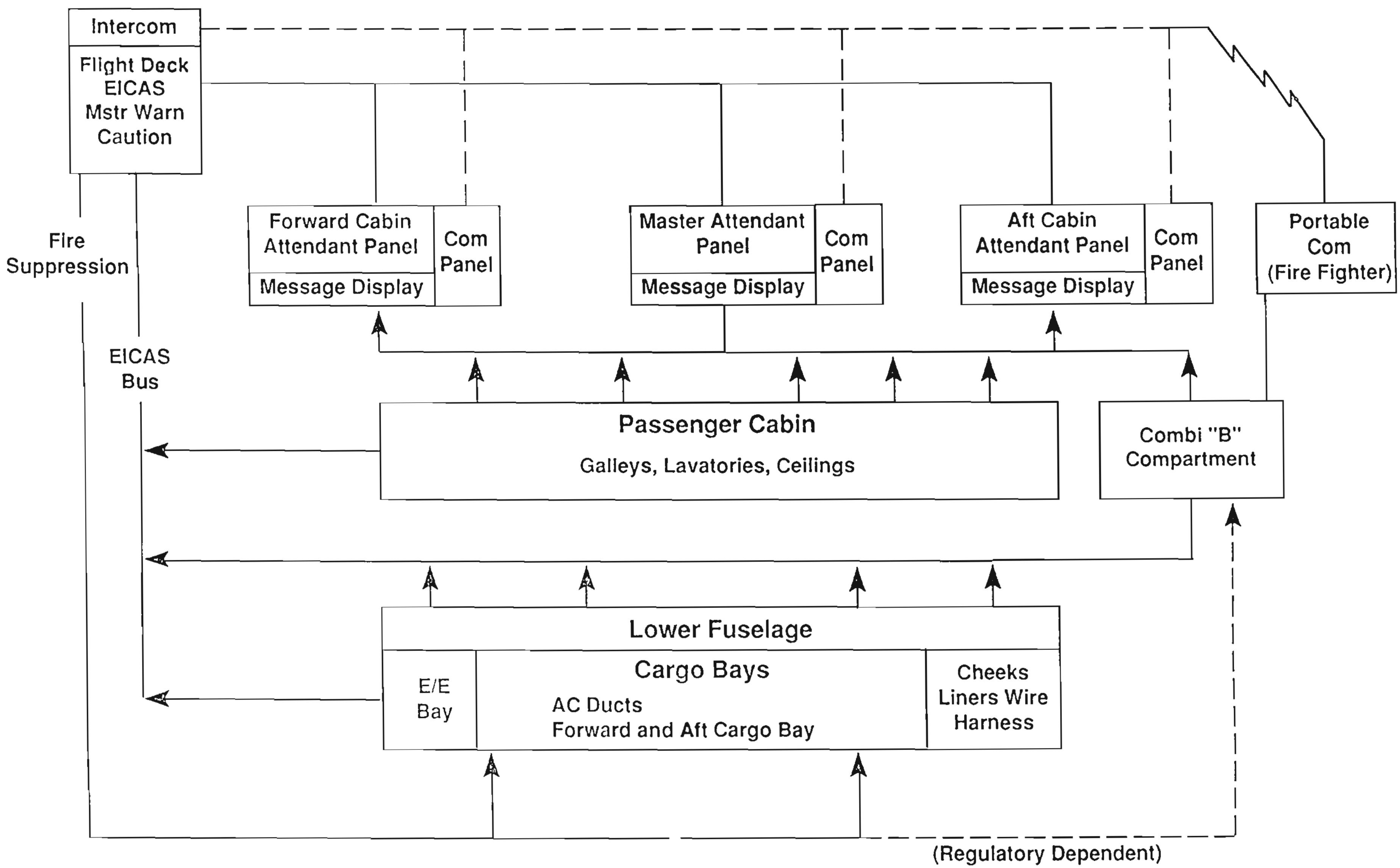


Figure 17

Engine Indication and Crew Alerting System

757-200

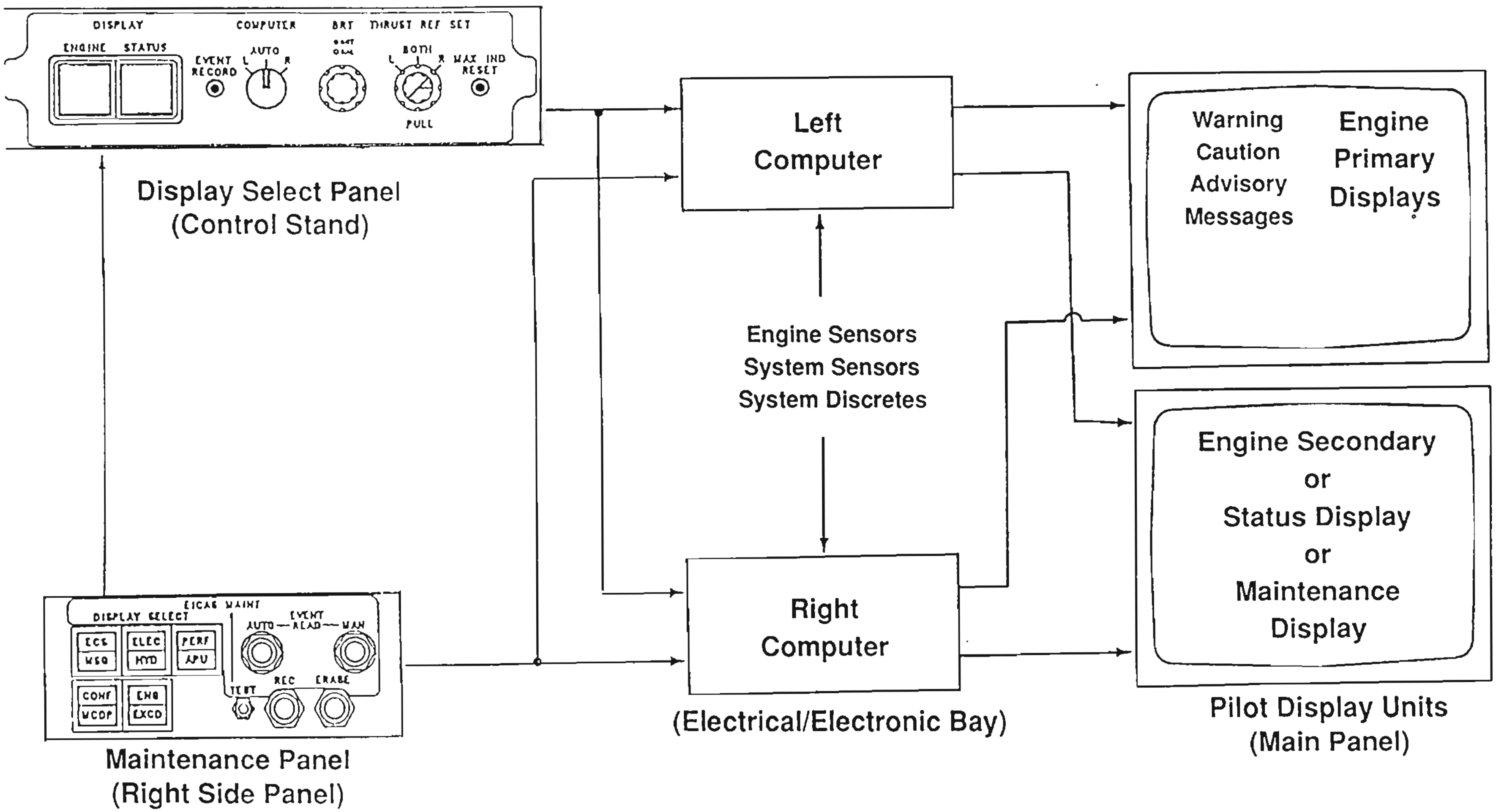


Figure 18

Central Crew Alerting System

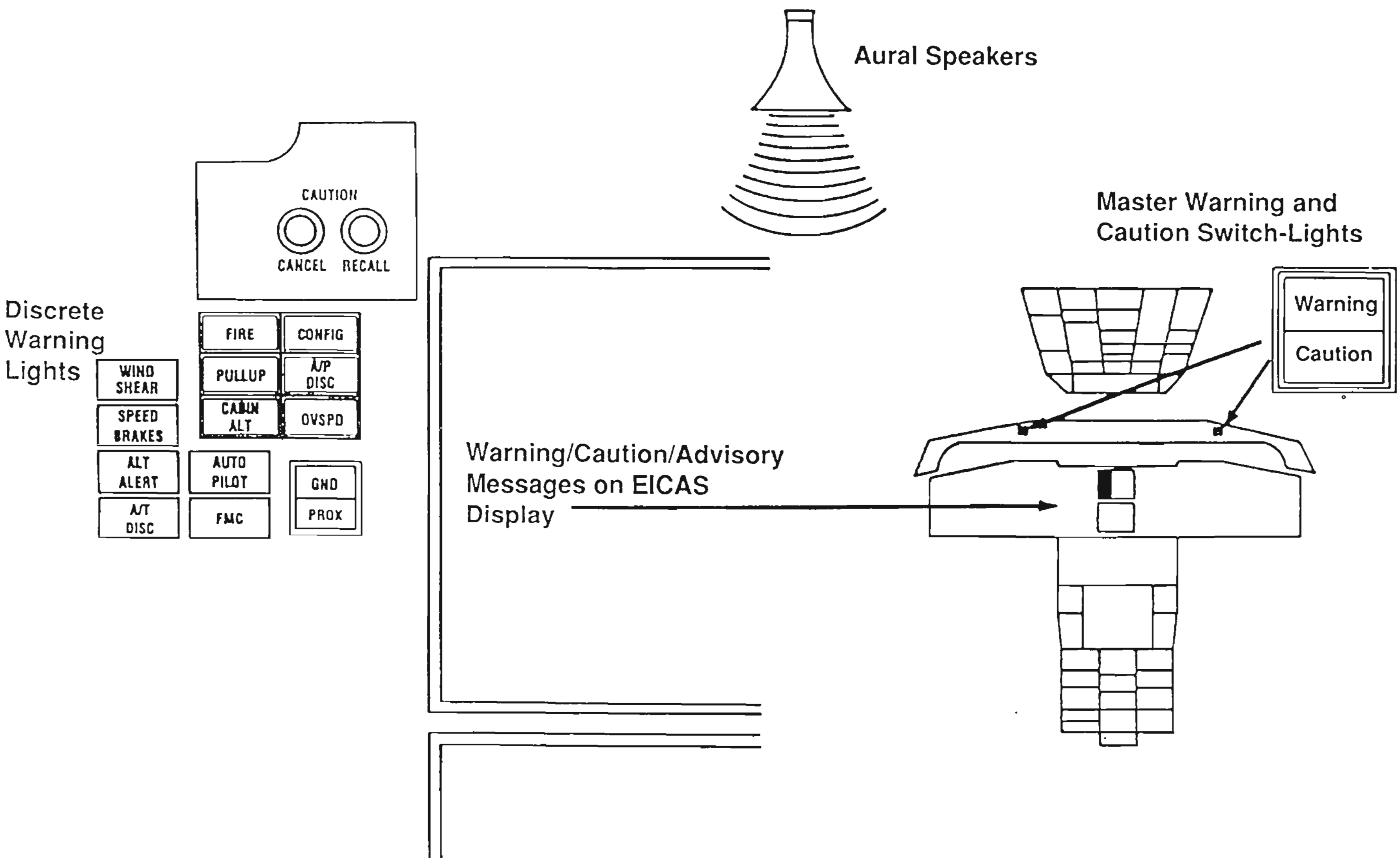


Figure 19

ACES

Electronic Checklist Demonstration – Aft Cargo Fire Checklist

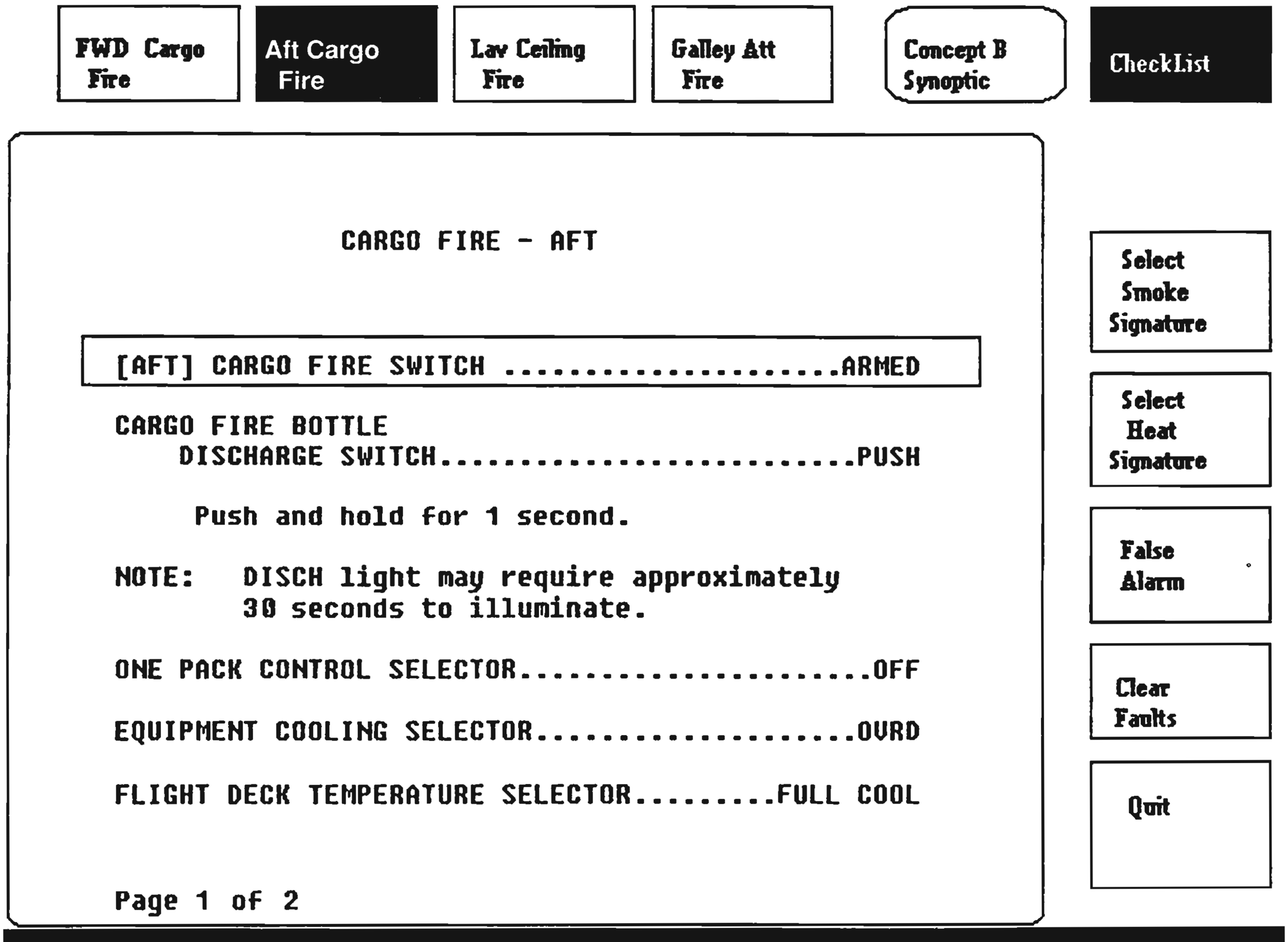


Figure 20

ACES

Synoptic Display – Layout (Concept "B")

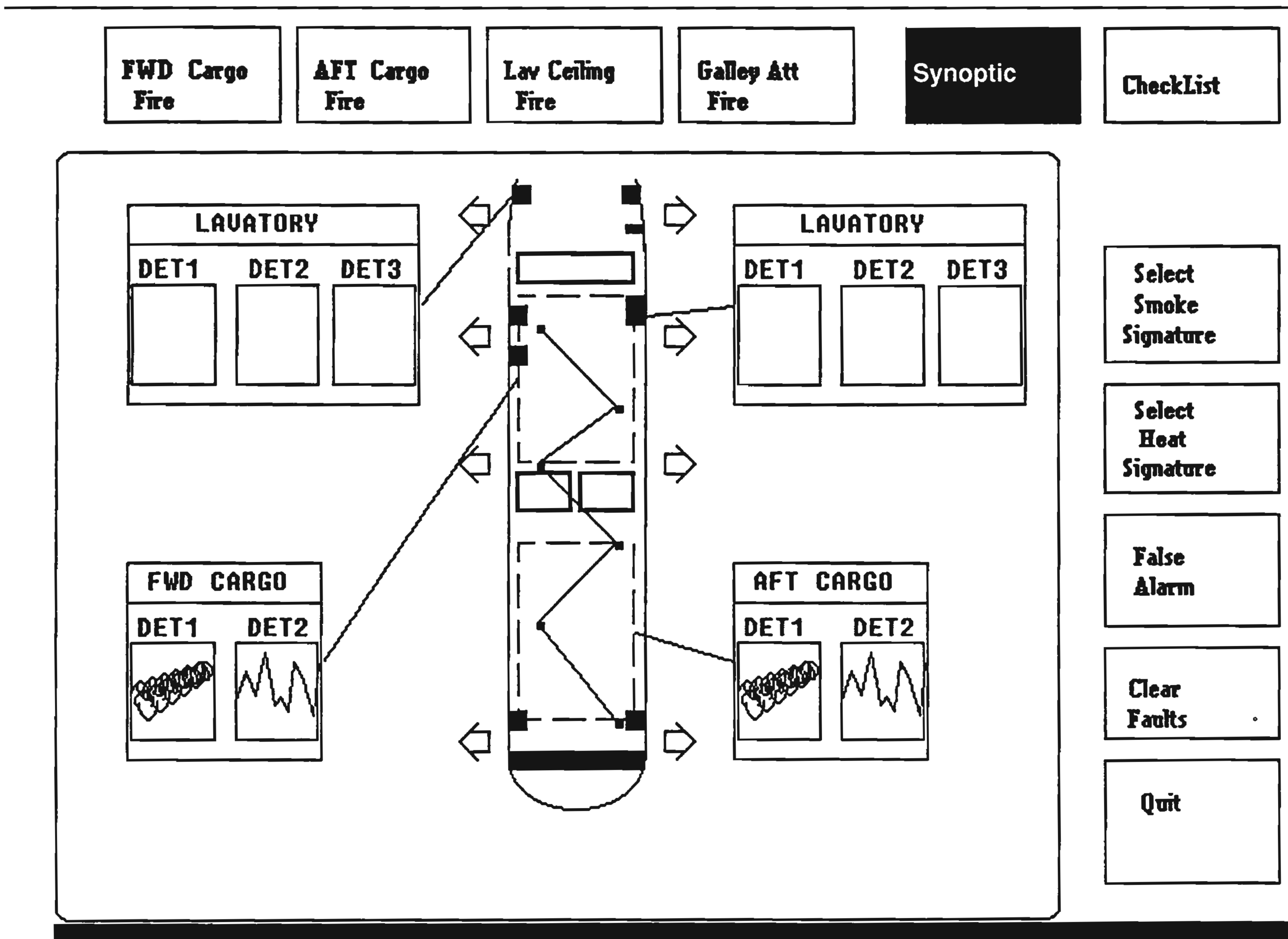


Figure 21

ACES

Synoptic Display – Sensor Signatures

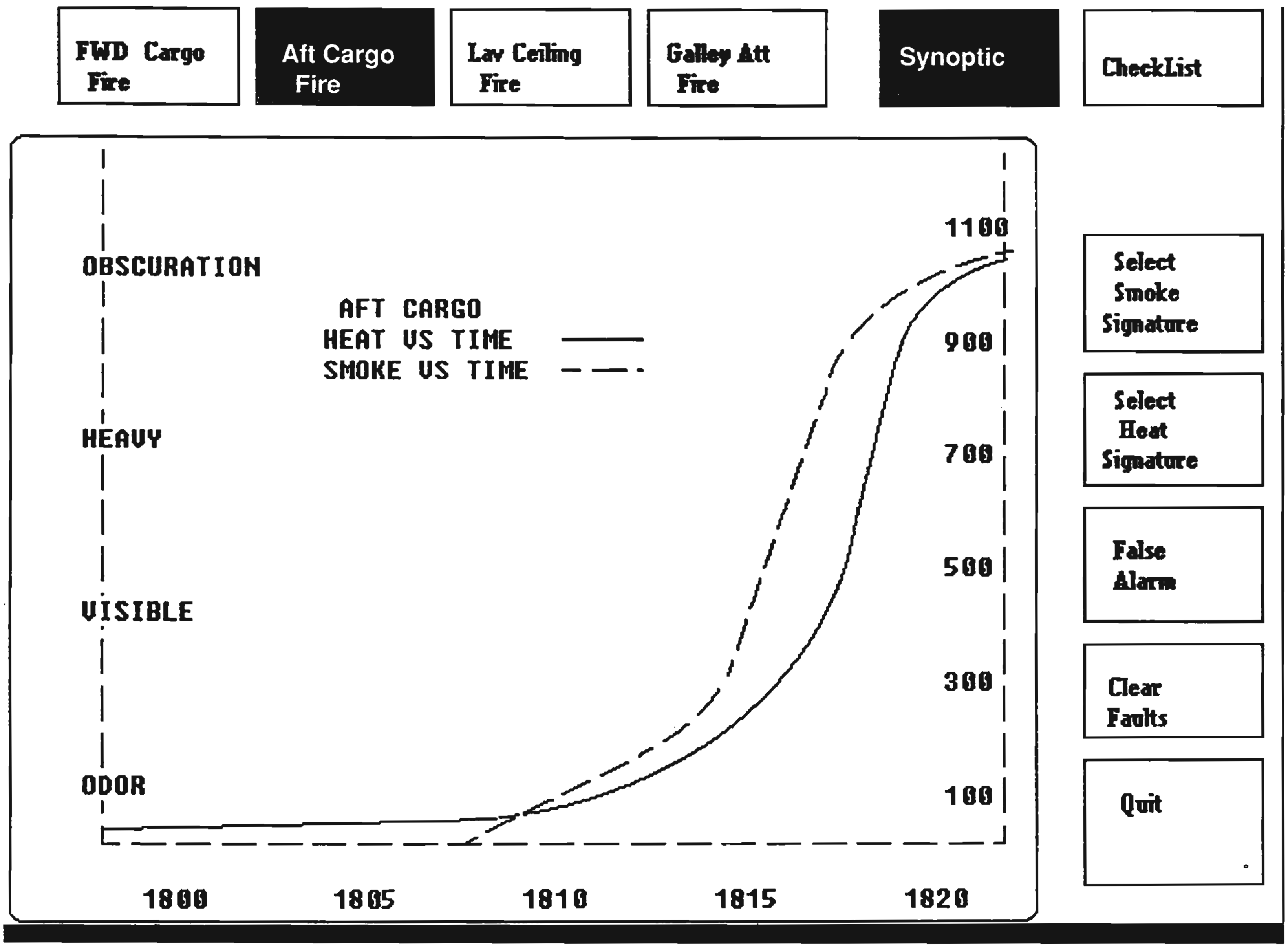


Figure 22

ACES

Synoptic Display – Extinguisher Feedback

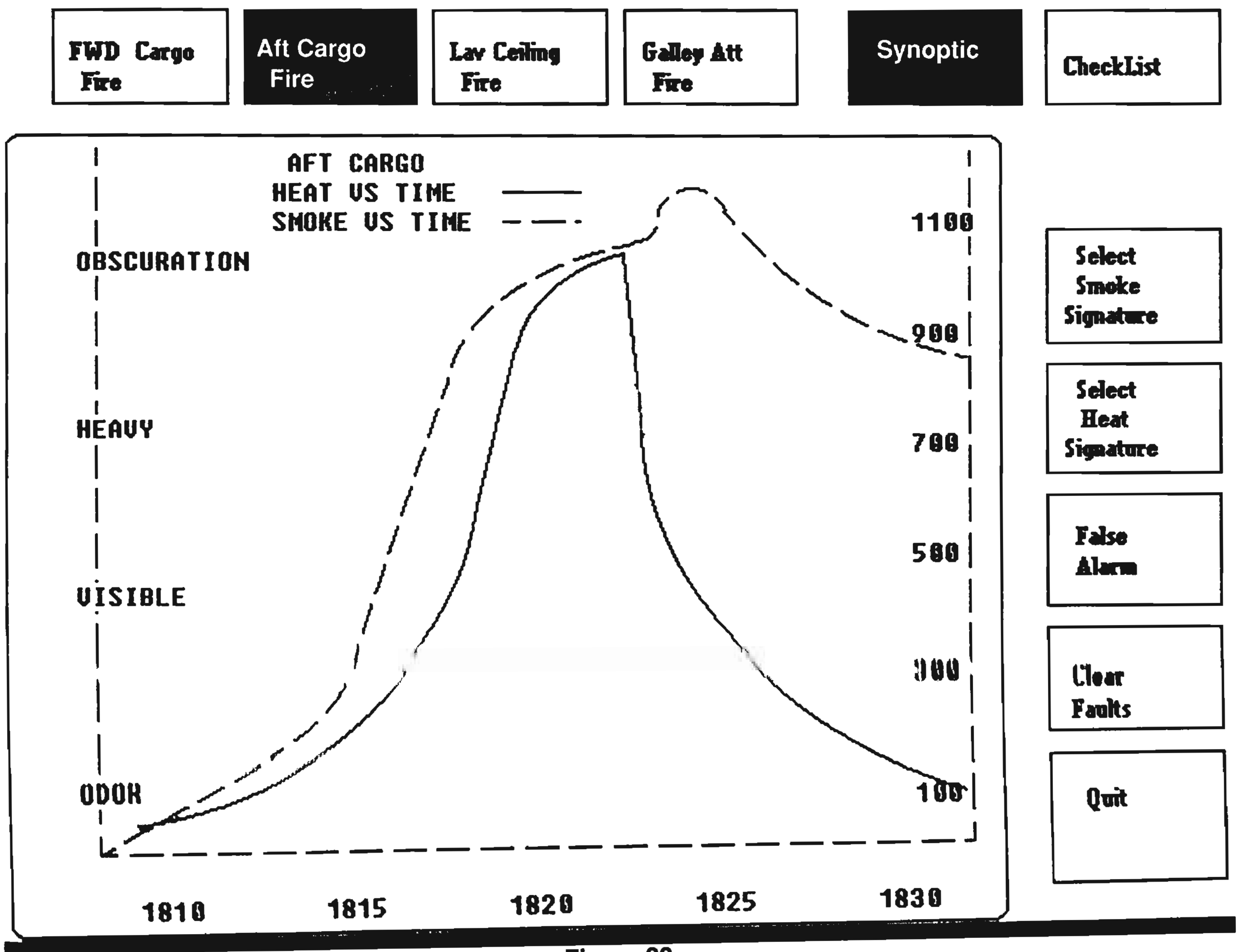


Figure 23

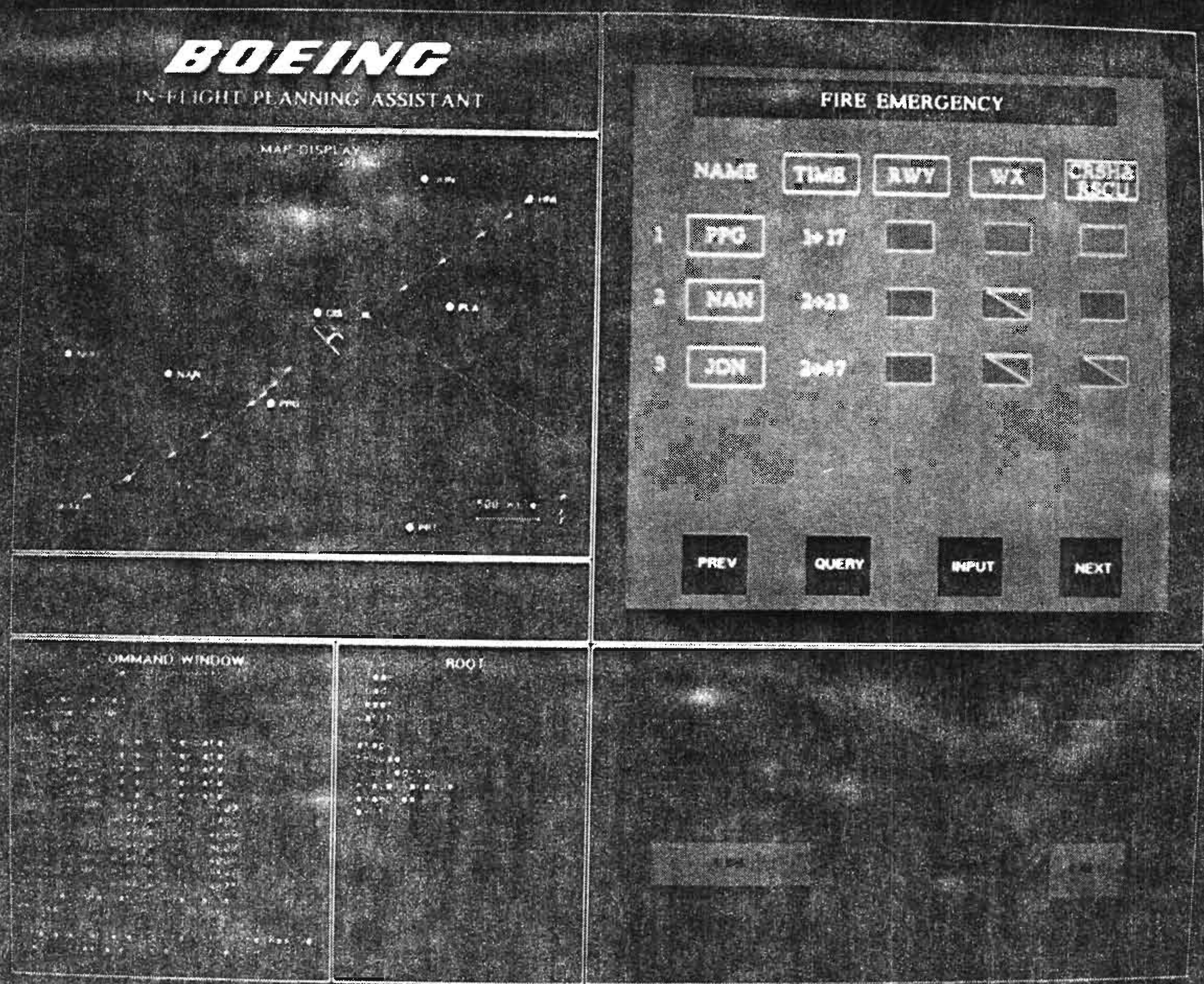

BOEING
IN-FLIGHT PLANNING ASSISTANT
MAP DISPLAY
FIRE EMERGENCY
NAME
TIME
RWY
WX
1
PPG
2
NAN
3
JON
PREV
QUERY
INPUT
NEXT
OMMAND WINDOW
ROOT

FIGURE 24

757 CABIN WATER SPRAY SYSTEM

STUDY CONCEPT

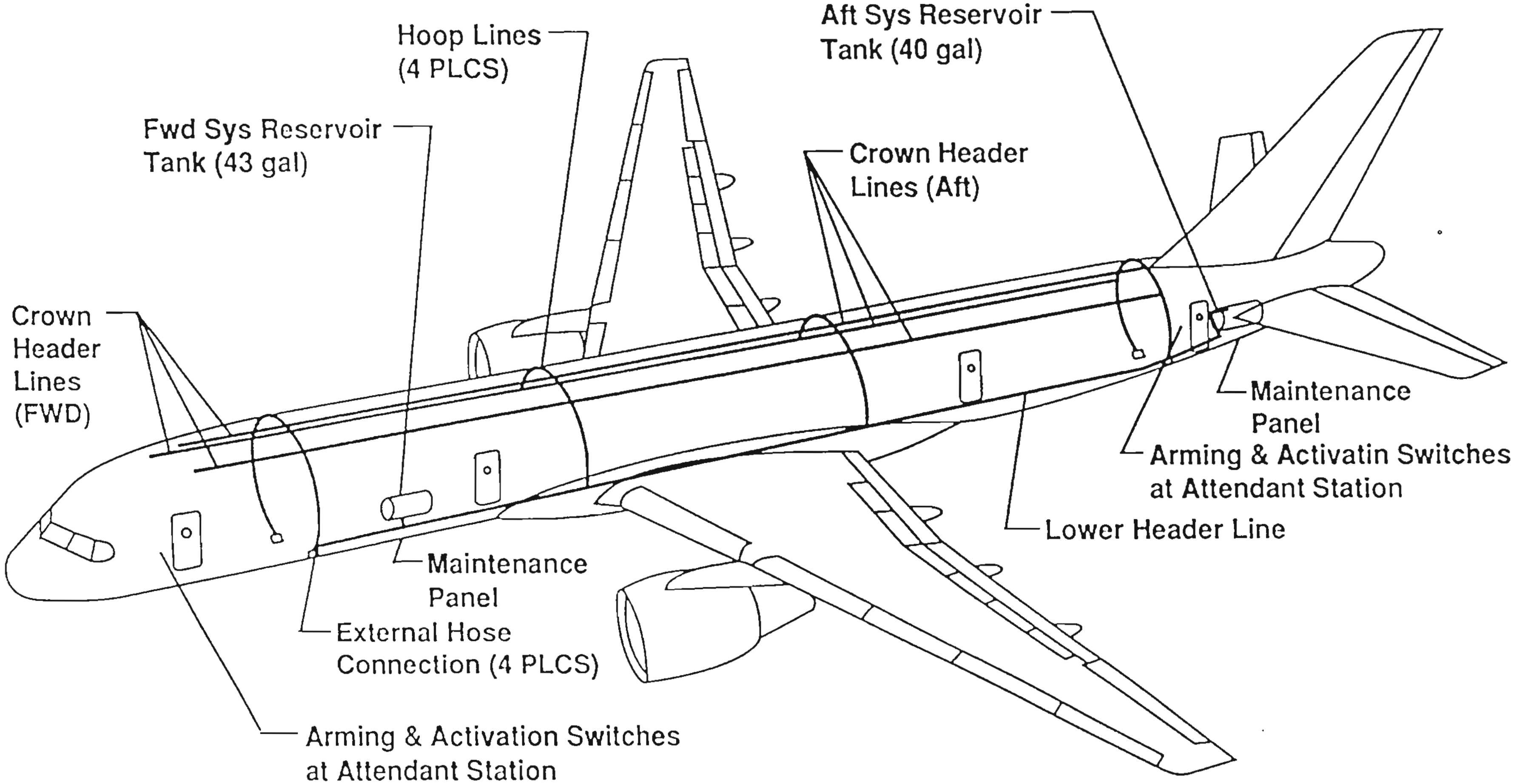


Figure 25