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AEMS IMPLEMENTATION COST STUDY FOR BOEING 727

Robert L. Allison

February 1977

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16. Abstract

This document presents the results of a study to determine costs for airline operational implementation of a NASA-developed approach energy management system (AEMS) concept, as applied to the 727 airplane. Estimated costs are provided for airplane retrofit and for installation of the required DME ground stations. Operational costs and fuel cost savings are presented in a cost-of-ownership study. The potential return on the equipment investment is evaluated using a net present value method. Scheduled 727 traffic and existing VASI, ILS, and collocated DME ground station facilities are summarized for domestic airports used by 727 operators.

The AEMS concept, developed and flight-tested on a CV-990 by NASA-ARC, was adapted to the 727 as part of a NASA-ARC/Boeing engineering and piloted simulation study program, reported in NASA CR 137907. The AEMS reduces approach time, fuel, and noise by providing computer-driven cockpit displays to assist the pilot in flying optimized delayed flap approach (DFA) procedures. A preliminary specification for the AEMS avionics is published as NASA CR 137906.

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1.0 SUMMARY

The NASA Ames Research Center (ARC) has developed an approach energy management system (AEMS) concept that reduces approach time, fuel, and noise on conventional glide slopes through the use of delayed flap approach (DFA) procedures. The AEMS provides computer-driven cockpit displays that indicate when to manually set the flaps, gear, and throttles to follow an optimized deceleration profile and consistently stabilize the final approach at a predetermined target speed and altitude. Operational implementation would require airplane retrofit and installation of DME ground stations collocated with VASI or ILS glide slopes.

The technical feasibility and potential benefits of the concept were evaluated during a Boeing engineering and piloted simulation study, reported separately. Since the concept appeared promising, the work was extended to include estimation of operational implementation costs, reported herein.

Budgetary costs in 1976 dollars for retrofit of a typical 727-200 configuration were estimated by Boeing with avionic vendor participation, for three market bases (100, 300, 500 shipsets). For a market base of 300 shipsets, the initial implementation cost was estimated to be \$66 000 per airplane, which includes purchase of a master change (MC) retrofit kit (\$56 000), installation by the customer (256 man-hours), and other one-time costs such as spares and maintenance training. Airplane down time could be minimized by accomplishing the installation (5 calendar days) concurrent with other scheduled layups (e.g., "C" check) and is not included in the cost estimate. A cost-benefits analysis indicates the estimated fuel savings would provide a 33% to 38% rate of return on investment which would pay back the investment costs in less than 3 years. In addition to conserving about 0.19m^3 (50 U.S. gal.) of fuel per approach (still air, VFR conditions) the AEMS has potential for substantially reducing approach time and noise.

No additional ILS or VASI facilities are necessary to meet the NASA study objective of using the AEMS on 50% of all 727 approaches. However, additional colocated DME stations are required, the number depending on the runway distribution criteria used. A DME cost of \$5 million appears representative for a distribution placing high priority on noise abatement. To equip all existing ILS runways with collocated DME at all 727 airports would cost \$12 million. These DME costs are relatively small compared to the cost of airline fleet retrofit.

Boeing studies were conducted to provide scoping level information as part of a NASA-ARC research program. There is no commercial program in progress for AEMS implementation. Additional studies with airline and FAA participation would be required to further develop the technical aspects of the concept and to evaluate operational feasibility before considering airline fleet retrofit.

2.0 INTRODUCTION

This cost study was conducted as part of a NASA Ames Research Center (ARC) program to develop and evaluate an approach energy management system (AEMS) and associated delayed flap approach (DFA) procedures for commercial jet transports. The NASA delayed flap approach procedures are an extension of the noise abatement approach techniques used by Air Transport Association (ATA) member airlines (ATA memo 72-90). These procedures reduce approach time, fuel, and noise by retaining a low drag configuration for as long as practical and by using the minimum landing flap setting where possible. The AEMS increases the benefits of the procedures by providing computer-driven cockpit displays to assist the pilot in the following optimized speed, thrust, and configuration schedules. Implementation of the AEMS would require aircraft retrofit and installation of distance measuring equipment (DME) ground stations collocated with the visual approach slope indicator (VASI) or instrument landing system glide slope.

The AEMS concept was initially developed and flight tested by NASA ARC on the CV-990. Boeing began an engineering and piloted simulation study in July 1975 (contract NAS2-8953) to adapt the NASA concept to the 727, determine the potential benefits, evaluate systems compatibility and pilot workload, and provide a preliminary avionic specification. The results showed that the concept has potential for substantially reducing approach time, fuel consumption, and noise with a moderate increase in aircrew workload. These studies are discussed in reference 1, and the resulting avionic configuration is specified in reference 2.

After reviewing the engineering and simulation study results, NASA-ARC continued the investigations to obtain additional information necessary for judging operational acceptability. Since an important operational consideration is the cost of the equipment, the Boeing study was extended to estimate implementation costs for (1) AEMS avionic development, and 727 fleet retrofit, and (2) DME ground station installation.

The intent of the cost study is to provide scoping level cost data for consideration by the NASA Research and Technology Advisory Council in deciding if further NASA research in this area, possibly including prototype hardware development and flight test, is warranted. It should not be inferred that a commercial retrofit program could be initiated at this time. Additional work to improve the concept and establish operational feasibility would be required before considering fleet retrofit.

The extent of the additional work necessary to further develop the AEMS and demonstrate operational acceptability and the degree of government involvement in such a program has not been determined. In addition to the technical and economic aspects which have been investigated, there are several other operational concerns such as:

- Will the required DME ground stations be installed?
- Can air traffic control (ATC) accommodate the higher initial approach speeds (220 kn)?

- Are the procedures safe and acceptable to airline pilots?

- Would the noise benefits be allowed in showing compliance with noise restrictions?

It would be difficult for an individual airline and/or airframe manufacturer to resolve these questions. For this implementation cost study, it was assumed that all work necessary to establish operational feasibility would be completed under NASA-funded research programs before beginning hardware implementation. This work would include further conceptual development, simulator evaluations to determine airline pilot acceptance, ATC compatibility studies, safety analyses, and update of the AEMS equipment specification as required to define an operationally acceptable configuration. This study considers only the costs for commercial implementation of a concept that has been fully developed and evaluated by NASA.

The preliminary 727 AEMS avionic specification (ref. 2), resulting from the initial Boeing engineering and simulator studies, was used as a basis for estimating implementation costs. Since the AEMS is advisory in nature, only a single-channel installation is specified. However, the specification requires high reliability and adequate failure detection.

Although the specification was considered to be final for purposes of the cost study, some revisions should be expected prior to releasing a specification for prototype hardware. A majority of the revisions would be in the digital computer program logic which should not appreciably affect the equipment costs. However, some additional avionics and airplane installation hardware may also be required: e.g.,

- A free air temperature input may be necessary to adjust the profile prediction for non-standard conditions. (Boeing studies to date have been limited to standard days only.)

- Additional avionics to provide independent monitoring of speed margins relative to flight safety limits may be desirable.

No allowances have been made in the cost estimates for these or any other components not included in the current specification.

The estimated prototype program costs through type certification, but excluding airline pilot flight demonstrations, were identified separately as requested by NASA. Recovery of the prototype program costs is included in the total retrofit kit price estimates.

A comprehensive NASA-commercial program for 727 AEMS development and implementation has not been established, since the concept is in research and feasibility study status. To provide a basis for distinguishing NASA study costs from equipment implementation costs, the following program was assumed:

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Program phase	Source of funding
1. Feasibility studies[a]	NASA
2. Prototype development and certification	Included in kit price
3. Flight demonstrations[a]	NASA
4. Operational implementation:	
DME ground stations	FAA
Airline fleet retrofit	Commercial

[a]Not included in the implementation cost estimates.

This program omits one important phase which should be considered in an actual program. Prior to the operational implementation phase, the possibilities for integrating the AEMS with other related airborne computer concepts should be explored, at least to the extent of configuring the production AEMS equipment to facilitate adding the other capabilities. Examples of other concepts which might be integrated with the AEMS are mentioned in section 4.3.

3.0 SYMBOLS AND ABBREVIATIONS

ADI	attitude director indicator
AEMS	approach energy management system
APP	approach
ARC	Ames Research Center
ARINC	Aeronautical Radio, Incorporated (electronic equipment standards)
ATA	Air Transport Association
ATC	air traffic control
ATR	Austin Trumbull Radio (ARINC designation for electronic case sizes per ARINC spec 404A)
CADC	central air data computer
DFA	delayed flap approach
DME	distance measuring equipment
DOC	direct operating cost
DOT	Department of Transportation
EPNdB	effective perceived noise, decibels
EPR	engine pressure ratio
FAA	Federal Aviation Administration
ft	feet
FY	fiscal year
F&E	facilities and equipment
gal	gallon

3.0 SYMBOLS AND ABBREVIATIONS (Continued)

G/S	glide slope
hr	hour
IFR	instrument flight rules
ILS	instrument landing system
INOP	inoperative
INS	inertial navigation system
KCAS	knots, calibrated air speed
kn	knot
lb	pound. The U.S. engineering unit for weight and force.
LRU	line replaceable unit
MC	master change
m	meter
min	minute
N	Newton, the SI unit for force. Throughout this report, airplane and fuel weights are expressed in N where 1 lb = 4.448 N
NASA	National Aeronautics and Space Administration
nmi	nautical mile
NPV	net present value
N_1	engine compressor speed (lower pressure stages)
OM	outer marker
P/N	part number
ref.	reference

3.0 SYMBOLS AND ABBREVIATIONS (Continued)

RNAV	area navigation
ROR	rate of return
R&D	research and development
TAT/EPRL	true air temperature/EPR limit
Vac	volt alternating current
VASI	visual approach slope indicator
VFR	visual flight rules
V_s	certified stall speed
$\Delta\theta$	pitch attitude variation

4.0 SYSTEM DESCRIPTION AND EVALUATION

The 727 DFA procedures, AEMS concept, and the equipment required to implement the concept (as defined by ref. 2) are outlined in sections 4.1 and 4.2. Equipment operation, flight profiles, estimated benefits (time/fuel/noise), and other results of the Boeing engineering and piloted simulator study program (ref. 1) are summarized in appendix A for convenience. Other possible applications for the AEMS equipment and an alternate independent speed monitor concept are discussed in section 4.3 for future consideration, if the AEMS is further developed.

4.1 CONCEPT

The delayed flap approach is an operational procedure that could be used with existing VASI or ILS glide slopes (one segment) to reduce approach time, fuel, and noise. As indicated in figure 1, the approach is initiated from a low drag configuration at a higher-than-normal initial approach speed; e.g., clean, 220 kn. Gear and flaps are extended by the pilot at distances computed on board by the AEMS while decelerating at reduced power to the final approach speed. The final approach is stabilized in the landing configuration at a target speed and altitude above 152m (500 ft) selected by the pilot. The deceleration phase of the approach is flown with throttles fixed—essentially at idle. Drag management rather than throttle modulation is used to control energy to arrive at the selected stabilization altitude at the proper speed. Otherwise, the airplane is controlled in the normal manner.

The AEMS employs a digital computer and computer-driven cockpit displays to assist the pilot in following an optimized flight profile (which is adjusted for variations in wind, weight, and other operational variables) and in consistently stabilizing at a minimum practical target altitude. The system can be used during either manual or autopilot coupled approaches, under visual flight rule (VFR) or instrument flight rule (IFR) conditions, and does not involve any modifications to the existing flight control systems. The AEMS is strictly an advisory system that can be used, ignored, or turned off at the discretion of the pilot.

4.2 EQUIPMENT

The 727 AEMS configuration as specified by reference 2, which was used as a basis for this cost study, includes the following avionics:

- Airborne digital computer and interface equipment
- Control panel
- Annunciator panel

The AEMS concept also requires a fast/slow indicator on the ADI, which would require an ADI modification for about 80% of the 727 fleet. The fast/slow indicator would be provided

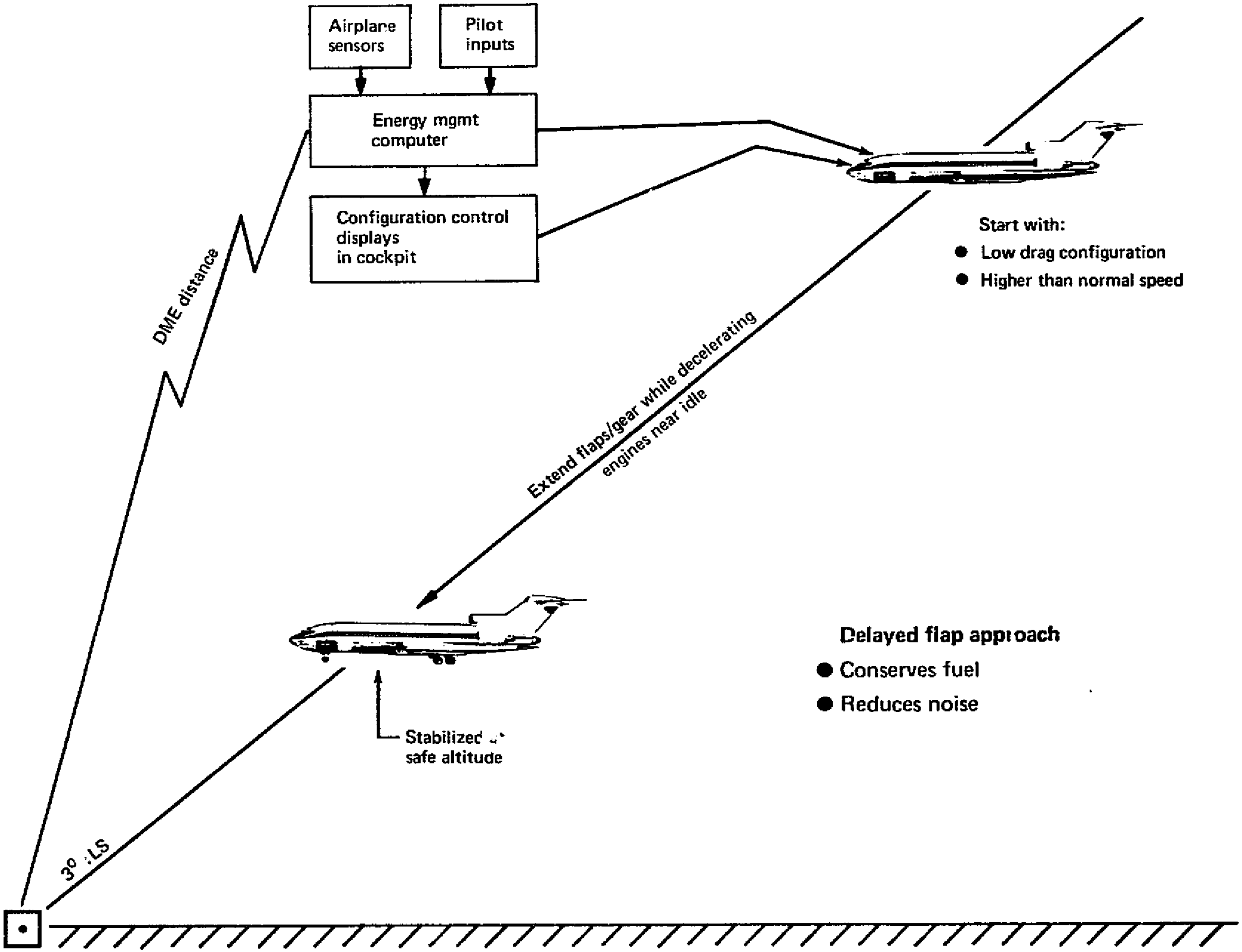


Figure 1.—727 AEMS Concept

as part of the AEMS retrofit kit as required. In addition to the airborne equipment, operational use of the AEMS requires a VASI or ILS glide slope (or other flight-path reference) and collocated DME ground station.

The AEMS avionic components and the required airplane sensor inputs are indicated schematically in figure 2. The proposed locations for the cockpit displays and the physical arrangements of the control panel and annunciator panel are shown in figures 3 through 5. These locations and arrangements are as defined in the preliminary avionic specification (ref. 2). The final configuration for an airline installation could be tailored to meet individual airline requirements.

4.3 OTHER POSSIBLE APPLICATIONS

The AEMS concept requires installation of:

- An airborne digital computer
- A cockpit control panel including a digital input keyboard
- Cockpit displays showing the proper settings for throttles, (EPR), flaps, and gear
- A fast/slow indication of energy

If the concept is further developed, it is expected that an independent speed monitor, probably based on angle of attack, would also be incorporated. In this case, the fast/slow indicator on the attitude director indicator (ADI) might be used as the independent speed monitor with the energy monitor(s) combined with the annunciator panel, as indicated in figure 6, or installed separately; e.g., adjacent to airspeed indicators.

The AEMS is utilized only during terminal area descent and approach, so the equipment is available for other functions during other flight phases such as:

- Takeoff Noise Abatement–Use of the computer, displays, and DME range information to assist the pilot in minimizing takeoff noise.
- Engine Limits–Systems to compute and display maximum power settings are currently in service on some Boeing aircraft (TAT/EPRL computer).
- Performance Optimization–Computation and display of optimum climb and cruise conditions and other performance information to minimize fuel consumption.
- Wind Shear Detection–The AEMS, using DME ground speed, continuously computes wind velocity during approach, which could be used for shear detection logic and implementation of cockpit warning.

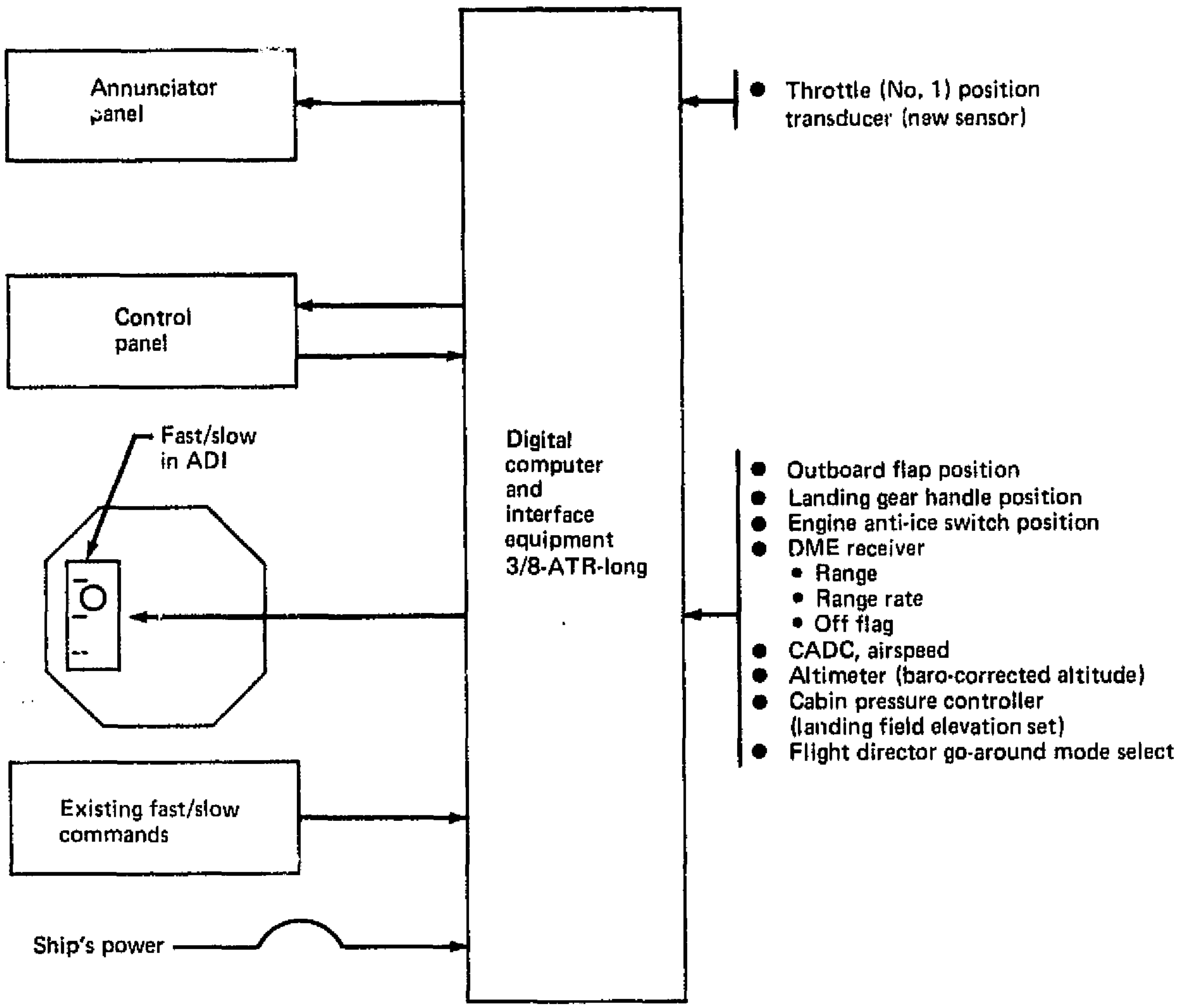


Figure 2.—727 AEMS Schematic

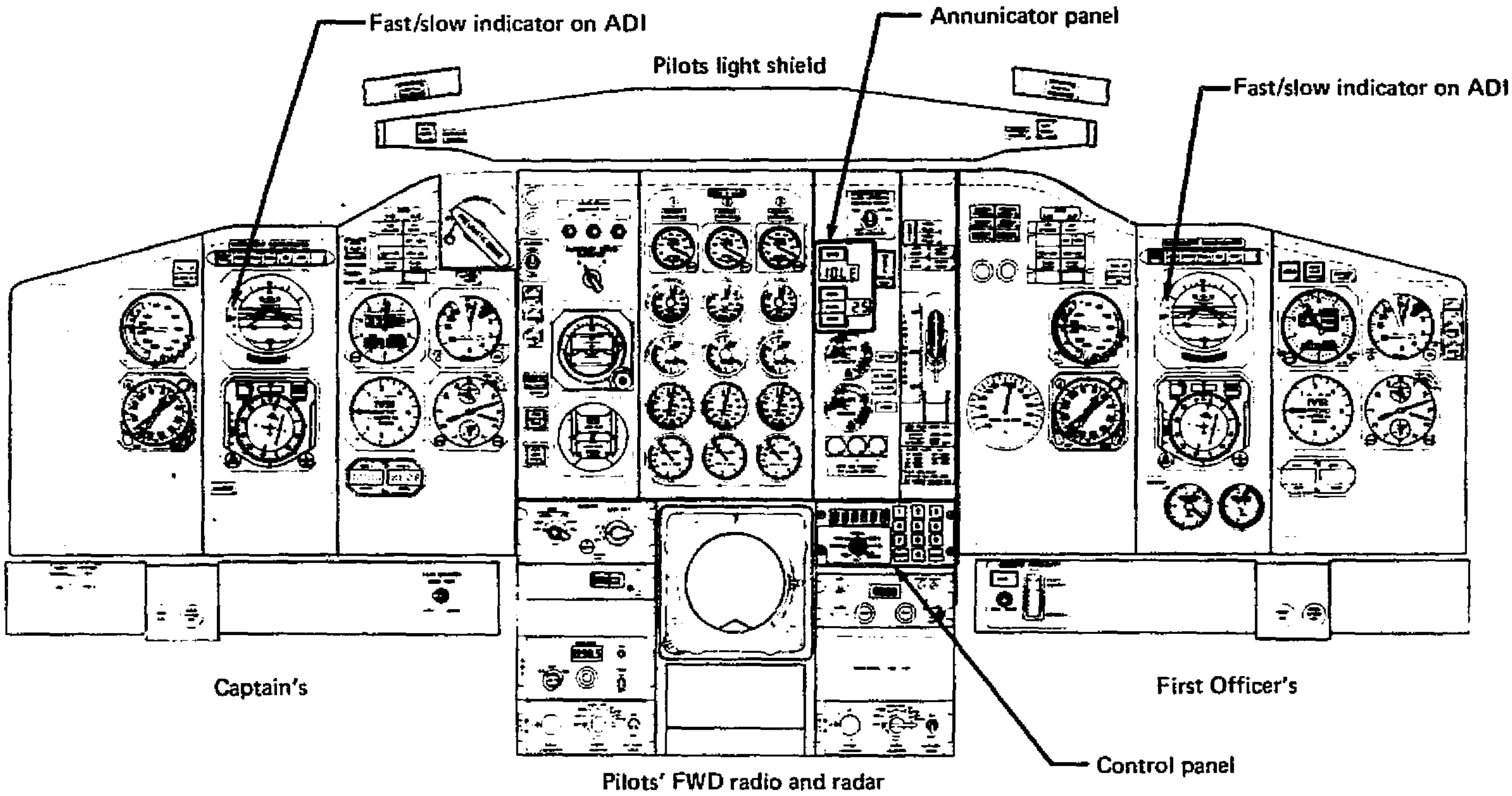


Figure 3.—727 AEMS Cockpit Displays

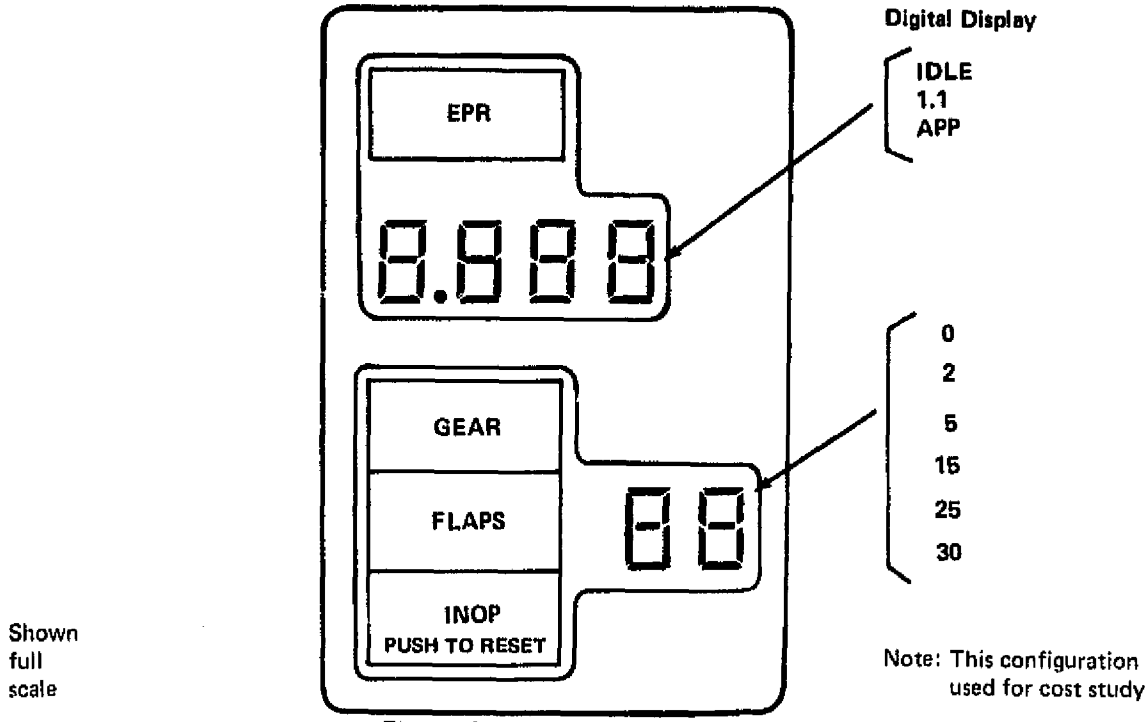


Figure 4.—Annunciator Panel

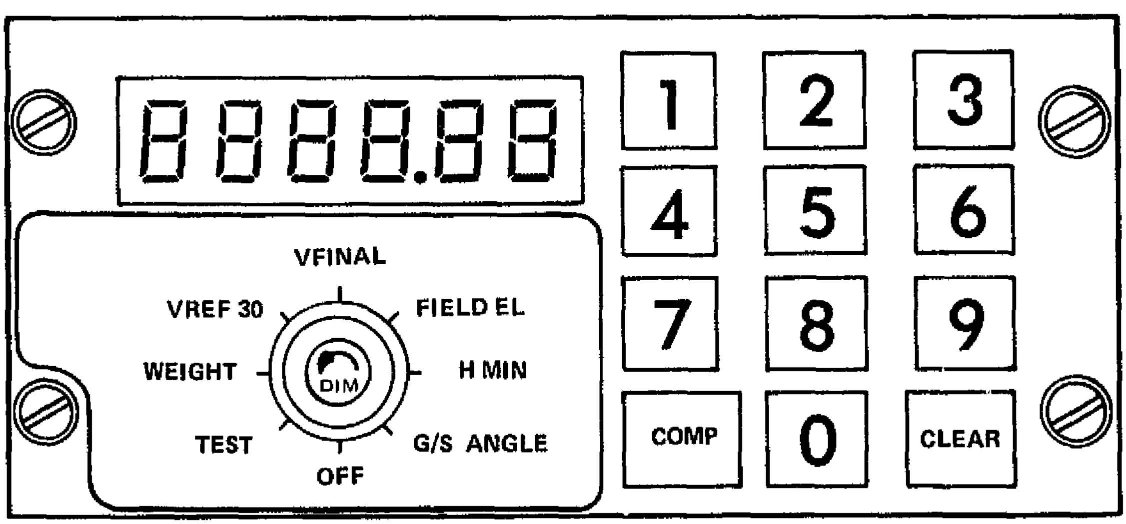
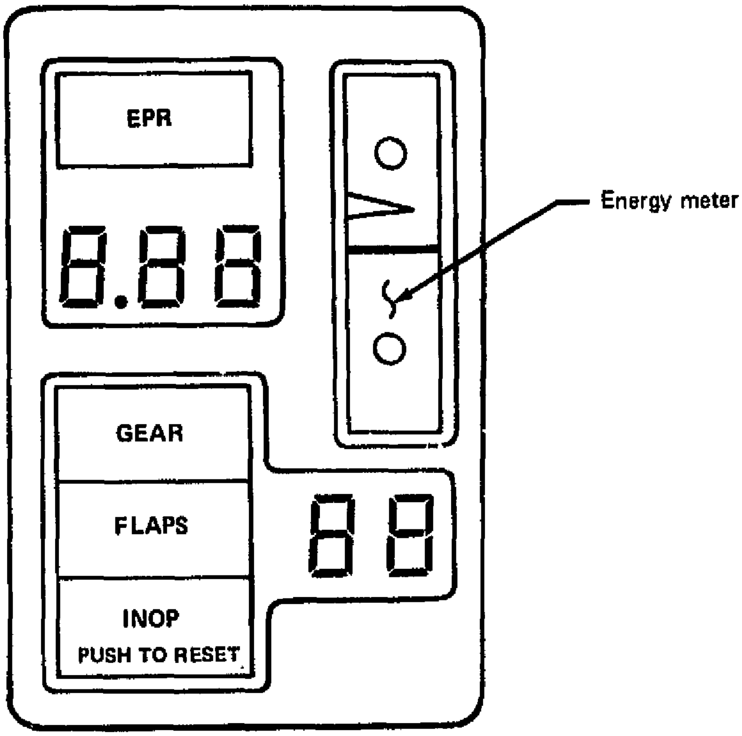


Figure 5.—Control Panel

Other applications for the AEMS computer, displays, and DME ground station have been suggested, but some of these (e.g., performance monitoring during takeoff roll, energy management for a two-engine-out landing) might have safety-of-flight implications that would alter the current AEMS design philosophy (advisory system only).

These potential applications have much in common. Selection of final onboard computer functions and configuration should explore further cost benefits of integrating related functions. (For cost of ownership of AEMS, see section 5.2.)



NOTE

- Not used for cost study.
- Proposed for future evaluation.
- Numerical EPR settings to be displayed rather than words "IDLE" and "APP".

Figure 6.—Combined Annunicator Panel/Energy Meter

5.0 AIRCRAFT AVIONIC RETROFIT COST STUDY

The AEMS retrofit cost study was conducted in two parts. Major emphasis was to determine the initial costs for AEMS implementation including prototype hardware development, certification, and airline fleet installation. These implementation costs were estimated by the Boeing 707/727/737 Division with avionic vendor participation. Estimating procedures were similar to those used in preparing budgetary estimates for an MC retrofit kit in response to an airline request. After the implementation costs had been determined, a brief cost of ownership study was conducted by the Product Assurance Engineering and New Technology Pricing groups. In addition to the implementation costs, this study included other cost considerations such as training, maintenance, spares, tax credits, and the return on the equipment investment resulting from fuel savings.

Note: There is no Boeing commercial program in progress for AEMS implementation. The cost data in this report are intended for use as part of a NASA R&D study to provide scoping-type information concerning system costs versus benefits and should not be interpreted as an offer to manufacture or install the equipment.

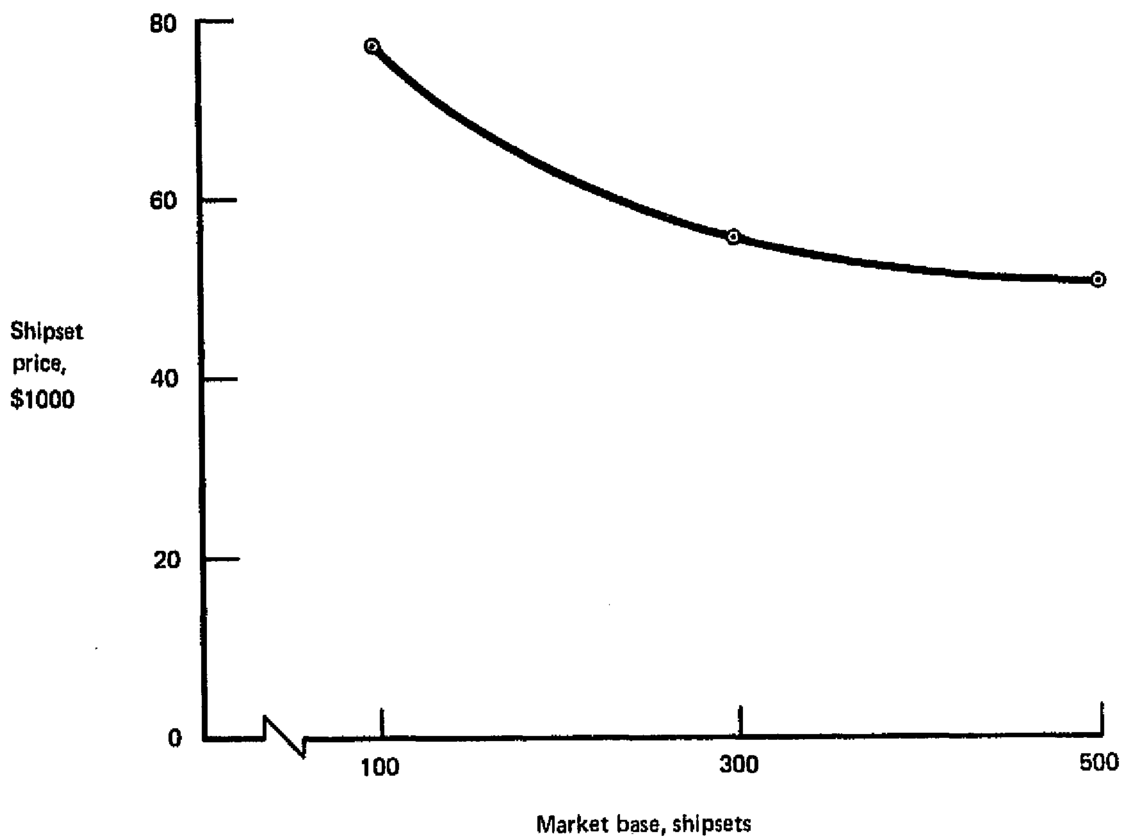
5.1 INITIAL IMPLEMENTATION COST STUDY

5.1.1 COST DATA

Estimated costs for implementing the currently defined AEMS (ref. 2) in the 727-200 are presented in figure 7. The price curve shown is for a Boeing-supplied MC kit, which includes the vendor-supplied avionics and other components as listed in table 1. Since the potential market for the AEMS has not been determined, the kit price is presented as a function of varying market base. The kit prices are expressed in 1976 dollars. The man-hours and calendar time estimated for customer airline installation of the kit are noted in figure 7 but are not included in the kit price curve.

Prototype development and type certification price of $2.2 million are identified as a lump sum as requested by NASA. The MC kit prices in figure 7 include recovery of the prototype program price as well as all other nonrecurring and recurring costs of the kits.

Cost data for the vendor-supplied avionics were obtained by requesting several avionic vendors to provide budgetary cost estimates based on the preliminary AEMS avionic specification (ref. 2). Five vendors responded with estimates for development and delivery of two prototype units to Boeing, including support of simulator and flight testing and for subsequent avionic production. Representative vendor estimates for the avionics are included in the Boeing estimates (fig. 7) for the prototype program and MC kits.



Note:

- Includes recovery of prototype program price ($2.2 million)
- Customer installation time (256 man hours, 5 days) not included
- 1976 dollars

Figure 7.—727 AEMS Retrofit Kit Price, Planning Estimate

Table 1.—727 AEMS Retrofit Kit Components

Digital computer and interface equipment[a]
Control panel[a]
Annunciator panel components[a]
Modified instrument panels (formed sheet metal only; i.e., no instruments)
Fast/slow installation kit for ADI
Parts kits to modify two DME interrogators for ARINC 568 outputs
Throttle position transducer[a]
Throttle cable quadrant and cables
Landing gear lever position switch
Engine inlet anti-ice switch
AEMS wire bundles
Miscellaneous wire stock and circuit breakers
Electronic equipment shelf modification parts
Documentation for customer installation, operation, and support

[a]Supplied by AEMS Avionic vendors.

5.1.2 DISCUSSION OF PROTOTYPE PROGRAM COSTS

The prototype program provides for hardware implementation and FAA certification of the 727 AEMS concept as currently defined by reference 2. The cost estimates include:

- Detailed definition of design requirements
- Avionic specification release and vendor selection
- Vendor development of prototype avionics (two shipsets)

- Computer software simulation and verification
- Failure analyses
- Avionic bench testing
- Engineering simulation (50 hr) to support:

  Design evaluation prior to avionics delivery

  Functional testing of avionic hardware prior to flight test
- Lease of a new factory airplane for flight test (6 weeks)
- Flight test installation design and parts fabrication
- Test aircraft modification and ground checks
- Engineering flight test (10 hr)
- FAA certification flight test (4 hr) red-labeled avionics
- Returning test aircraft to customer production configuration
- Test data reduction, analyses, and report
- FAA certification coordination and substantiation data

Prototype costs have been estimated with the assumption that an operationally satisfactory preliminary design concept has been defined by NASA prior to initiating hardware development. Hence, the engineering estimates reflect only detailed design costs and do not include any exploratory development or simulator evaluations to establish feasibility.

Flight test costs are based on the use of a new factory airplane to be modified by Boeing flight test operations. The airplane would be used for the AEMS test and then returned to the normal production configuration prior to delivery to the customer. This approach was selected because Boeing at present has no suitable 727-200 flight test airplane, and it would cost more to use an operational aircraft leased from the owner; e.g., the inspections required to establish conformity to specifications would already be accomplished on the factory airplane at no cost to the AEMS program.

The prototype program emphasizes simulator testing rather than flight testing of the AEMS hardware in order to minimize costs. Computer logic and cockpit display operation should be completely checked on the simulator before making the first flight. As currently envisioned, the only requirement for engineering flight testing of the AEMS is to adjust the thrust and drag models in the airborne computer, if necessary, to match the actual airplane and to confirm proper equipment operation in flight. Type certification tests would be flown on the same airplane immediately following the engineering flight test program. The prototype avionics, "red-labeled" to identify any modifications incorporated during the flight test program, would be used for the type certification testing.

5.1.3 DISCUSSION OF FLEET RETROFIT COSTS

Costs for 727-200 fleet retrofit were estimated using one typical airline customer configuration as a baseline for determining the MC kit price and customer installation costs. The vendor-supplied avionics were assumed to be identical for all customers. Therefore, it should be noted that the current AEMS computer program applies only to the 727-200 with JT8D-9 engines. Additional costs, including first of model certification for each airframe/engine combination, would be incurred in adapting the AEMS for use on airplanes equipped with other engines or with engine intermix. These costs have not been included in figure 7.

A majority of the avionic design work and part of the airplane installation design would be accomplished during the prototype program. The engineering necessary to provide suitable airplane sensor inputs to the AEMS (e.g., new throttle position transducer, sensor interface isolation to prevent failure propogation, etc.) are included in the prototype program.

Additional engineering and customer support man-hours will be required following prototype certification to implement the AEMS into airline fleet service. These production engineering and support costs along with manufacturing and acceptance test costs are included in the curves of retrofit kit price.

Retrofit kit program costs common to all 727-200/JT8D-9 customer configurations include:

- Avionic production (engineering, tooling, manufacturing, and manuals)
- Avionic qualification and bench testing
- Computer production software
- Common installation components (cable assemblies for throttle position transducer, electrical wires, etc.)
- Design support and documentation of common components

Planning estimates are shown in figure 7 for market bases to 500 shipsets. Because of the numerous airframe/engine combinations and customer configuration variables involved it should be recognized that few components other than the avionics hardware would be the same for all kits. There would be minor variations in the computer software to account for airframe/engine model differences, and the AEMS cockpit display packaging may vary depending on customer preferences. In addition to variations in the AEMS avionics, much of the Boeing work necessary to supply a retrofit kit is applicable only to one customer configuration. This includes:

- Flight deck rework design and parts
- Electronic equipment shelf rework design and parts
- Design of wire routing and interface with ADI and air data systems
- Revision of customer manuals (operations, training, maintenance, and wiring diagram)
- Service bulletin preparation

The estimated man-hours and calendar time required for customer installation of the retrofit kit include ground functional checkout of the AEMS but do not include defueling or normal preflight and/or postflight inspections of the airplane. The installation could be made concurrent with other scheduled maintenance layups to minimize airplane down time.

5.1.4 TECHNICAL WORK DESCRIPTION

Implementation of the AEMS requires several airplane modifications to install the avionics and provide the necessary sensor inputs. To establish a good basis for estimating retrofit costs, engineering work statements were prepared by the appropriate 727 project groups to define the AEMS retrofit kit and kit installation requirements. One typical customer airline configuration, requiring a representative amount of rework, was selected for study. A general description of the installation corresponding to the cost estimates is presented in the following paragraphs.

Figure 8 shows the relative locations of the various AEMS components and inputs located in two general areas: the electronic bay and the cockpit.

- Electronic Bay—The AEMS computer and interface equipment, including a power supply module, are packaged in a 3/8-ATR-long box which is installed on a reworked electrical equipment shelf. The central air data computer (CADC) and the DME receivers, which provide inputs to the AEMS computer, are also located in this area. Although the flap position transmitter is located in the wing, the AEMS wiring can be spliced into existing wire runs to the flap position indicator in the cockpit.

- Cockpit—The AEMS annunciator panel, control panel, fast/slow indicator, and throttle position transducer are installed in the cockpit area, where the other required sensors and switches are also located.

The throttle position transducer is a completely new installation which requires installing a throttle cable quadrant and two new cable assemblies (replacing one existing cable assembly) in addition to the transducer and wiring. The landing gear lever switch is a new switch that provides a logic signal (ground) to the AEMS computer when the gear lever is placed in the down position. The engine inlet anti-ice logic signal (ground) is provided by adding an

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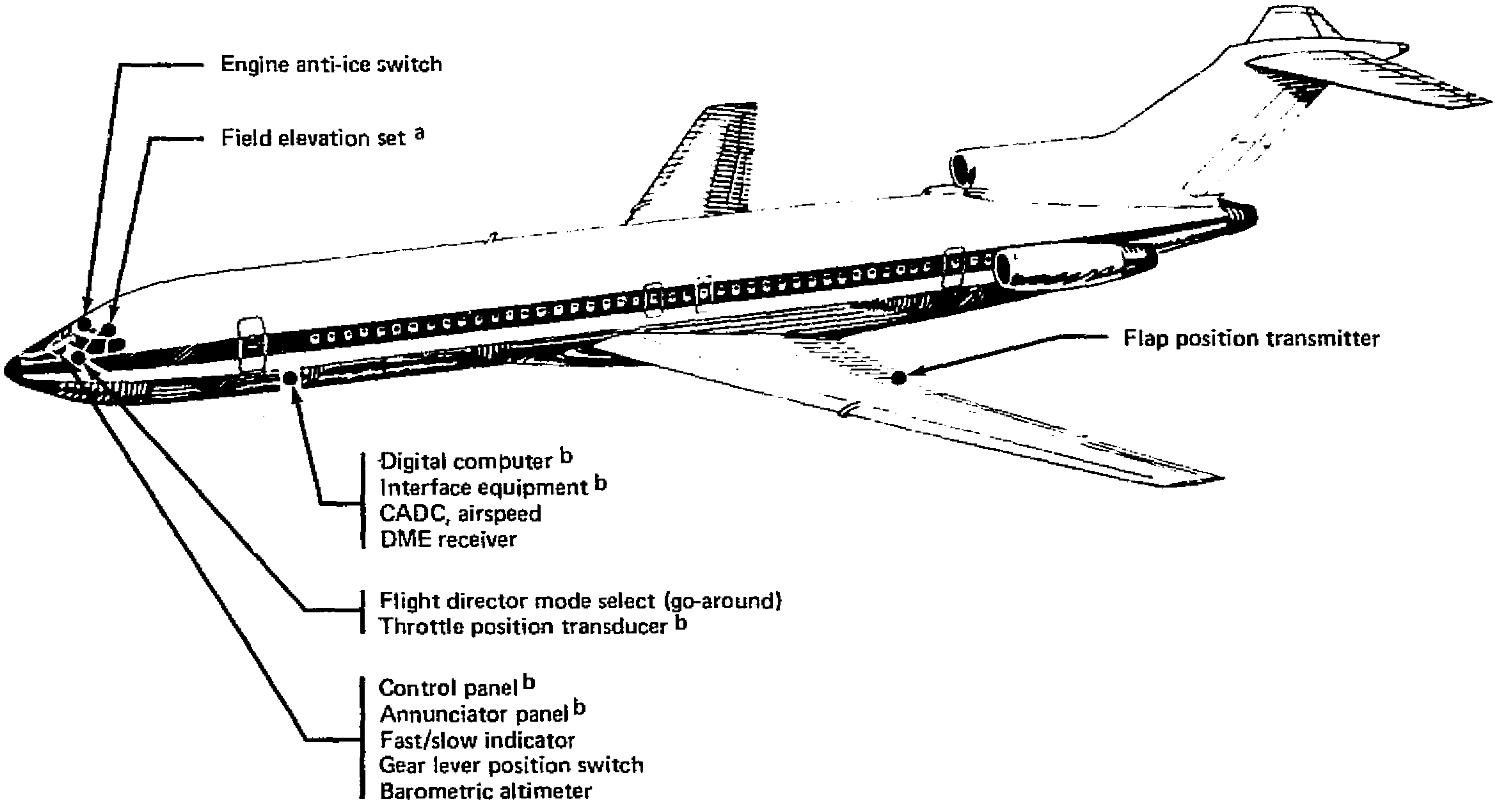


[a] Not available on some 727 models.
[b] Supplied by AEMS vendor.

Figure 8.—727 AEMS Installation

additional contact to an existing switch. The flight director go-around mode logic signal is provided from an existing switch. This signal returns the AEMS computer to standby status when a go-around is initiated.

The field elevation input from the electronic cabin pressure controller is used by the AEMS as a default value which the pilot can replace through the AEMS control panel if he so chooses. While useful in reducing pilot workload, this input may not be essential. Since many 727 aircraft are equipped with a pneumatic rather than electronic cabin pressure controller, deletion of the requirement for this input should be considered if the AEMS is further developed.

The airspeed synchro signal and a CADC-valid signal are available from the CADC. Baro-corrected altitude signals (fine and course synchro) are obtained from the captain's altimeter.

The existing DME interrogators (two per airplane) are of the ARINC 521D type for the particular 727 customer configuration selected as a baseline for preparing the work statements. It was assumed these would be modified by the customer to provide the ARINC 568 range (pulse pair) and range rate required for AEMS operation. The DME-valid signal is available without modification. The technical concepts for obtaining and processing the DME information should be carefully reviewed, including consideration of serial word (ARINC 561) transfer, if the AEMS is further developed. However, the approach used in this study should provide representative cost data.

There is no fast/slow indicator on the ADI installed in the particular 727 airplane selected for this study. However, the manufacturer has a kit for modifying the existing ADI, so it would not be necessary for the customer to purchase a new instrument. Since a fast/slow indicator is already installed on some customer configurations, provisions for switching the fast/slow signal source are incorporated within the AEMS. Modification of the existing fast/slow wiring on airplanes so equipped would be required to bring the existing signal into the AEMS computer. Installation of the AEMS control and annunciator panels requires rework in the flight deck area. For the customer configuration selected for this study, it would be necessary to:

- Install modified ADI's
- Relocate the ATC controller from the pilots' forward electronic panel to the pilots' overhead panel
- Install the AEMS control panel in the space vacated by the ATC controller
- Install the annunciator panel components: light plate, incandescent numeric displays, and annunciator lights. (These would be installed individually rather than being incorporated in a single box.)

Electrical power for lighting the AEMS control and annunciator panels is available from existing 0- to 5-Vac cockpit lighting circuits. Input power (115-Vac, four-wire, three-phase ship's power) to the AEMS computer power supply is available in the electronic bay. The

AEMS computer receives inputs from the AEMS control panel and from all other sensors and switches, including the reset switch on the annunciator panel. Outputs from the computer must be provided to the annunciator panel, the digital readout on the control panel, and the fast/slow indicator. Electrical equipment shelf wiring must be revised and additional wires added to connect the various components. About 20 existing wire bundles are affected.

Installation details would vary between customer configurations. However, these types of modifications are typical.

5.1.5 COST STUDY GROUND RULES

The implementation cost estimates were based on the following ground rules:

- Kit Prices–Prices are to be in 1976 dollar budget estimates presented as a function of market base (100, 300, and 500 shipsets).

- Prototype Program–For NASA planning purposes, the prototype program costs included in the kit price are to be identified as a lump sum.

- Airplane Configuration–Only the 727-200 with JT8D-9 engines in a typical airline customer configuration, requiring an average amount of rework in order to install the delayed flap system, will be considered.

- Fleet Installation–To be accomplished by the individual airlines using an MC retrofit kit supplied by Boeing. Customer installation costs to be expressed as kit installation man-hours and calendar time.

- Certification–A revision to the 727 basic type certificate will be obtained as part of the prototype program. First-of-a-model certification to cover customer variations will be accomplished by the airline.

- Avionics–The AEMS computer and cockpit displays will be part of the retrofit kit. Although cockpit arrangement may vary, the avionic components will be assumed to be identical for all customers.

- Fast/Slow Indicator–It will be assumed that the existing ADI has no fast/slow indicator and will be modified by installing a Collins fast/slow kit P/N 768-1352-001 per Collins service bulletin No. 7. The AEMS kit costs will include the cost of the Collins fast/slow kit but not the cost of the entire ADI.

- Autothrottle–Costs are to be estimated for airplanes not equipped with autothrottles. Autothrottles are not required for AEMS implementation. Existing autothrottles would have to be modified (additional cost) or turned off for delayed flap approaches.

- Simulator Testing–All simulator testing required for design support and testing of the avionic software and hardware will be conducted using Boeing simulation facilities, with vendor participation as required.

- Prototype Installation–The prototype installation is to be made by Boeing Flight Test Operations on a new factory airplane as normally delivered. The airplane is to be leased for the AEMS test program and then returned to the production configuration prior to delivery to the customer.

- Flight Testing–All engineering flight testing and type certification (one 727-200 only) will be conducted by Boeing in Seattle, Washington. No costs are to be included for: (1) DME ground station and (2) noise measurements.

Note: It is assumed the DME ground station will be supplied by NASA for the flight test program. Since noise certification would not be affected, noise measurements are not required for AEMS certification.

5.2 COST-OF-OWNERSHIP STUDY

A brief cost-of-ownership study was conducted to give an indication of the total costs for AEMS implementation and operation and of the potential return on the equipment investment which could accrue from the resultant fuel savings. A typical domestic airline with a 727 fleet of 58 airplanes (average) was selected for study.

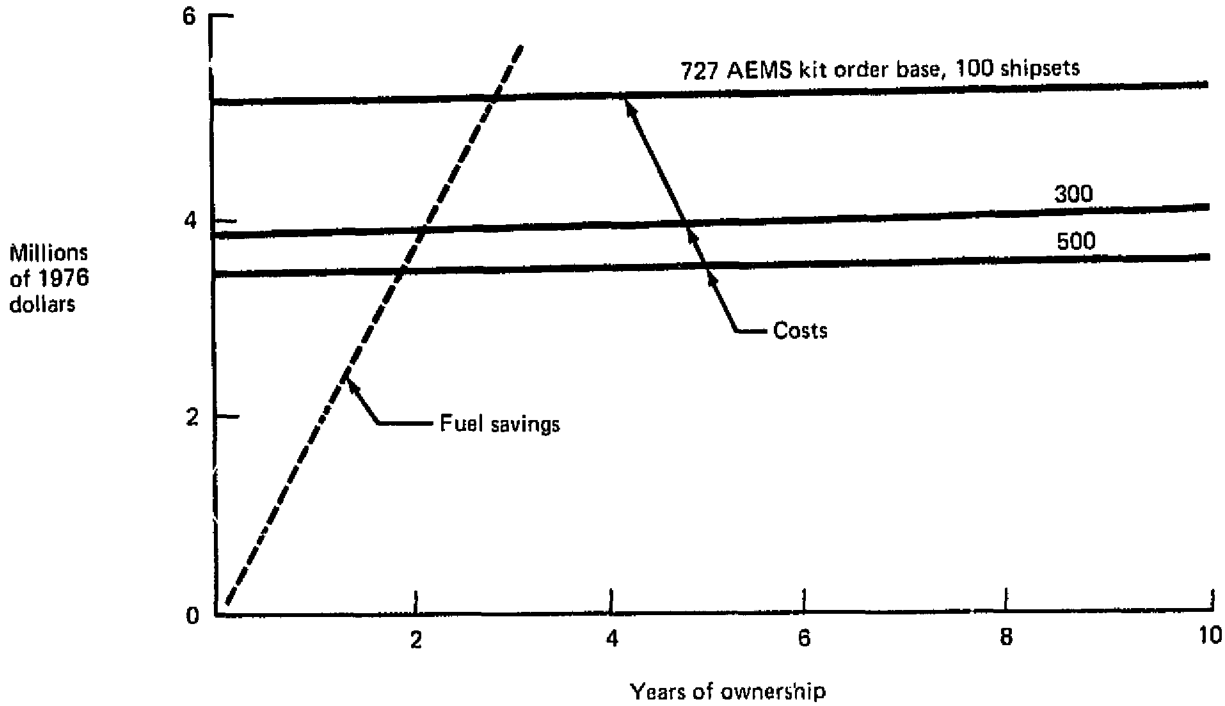
Cumulative costs for implementation and operation of the AEMS and the cumulative dollar value of the estimated fuel savings (at 1976 fuel price) are shown in figure 9 in constant (1976) dollars. In the absence of a defined retrofit program, the cost curves are shown for three arbitrary AEMS retrofit kit market bases (100, 200, and 500 shipsets), assuming all 58 airplanes are modified simultaneously at year zero. Although simultaneous modification is not practical, the curves illustrate the total magnitude of costs for a typical fleet. The same cost data are presented on a per-airplane basis in figure 10.

Assuming an AEMS retrofit kit market base of 300 shipsets, cost and benefit data from figure 9 were used in an investment analysis for the 58-airplane fleet. This analysis (sec. 5.2.3) was based on present value of net cash flows, referred to as net present value (NPV). Two NPV models were examined, one in constant (1976) dollars with constant (1976) fuel prices and the other in real time (inflated) dollars with increasing fuel prices. The cash flows (fig. 11) include a discount rate of 15% and adjustments for Federal taxes, which were excluded from the cost and benefit data shown in figures 9 and 10.

Results indicate the fuel savings would pay back the initial investment in less than 3 years and provide a 33% to 38% rate of return on the investment, based on NPV. The additional AEMS benefits of reduced approach time and noise were not included in the economic analysis.

5.2.1 OPERATIONAL COSTS (EXCLUDING FUEL SAVINGS)

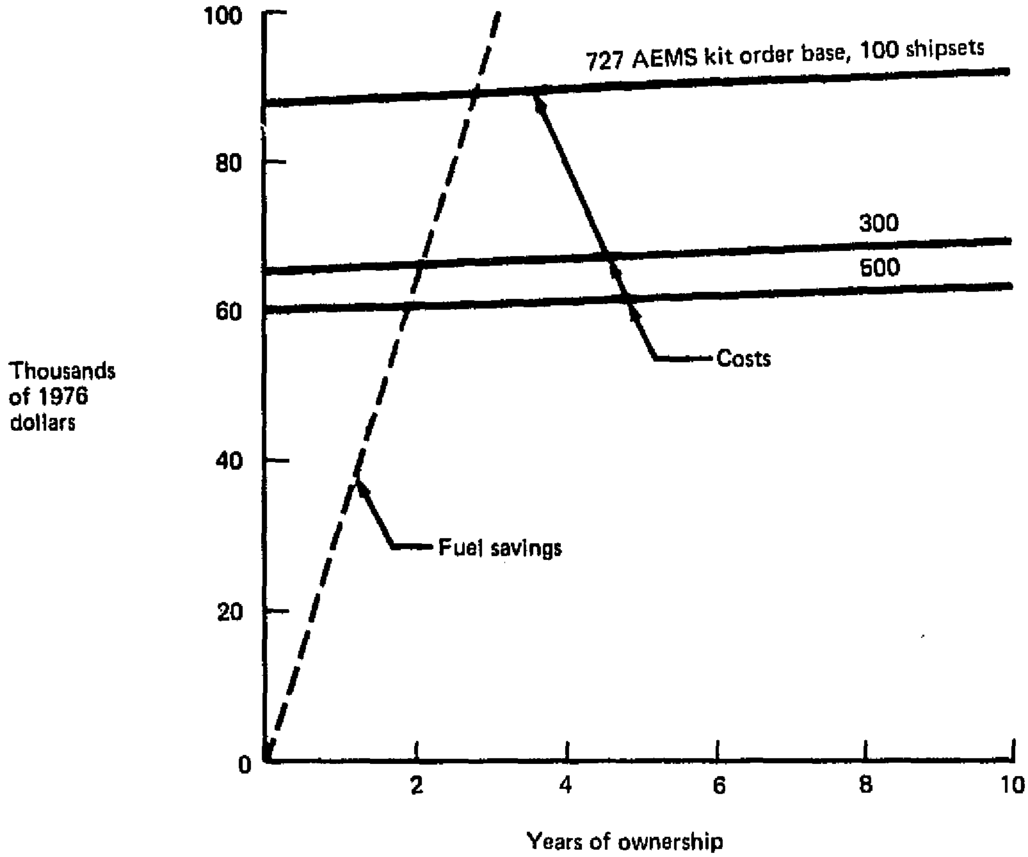
The cumulative cost curves (figs. 9 and 10) include initial implementation costs as follows (per airplane):



Note:

- Tax adjustments and finance costs not included
- Constant dollars and fuel prices (1976)

Figure 9.—Cumulative Costs and Fuel Savings for 58 Airplane Fleet



Note:

- Tax adjustments and finance costs not included
- Constant dollars and fuel prices (1976)

Figure 10.—Cumulative Costs and Fuel Savings per Airplane

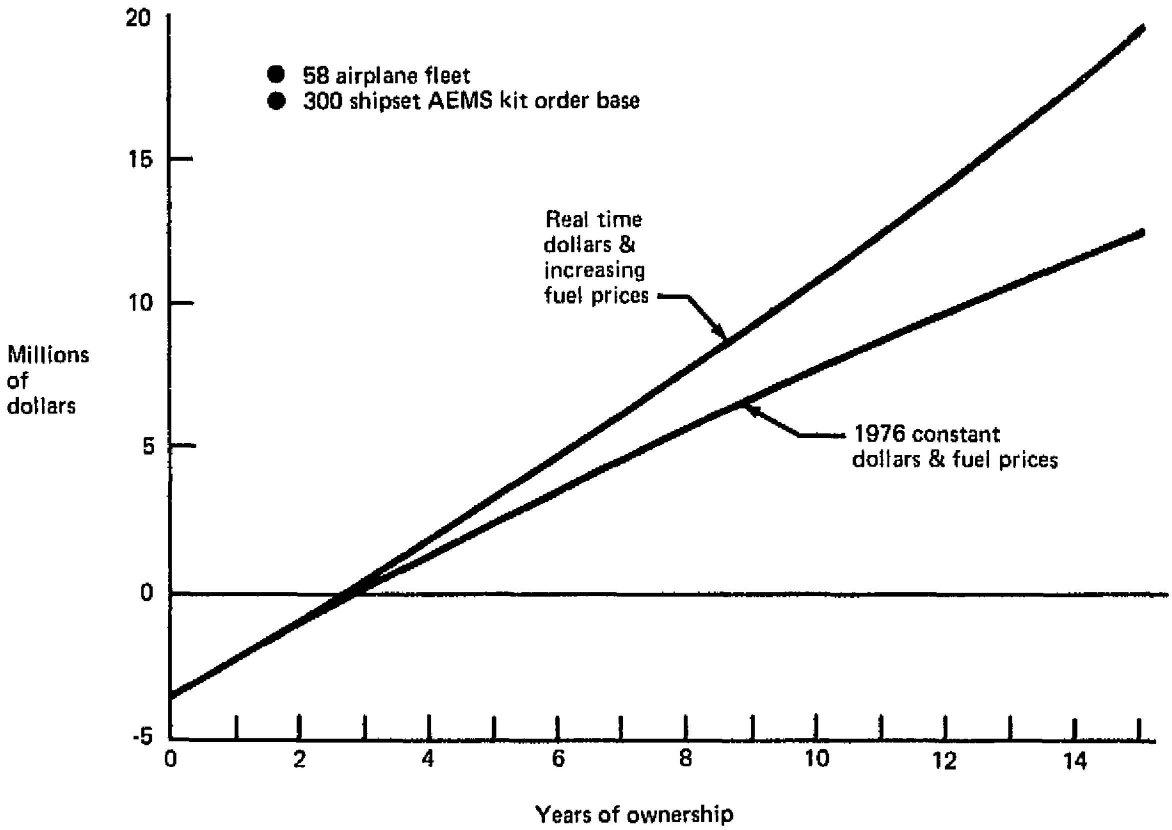


Figure 11.—Cumulative Cash Flows for 727 AEMS Retrofit

- AEMS retrofit kit purchase price (fig. 7)
- Kit installation man-hours ($6100)
- Spares purchase (10% of LRU costs)
- Maintenance training ($500)
- Support equipment (main base only)
- Insurance ($650)

The slope of the cost curve reflects the annual operation costs ($400 per airplane) for maintenance, spares holding, and the slight [less than 4.45 N (1 lb) per flight] cruise fuel penalty caused by the AEMS equipment weight, 111 N (25 lb).

Line and shop maintenance cost estimates were based on the reliability requirements of the avionic specification and on inservice data for similar equipment. These data were also used in determining the number of spare avionic units required (10% of fleet). In determining the number of spares, it was assumed there should be one spare at each line maintenance base and enough spares at the main base to sustain the system with a 14-day main-base shop turnaround time. The maintenance training costs were based on the number of line and shop mechanics employed by the airline considered, assuming training times of 20 hr for each line mechanic and 80 hr for each shop mechanic. Main-base ground support equipment costs were estimated to be $50 000.

Some possible costs not included in the curves are:

- Airplane Down Time—It was assumed the AEMS would be installed during other scheduled layups.
- Installation Checkout Flight—Except for first-of-a-model certification flights, ground checkout should suffice.
- Delays and Cancellations—Since the AEMS is advisory in nature and would not be required for dispatch, it was assumed there would be no delays or cancellations of revenue flights due to the AEMS.
- Flightcrew Training and Simulator Modification—Costs would vary with the airline and have not been estimated. Probably the most economical way to modify the airline simulators would be to install the actual AEMS flight hardware, including computer.

5.2.2 FUEL COST SAVINGS

As discussed in appendix A, the AEMS allows use of DFA procedures that conserve 1420 to 1750 N (320 to 395 lb) of fuel per approach, relative to current airline procedures. The dollar value of the fuel savings resulting from use of the AEMS was computed from:

$$\text{Annual Fuel Cost Savings} = (G)(P)(n_{DFA})$$

where:

G = Quantity of fuel saved per approach

P = Price of fuel

n_{DFA} = Number of delayed flap approaches per year

The values used in computing the constant dollar, constant fuel price lines shown in figure 9 are:

G = $0.17 m^3$ (45 gal) per approach (see app. A)

P = $\$90/m^3$ (\$0.34/U.S. gal)

n_{DFA} = $0.75 \times 160,700$ approaches per year

The number of DFA's assumes that delayed flap procedures can be used for 75% of the approaches. The domestic airline used as a basis for this study made 160 700 landings in 1 year with a 58 airplane 727 fleet (average of about 7.6 landings per airplane per day). Applying the 75% factor (assumed) gives about 120 000 DFA's per year for the fleet (5.6 per airplane per day).

Using these data, fuel savings are computed to be about \$15.30 per approach. This accumulates into about \$31 800 per airplane per year (fig. 10), which results in a total savings (before taxes) of about \$1.8 million per year for the 58 airplane fleet considered (fig. 9).

These savings based on 1976 fuel prices were used for the constant dollar investment analysis in section 5.2.3. The real time (inflated dollar) analysis used the same fuel savings data, except domestic fuel prices were assumed to increase linearly from $\$90/m^3$ (\$0.34/U.S. gal) in 1976 to $\$148/m^3$ (\$0.56/U.S. gal) in 1985.

5.2.3 RETURN ON INVESTMENT

A costs-benefits analysis, based on present value of net cash flows [referred to as net present value (NPV)], was used to determine the return on the investment for AEMS implementation and operation. Two NPV models were examined, one in real time or inflated dollars and the other in 1976 or constant dollars.

In evaluating an investment decision, NPV measures the relationship of cash expenditures versus cash receipt—the net difference being annual cash flows. In determining annual cash flows, the annual fuel savings less the yearly direct operating costs (DOC) adjusted for taxes (50%) were added to the yearly depreciation tax credits and computed on the double-declining balance method, a form of accelerated depreciation. The yearly flows start at period zero and run through period 15.

The basic idea of net present value is simply to find the balance of the tradeoff between the investment outlay and the future benefits or cost savings, in terms of time-adjusted present value dollars. Present value is the inverse of compound interest. A dollar earned today, even without inflation, is worth more than a dollar earned 5 years from now, because the dollar today could be invested to provide a rate of return or earnings. In the analysis, a 15% discount rate was used. The term discount rate may be viewed as the minimum acceptable rate of return or an earnings standard. Given such a standard, it is possible through a computer program to determine the present value of all cash inflows over the economic life of the system. Since the net present value was positive in both models, it indicates that the project exceeded the earnings standard or minimum acceptable rate of return.

Tables 2 and 3 show the annual flows, the annual discounted flows, the cumulative flows, and the cumulative discounted flows. Table 2, presented in 1976 constant dollars, shows a net positive present value of $3.0 million or an internal rate of return of 33% after taxes. Table 3 presented in real time or inflated dollars, shows a net positive present value of $4.8 million or an internal rate of return equivalent to 38% after taxes.

Whether viewing the investment in terms of real time or constant dollars, the return or yield (33% to 38%) is greater than the assumed minimum acceptable return rate of 15%. In the constant dollar model, the rate of return was computed at 33.03%. This is the same as saying that with an initial investment of $3 433 691 an average yearly return of profit of 33.03% would be realized. In the real time or inflated dollar model, the rate of return was computed at 38.22%; here an average yearly return or profit of 38.22% would be realized.

In both models the payback period occurs in less than 3 years. This is the time required to recoup the initial cash outlay needed for purchase and installation of the AEMS. This break-even point is illustrated in figure 11 by showing cumulative cash flows and nondiscounted values for the two respective models. Initial cash outlay, the negative value entered in period zero for both models, is computed as: $3 815 212 the nonrecurring costs less the 10% investment tax credit of $381 521 which equals $3 433 691.

Table 2.—Net Present Value

$$\frac{\text{(Annual Fuel Savings - DOC)}}{2} + \text{Depreciation Credit} = \text{Annual Cash Flow After Taxes}$$

1976 Constant Dollars

Flow	Annual flows	15% discount rate	Cumulative flows	Cumulative discount flows
0	$ -3 433 691	$ -3 433 691	$ -3 433 691	$ -3 433 691
1	1 239 200	1 078 104	-2 194 491	-2 355 587
2	1 186 210	896 775	-1 008 281	-1 458 812
3	1 162 125	764 678	153 844	694 134
4	1 138 037	650 957	1 291 881	-43 177
5	1 113 952	553 634	2 405 833	510 457
6	1 089 866	470 822	3 495 699	981 279
7	1 065 781	400 734	4 561 480	1 382 013
8	1 041 694	340 634	5 603 174	1 722 647
9	1 017 608	289 001	6 620 782	2 011 648
10	993 523	245 379	7 614 305	2 257 027
11	969 437	208 429	8 583 742	2 465 456
12	945 350	176 780	9 529 092	2 642 236
13	921 265	150 166	10 450 357	2 792 402
14	921 265	129 898	11 372 622	2 922 300
15	921 265	113 316	12 292 887	3 035 616

Net present value (NPV) = $ 3 035 616
Rate of return (ROR) = 33.03%

Table 3.—Net Present Value

$$\frac{\textit{(Annual Fuel Savings - DOC)}}{2} + \textit{Depreciation Credit} = \textit{Annual Cash Flow After Taxes}$$

Real Time Dollars

Flow	Annual flows	15% discount rate	Cumulative flows	Cumulative discount flows
0	$ -3 433 691	$ -3 433 691	$ -3 433 691	$ -3 433 691
1	1 238 422	1 077 427	-2 195 269	-2 356 364
2	1 251 591	946 203	943 678	-1 410 061
3	1 293 597	851 187	349 919	-558 874
4	1 335 528	763 922	1 685 447	205 048
5	1 377 383	684 569	3 062 830	889 607
6	1 419 153	613 074	4 481 983	1 502 681
7	1 460 832	549 273	5 942 815	2 051 954
8	1 502 411	491 288	7 445 226	2 543 242
9	1 543 883	438 463	8 989 109	2 981 705
10	1 585 241	391 555	10 574 350	3 373 260
11	1 626 474	349 692	12 200 824	3 722 952
12	1 667 571	311 836	13 868 395	4 034 788
13	1 708 025	278 408	15 576 420	4 313 196
14	1 773 407	250 050	17 349 827	4 563 246
15	1 837 619	226 027	19 187 446	4 789 273

Net present value (NPV) = $ 4 789 273
Rate of return (ROR) = 38.22%

6.0 GROUND FACILITY COST STUDY

A DME ground station collocated with a glide slope reference (ILS, VASI, or other) is required for operational use of the 727 AEMS. A study to determine the availability of existing ground facilities and the cost of the necessary additional ground facilities was conducted as part of the AEMS implementation cost study. Objectives of the ground facility study, as specified by NASA, were to determine the number and cost of the new installations necessary so that DFA procedures using the AEMS could be employed for 50% of all domestic 727 approaches. To establish a data base for this study, the ATC Systems Analysis group at Boeing provided cost estimates for typical DME installations, and the 727 airport traffic and facilities summaries presented in Appendices B and C.

Based on review of the traffic and facilities data, it was concluded that no new ISL or VASI installations would be required to meet the 50% of 727 traffic objective. However, collocated DME ground stations are currently available on only 14 domestic runways which handle less than 10% of the 727 traffic (see sec. 6.2).

The cost of installing one new DME station is estimated to be:

DME location	DME cost	Reference
ILS	\$ 60 300	FAA facilities and equipment (F&E) budget, FY '76
VASI	\$100 000	Boeing estimate (includes additional costs for shelter and power)

The number of new DME installations required to meet the 50% of 727 traffic objective could vary widely, depending on the criteria used in selecting the runways to be equipped. Ground facility expense could be minimized by installing the DME staitons at the specific runways handling the most 727 traffic. This approach was not used, partly because available airport traffic data for the 727 do not list traffic for individual runways. Instead, the number of new DME stations was based on two sets of DME runway selection criteria. As discussed in section 6.5, one method (low DME cost) emphasizes DME installation on runways with high density 727 traffic. The other method (noise emphasis) requires more DME stations distributed at more airports, including some with relatively low density traffic but with communities located so that the AEMS would be effective for noise abatement.

Cumulative costs for the DME installations are shown in figure 12 as a function of cumulative approaches. It is seen that DME installation costs to accommodate 52% of 727 approaches vary from \$3 to \$5 million for the two selection criteria considered.

Operating and maintenance costs per year to keep one DME operational were estimated to be \$34 663 computed as follows. Reference 3 indicates that the FAA allocation for maintenance is 0.71 man-years per DME. Reference 4 indicates that FAA maintenance man-year

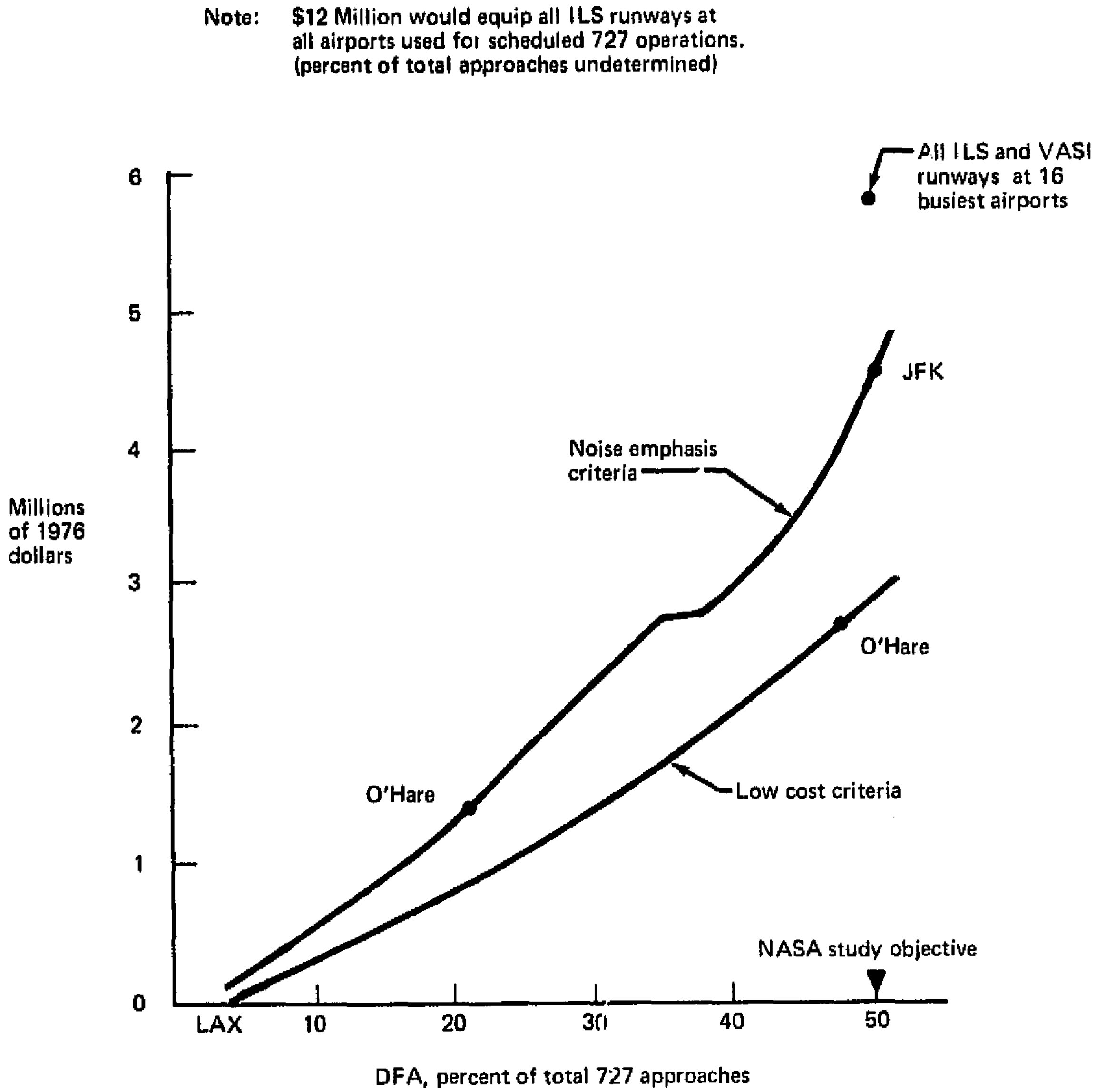


Figure 12.—Cumulative Costs for New DME Stations

costs are approximately \$45 000. Thus, maintenance costs would be \$31 950. Stocks and stores (4.5%) would be \$2713 for a total of \$34 663/unit/year. Total annual costs would be about \$1.7 million for 49 units (low cost criteria) and \$2.4 million for 69 units (noise emphasis criteria).

Because of the arbitrary nature of the criteria used for this scoping study, these data should be used primarily as an indication that costs for new DME ground stations are relatively small compared with airplane retrofit costs, e.g.:

	Assumed installations	Approximate cost
DME ground stations	69	\$ 5 million
Airplane retrofit	500	\$30 million

A 500 airplane retrofit program would equip only part of the domestic 727 fleet. If the AEMS were installed in all transport models, the ground facility costs might become insignificant compared to the airline fleet implementation costs.

If an AEMS implementation program were initiated, a much more comprehensive study would be required to select the best locations for new DME installations. Such a study should involve the FAA (ATC, and F&E) and the airlines. The study should consider individual airline route structure so that each AEMS-equipped airplane could use the system at every destination.

6.1 REQUIRED GROUND FACILITIES

DFA procedures are flown on conventional one-segment glide slopes. Since the AEMS predicts deceleration profiles for a preselected glide slope angle, some type of flightpath reference (ILS, VASI, or other) is required so that the airplane can be flown along approximately the same final approach glide slope as that set into the computer. The path reference need not be electronic because the AEMS computer determines the airplane's position in space from altitude and distance information; i.e., ILS glide slope deviation is not used. Availability of an ILS glide slope is preferable from a pilot workload point of view, so that the autopilot can be used. However, in the interest of operational flexibility, the current 727 AEMS avionic configuration (ref. 2) does not require ILS signals, either for the energy calculations or as an operational interlock.

Distance and groundspeed information are necessary to adjust the profile predictions for wind, to compare actual energy against the desired profile, and to determine when successive flap, gear, and EPR settings should be made. Since a typical 727 is not equipped with inertial navigation system (INS) or area navigation (RNAV) capability, the current 727 AEMS avionic concept requires that the necessary distance and groundspeed information be obtained from a DME ground station colocated with the glide slope.

In the interest of eliminating the requirement for installing collocated DME ground stations, an engineering study was conducted to determine if the 727 AEMS could be adapted to work with range information derived from the ILS. Two concepts were evaluated: one using barometric altitude and glide slope deviation and the other using localizer only (antennas on each wingtip). It appeared that AEMS performance would not be very satisfactory with either concept for several reasons:

- Initial Approach Configuration–ILS derived distance would not be available until localizer glide slope capture. To preclude overshooting, the pilot would have to establish a reduced speed, higher drag configuration sooner than if DME were available. This would reduce the operational utility and approach time, fuel, and noise benefits.

- Beam Irregularities–Sample calculations of distance based on actual ILS beam data showed that large fluctuations in computed distance relative to true distance could be expected, even for "good" beams.

- Wind Effects–A derived distance signal would be too irregular to use in deriving groundspeed, so the profile predictions would have to be based on an assumed wind. Computer studies indicated that the AEMS could advance or delay the flap, gear, and EPR commands to hit the stabilization point for reasonable wind variations. However, the command spacing and speed margins relative to flight limits were degraded, particularly for headwinds.

Although the study results did not conclusively rule out the possibility of eliminating the DME requirement, no satisfactory alternative was apparent. The studies of the ILS-only concept were terminated, and the DME inputs were retained in the AEMS avionic specification. The ILS-only studies are reported in more detail in ref. 5.

6.2 AIRPORT TRAFFIC REVIEW

Using information extracted from Boeing computerized files of airline operational data, 727 approaches were summarized by airport and operator. In a typical week, Boeing 727 aircraft operated by 26 domestic air carriers made 30 455 approaches at 155 airports in the United States. The data for each airport, ranked according to total approaches for a typical week, are tabulated in appendix B. A running total of approaches flown at these airports, beginning at the most active (Chicago O'Hare), is presented in figure 13, which illustrates that a majority of 727 approaches are flown at relatively few of the 155 airports:

Cumulative approaches	Cumulative airports
25%	5
50%	16
75%	40

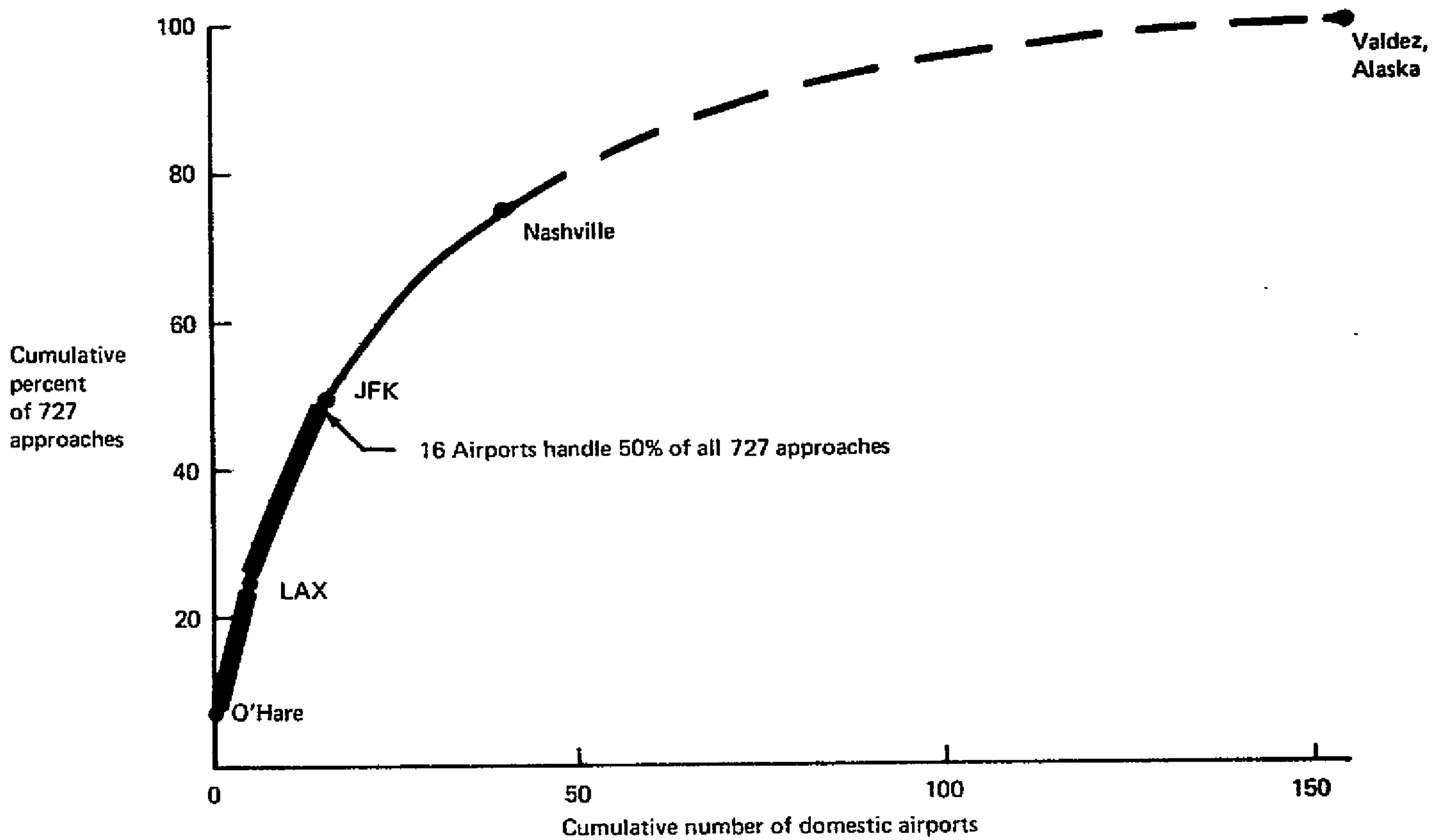


Figure 13.—Airport 727 Traffic Summary, 1975

Five most active airports

	Airport	727 approaches/week
1.	O'Hare	2744
2.	Dallas/Ft. Worth	1567
3.	Atlanta	1382
4.	LaGuardia	1205
5.	Los Angeles	1106

6.3 AIRPORT FACILITIES REVIEW

Existing ILS, VASI, and colocated DME facilities at the 155 airports considered in the study are tabulated in appendix C. The ILS- and VASI-equipped runways are indicated for the 30 most active airports. Thereafter, non-ILS runways are generally not included.

Runways with existing DME ground stations colocated with the ILS are listed in table 4. Airports included in the FY '76 or FY '77 Department of Transportation (DOT) appropriations (FAA F&E budget) for new colocated DME installations are listed in table 5.

6.4 RUNWAY RANKING FOR NOISE ABATEMENT

The DFA procedure reduces noise under the flightpath beyond the stabilization point, 152 m (500-ft) altitude. To identify some of the runways that should be equipped with DME if noise abatement were used as the selection criteria, a brief study of community locations relative to the runways was conducted by the Boeing noise staff. Consideration was limited to ILS runways at airports used by 727 operators for which community location data were readily available.

The runways were ranked as shown in table 6 by the extent, in nautical miles, of communities located under the flightpath. Only communities between 1.3 nmi and 3.3 nmi from the runway threshold were considered because the AEMS would offer no noise benefits at distances closer than the final approach stabilization point, and community location data were not readily available beyond 3.3 nmi. Due to unavailability of data beyond 3.3 nmi, a maximum community extent of 2 nmi is shown in table 2 for the first 28 airports listed. The noise benefits would extend for several additional miles at some of the cities.

Since table 6 lists only ILS runways for which community location data were readily available, it should not be inferred that a runway not on the list would not benefit. For example, the VASI-only runways at Washington National were not evaluated.

Table 4.—Existing ILS/Collocated DME Installations

Airport	Runway	727 approaches per week
Los Angeles International	(six runways)	1106
Minneapolis-St. Paul	29L	554
John F. Kennedy	4R	510
Cleveland	23L	439
San Diego	9	356
Reno	16	70
Santa Barbara	7	28
Fairbanks	1	24
Ketchikan	11	14
Total		3101

Table 5.—727 Airports Included in FAA F&E Budgets (FY '76, '77) for Collocated DME Installation

Denver	Allentown
St. Louis	Santa Barbara
Ft. Lauderdale	Long Beach
Portland, Ore.	Sioux Falls
Oklahoma City (two)	Grand Forks
New Orleans	Youngstown
Columbus	Wilkes-Barre
Wichita	Alexandria
Albuquerque	Jamestown
El Paso	Islip (Mac Arthur)
Dayton	Phoenix
Spokane	Little Rock
Lubbock	Ontario
Colorado Springs	Windsor Locks
Tucson	Greater Cincinatti
Billings	Louisville
Rochester, Minn.	Columbia, Mo.
Fargo	John F. Kennedy
Moline	Tulsa
Newport News	Dallas-Ft. Worth
Bismarck	Houston
	Milwaukee

Table 6.—Runway Ranking by Community Location[a]

Rank	Airport	Runway	Community extent, nmi[b]
1	O'Hare (ORD)	22R	2
2	Atlanta (ATL)	26	
3	Atlanta (ATL)	9R	
4	Los Angeles (LAX)	25L	
5	Los Angeles (LAX)	25R	
6	Los Angeles (LAX)	24L	
7	Los Angeles (LAX)	24R	
8	Miami (MIA)	27L	
9	Miami (MIA)	27R	
10	Logan (BOS)	15R	
11	St. Louis (STL)	24	
12	John F. Kennedy (JFK)	22L	
13	John F. Kennedy (JFK)	22R	
14	John F. Kennedy (JFK)	13L	
15	Detroit (DTW)	21R	
16	Cleveland (CLE)	23L	
17	Memphis (MEM)	17L	
18	San Antonio (SAT)	30L	
19	Phoenix (PHX)	8R	
20	Columbus (CMH)	10L	
21	Columbus (CMH)	28L	
22	Nashville (BNA)	2L	
23	San Jose (SJC)	30L	
24	Milwaukee (MKE)	19R	
25	Indianapolis (IND)	22R	
26	Louisville (SDF)	29	
27	Rochester (ROC)	22	
28	Birmingham (BHM)	5	2
29	Cleveland (CLE)	5R	1.82
30	Baltimore (BAL)	28	
31	Buffalo (BUF)	23	1.82
32	O'Hare (ORD)	9L	1.67
33	O'Hare (ORD)	9R	
34	LaGuardia (LGA)	22	
35	Providence (PVD)	5R	1.67
36	Milwaukee (MKE)	1L	1.58
37	Atlanta (ATL)	27L	1.49
38	Detroit (DTW)	27	1.49
39	Seattle (SEA)	16R	1.49
40	O'Hare (ORD)	32L	1.33
41	O'Hare (ORD)	32R	
42	Minneapolis (MSP)	4	
43	San Diego (SAN)	9	
44	Palm Beach (PBI)	9L	1.33
45	Tulsa (TUL)	35R	1.24
46	Dayton (DAY)	6L	1.16
47	Spokane (GEG)	21	
48	Indianapolis (IND)	31	
49	Reno (RNO)	16	1.16
50	John F. Kennedy (JFK)	4L	0.99
51	LaGuardia (LGA)	13	0.84
52	Denver (DEN)	26L	
53	St. Louis (STL)	12R	
54	John F. Kennedy (JFK)	31R	
55	John F. Kenendy (JFK)	31L	
56	Louisville (SDF)	1	0.84
57	O'Hare (ORD)	27L	0.67
58	O'Hare (ORD)	27R	
59	Atlanta (ATL)	8	
60	John F. Kennedy (JFK)	4R	0.67
61	San Jose (SJC)	12R	
62	Milwaukee (MKE)	7R	
63	Baltimore (BAL)	15R	
64	Baltimore (BAL)	10	
65	Norfolk (ORF)	5	0.67
66	Detroit (DTW)	3L	0.50
67	Tucson (TUS)	11L	0.50
68	Oklahoma City (OKC)	17R	0.42
69	Dallas-Ft. Worth (DFW)	31R	0.33
70	Houston (HOU)	26	0.25
71	Newark (EWR)	4L	0.17
72	Newark (EWR)	4R	
73	Newark (EWR)	22L	
74	Pittsburgh (PIT)	28L	0.17

[a]Listed in order of airport total weekly 727 approaches for a given community extent grouping.

[b]Between study distance limits of 1.33 to 3.32 nmi.

6.5 DISTRIBUTION AND COST OF DME INSTALLATIONS

The intent of this section is not to recommend particular runways for actual installation of DME stations, but rather to outline how the number of DME installations was determined for the various DME installation cost estimates shown in figure 12. Since this is a scoping level study and the airlines, if any, that might install the AEMS are unknown, it appeared inappropriate to consider the route structure of particular airlines. Furthermore, data regarding traffic on individual runways and information concerning ATC practices at specific airports were not readily available, so no attempt was made to investigate the choice of runways to that level of detail.

A quick estimate of DME requirements was made by considering only the 16 busiest airports which account for 50% of the 727 traffic. There are a total of 63 ILS-equipped runways and 27 VASI-equipped runways at these airports. Collocated DME stations are currently available on eight of the ILS runways, with installations on four other ILS runways included in the FAA FY '76, and '77 F&E budget. Additional DME installations would be required on 51 more ILS runways and on the 27 VASI runways. The cost for the 78 additional DME installations necessary to equip all 90 ILS and VASI runways would be about $5.8 million.

A second estimate was made using a low cost criteria to determine DME placement. The cost per approach for a DME installation was computed by dividing the DME cost by the number of approaches per week, assuming all 727 approaches to be flown on the ILS runways only. Exceptions were made for busy airports having only one ILS runway (e.g., Washington National and Fort Lauderdale) where one VASI runway was also included. The airports were then ranked in order of lowest cost per approach as indicated in table 7. Los Angeles ranks first because all ILS runways are currently equipped with collocated DME. The cumulative dollars and approaches from table 7 are plotted in figure 12. With this low cost criteria, 49 new DME installations would be required at 20 airports at a cost of about $3 million.

These methods for estimating DME requirements considered primarily the busiest airports. It is expected that the DME installations would be more widely distributed in an actual implementation program and that noise abatement considerations would be given high priority. Consequently, noise emphasis criteria were set up which would result in DME installations at more airports than considered in the second estimate. The airports and the number of runways used in plotting the noise-emphasis DME cost curve are listed in table 8 along with some of the factors considered in making the selections. The airports are listed in order of average approaches per runway computed by dividing the total number of ILS and VASI runways per airport into the total number of approaches per airport. The number of runways at each airport used for estimating DME costs was based on equipping:

- At least the first 56 runways shown in table 6, for which noise benefits of the AEMS would extend over 0.8 nmi or more of the community

Table 7.—DME Costs Based on Low-Cost Criteria

Airport	Investment cost	Approaches per week	Dollars per approach	Cumulative percent approach	Cumulative dollars
Los Angeles	$ 0	1106	$ 0	3.6	0
Denver	120 600	824	146.35	6.3	$ 120 600
La Guardia	180 900	1205	150.12	10.3	301 500
Washington National	160 300	1080	151.20	13.8	461 800
Portland, Ore.	60 300	376	160.37	15.1	522 100
Oklahoma City	60 300	355	169.86	16.2	582 400
Atlanta	241 200	1382	174.53	20.8	838 600
New Orleans	60 300	343	175.80	21.9	883 900
Dallas-Ft. Worth	301 500	1567	192.70	27.1	1 185 400
San Francisco	180 900	862	209.86	29.9	1 366 300
Tampa International	120 600	566	213.07	31.7	1 486 900
Minn.-St. Paul	120 600	554	217.69	33.6	1 607 500
St. Louis Lambert	120 600	519	232.39	35.3	1 728 100
Columbus	60 300	244	247.13	36.1	1 788 400
Ft. Lauderdale	100 000	400	250.00	37.4	1 888 400
Wichita	60 300	232	259.91	38.1	1 948 700
Houston	180 900	694	260.66	40.4	2 129 600
O'Hare	603 000	2274	265.17	47.9	2 732 600
Cleveland	120 600	439	274.72	49.3	2 853 200
Logan-Boston	180 900	651	277.88	51.5	3 034 100
San Diego	100 000	356	280.90	52.6	3 134 100
Seattle-Tacoma	120 600	417	289.21	54.0	3 254 700
Kansas City	180 900	583	310.29	55.9	3 435 600
Miami	241 200	554	313.65	57.7	3 676 800
Philadelphia	180 900	486	372.22	59.3	3 857 700
Detroit	180 900	478	378.45	60.9	4 083 600
Albuquerque	100 000	230	434.78	61.7	4 138 600
El Paso	100 000	189	529.10	62.3	4 238 600
Spokane	100 000	161	621.12	62.8	4 338 600
Dayton	120 600	183	659.02	63.4	4 459 200
John F. Kennedy	$ 361 800	510	$ 709.41	65.0	$ 4 821 000

Table 8.—DME Costs Based on Noise Emphasis Criteria

Airport	Number of runways				727 approaches per week				New DME requirement		
	Total (ILS & VASI)	ILS	Noise Benefit	DFA	Total	Per Runway	DFA	Cum. % DFA	Collocated ILS	Collocated VASI	Cum. cost[a]
	Runways Selected on Basis of Approaches per Runway										
Dallas-Ft. Worth	5	5[b]		5	1567	313	1567	5.1	4		0.2
La Guardia	4	3	2	4	1210	301	1210	9.1	3	1	0.5
Altanta	5	4	3	4	1382	277	1108	12.7	4		0.8
Houston	3	3[b]		3	694	231	693	15.0	2		0.9
San Francisco	4	3		3	862	213	639	17.1	3		1.1
O'Hare	11	10	5	6	2274	206	1236	21.1	6		1.4
Portland	2	2[b]		2	376	188	376	22.4	1		1.5
Washington National	6	1		4	1080	180	720	24.7	1	3	1.9
San Diego	2	1[c]		2	356	178	356	25.8		1	2.0
Oklahoma City	2	2[b]		2	355	177	355	27.1	1		2.0
New Orleans	2	2[b]		2	343	171	343	28.2	1		2.1
Philadelphia-Wilmington	3	3		3	486	162	486	29.8	3		2.3
Detroit	3	3	2	3	478	159	478	31.4	3		2.4
Cleveland	3	3[c]	2	3	439	146	439	32.8	2		2.6
Kansas City	4	3		3	583	146	438	34.3	3		2.7
Tulsa	2	2[b]	1	2	287	143	286	35.2	1		2.8
Los Angeles	8	6[c]	4	6	1106	138	828	37.9			2.8
Minn.-St. Paul	4	3[c]	1	3	554	138	414	39.2	2		2.9
Denver	6	3[b]	1	3	824	137	411	40.5	2		3.0
Phoenix	1	1[b]	1	1	272	136	136	41.1			3.0
Boston-Logan	5	3	1	3	651	130	390	42.4	3		3.2
Miami	6	4	2	4	769	128	512	44.1	4		3.5

[a]Millions of 1976 dollars.

[b]DME to be installed.

[c]DME already installed (all ILS runways at LAX).

Table 8.—(Concluded)

Airport	Number of runways				727 approaches per week				New DME requirement		
	Total (ILS & VASI)	ILS	Noise Benefit	DFA	Total	Per Runway	DFA	Cum. % DFA	Collocated		Cum. cost[a]
									ILS	VASI	
	Runways Selected on Basis of Noise Abatement										
Columbus	2	2	2	2	244	122	244	44.8	1		3.5
Palm Beach	1	1	1	1	215	107	107	45.3	1		3.6
Sea-Tac	4	2	1	2	417	104	208	46.0	2		3.7
St. Louis	5	3	2	2	519	104	208	46.6	1		3.8
Nashville	1	1	1	1	204	102	102	46.9	1		3.8
San Jose	2	2	1	1	194	97	97	47.2	1		3.9
Tampa[d]	6	2		2	566	94	188	47.9	2		4.0
San Antonio	3	3	1	1	277	92	92	48.1	1		4.1
Memphis	4	4	1	1	325	81	81	48.4	1		4.1
Spokane	1	1	1	1	161	80	80	48.6			4.2
Louisville	2	2	1	1	146	73	73	48.8	1		4.2
Milwaukee	3	3	2	2	192	64	128	49.3	2		4.4
John F. Kennedy	8	7[b]	6	6	510	64	384	50.6	4		4.6
Dayton	3	3	1	1	183	61	61	50.8			4.6
Baltimore	3	3	1	1	159	53	53	50.9	1		4.7
Buffalo	2	2	1	1	105	52	52	51.1	1		4.7
Birmingham	1	1	1	1	91	45	45	51.3	1		4.8
Providence	1	1	1	1	83	41	41	51.4	1		4.8
Rochester	1	1	1	1	72	36	36	51.5			4.8
Reno	1	1[b]	1	1	70	35	35	51.6			4.8

[a]Millions of 1976 dollars.

[b]DME to be installed.

[c]DME already installed (all ILS runways at LAX).

[d]Included due to total traffic.

- At least two runways at each of the 20 busiest airports, with the minimum number increasing proportionally with total traffic

- All ILS runways at the airports having the most average approaches per runway, except no more than six runways at any airport. (The number of airports selected on this basis (table 8) was limited to meet the 50% of 727 traffic objective.)

Using these criteria, 101 runways at 42 airports were identified as DFA runways. Excluding the currently planned DME installations listed in table 3, an additional 74 DME stations would have to be installed. Of these, 69 would be on ILS runways and five on VASI runways. As indicated in table 8, these installations would cost about $4.8 million.

Another estimate of DME installation costs was made (neglecting the 50% of 727 traffic objective) to determine the cost of equipping all existing ILS runways with collocated DME. To equip all 258 ILS runways at the 155 airports listed in appendix B, 200 additional DME installations would be required. This excludes the 14 existing collocated DME's and the 44 additional installations already budgeted. The cost of the 200 installations would be $12 million.

7.0 CONCLUSIONS

Prior NASA/Boeing engineering and piloted simulator studies have shown that the AEMS concept can be adapted to the 727 and has potential for reducing approach time, fuel, and noise. Pilot workload was found to be higher than for current ILS procedures but reasonable, being comparable to an IFR nonprecision approach. The procedures are compatible with current systems, with no modifications required to the existing autopilot or flight director except for installation of a fast/slow indicator. No operational restrictions on usage in tailwinds or icing conditions are necessary, although benefits are reduced, particularly with the higher power settings ($N_1 \geqslant 55\%$) required for inlet anti-ice.

Costs for avionic development and airplane retrofit have been estimated using the preliminary AEMS avionic specification prepared in the prior study. The price of prototype hardware development and type certification is estimated to be $2.2 million. The price of an AEMS retrofit kit for airline fleet implementation would depend on the AEMS kit market base. Budgetary estimates of kit prices, based on a typical 727-200 customer configuration are as follows (1976 dollars):

AEMS market base (shipsets)	Kit price (per shipset)
100	$78 000
300	$56 000
500	$51 000

Additional one-time costs to the airline are estimated to be $10 000. This includes kit installation by the airline (256 man-hours) and other costs such as spares purchase and maintenance training. Airplane down time, not included in the costs, could be minimized by installing the AEMS during other scheduled layups. Annual continuing costs are estimated to be $400 per airplane for maintenance, spares holding, and the slight cruise fuel penalty due to AEMS equipment weight. A cost-benefits analysis indicates the estimated approach fuel savings would provide a 33% to 38% rate of return on the investment, which would pay back the investment costs in less than 3 years.

No additional ILS or VASI installations are required to meet the NASA study objective of using the AEMS for 50% of all 727 approaches. Based on a study criteria emphasizing noise abatement, 74 collocated DME installations, in addition to those included in FAA FY 76, 77 budgets, would be necessary at a cost of $5 million. If desired to accommodate additional approaches, the cost of installing DME on all ILS runways at all 727 airports would be $12 million. In either case, the DME costs are relatively small compared with the costs for airline fleet retrofit. Individual airline route structure, not considered in this scoping level study, should be reviewed prior to selecting runways for actual DME installation, so that each AEMS-equipped airplane could use the system at every destination airport.

Additional development to improve the concept and further evaluations involving the FAA and airlines are required before reaching a conclusion regarding operational acceptability. If operationally acceptable, the AEMS appears to offer an economically attractive means of reducing approach time, fuel, and noise. Prior to selecting the final AEMS configuration for fleet retrofit, the potential benefits of integrating the AEMS with other related concepts, which might utilize the same computer and displays, should be explored.

APPENDIX A

This appendix supplements the descriptive data provided in section 4.0, to summarize major results of the Boeing engineering and piloted simulator studies. This work, which preceded the implementation cost study, is reported more completely in reference 2.

A-1. EQUIPMENT OPERATION

The pilot uses the control panel (fig. 5, sec. 4.2) to enter the desired final approach speed, stabilization altitude, and other operational variables (weight, glide slope angle, and field elevation). The proper time to make the successive flap, gear, and power settings is determined by the computer and displayed on the annunciator panel (fig. 4, sec. 4.2) by illuminating the appropriate annunciator light. At the same time the corresponding digital display indicates the desired flap or EPR setting. When the pilot responds to the command, as determined by the flap, gear, and throttle position sensors, the annunciator light is automatically turned off. The fast/slow indicator allows the pilot to monitor total energy relative to the desired profile, which is particularly useful during the descent and initial approach phase.

To generate the information required for the cockpit displays, the AEMS computer performs three basic functions:

1. Profile Prediction–Using airplane thrust and drag data, a speed versus distance profile is computed starting at the existing flight condition and following a predetermined speed schedule for flap/gear/throttle setting. The prediction is updated at least once a second.

2. Operational Logic–Logic is provided to determine when the next flap/gear/throttle command should be displayed to the pilot, based on the results of the profile prediction. Airplane flight limits (e.g., flap placards and stall speeds) are included in the logic.

3. Energy Reference–The predicted profile is stored in the computer as an energy refererence for use in driving the fast/slow doughnut on the ADI.

The AEMS compensates for wind variations and other operational factors so as to consistently hit-the-target speed and altitude. For example, if high in energy (overshooting), the next configuration command will be given sooner to increase drag.

A-2. FLIGHT PROFILES

A 727 DFA profile for a typical weight condition of 578 000 N (130 000 lb) is illustrated in figure A-1. The airspeeds for selecting the next flap detent were chosen to minimize pitch attitude variations ($\Delta\theta$) on final. The distance from touchdown corresponding to the first flap command is determined by the computer, and the fast/slow indicator assists the pilot in arriving at this point at the desired speed. Thereafter, the fast/slow indicates energy deviations from the computed profile.

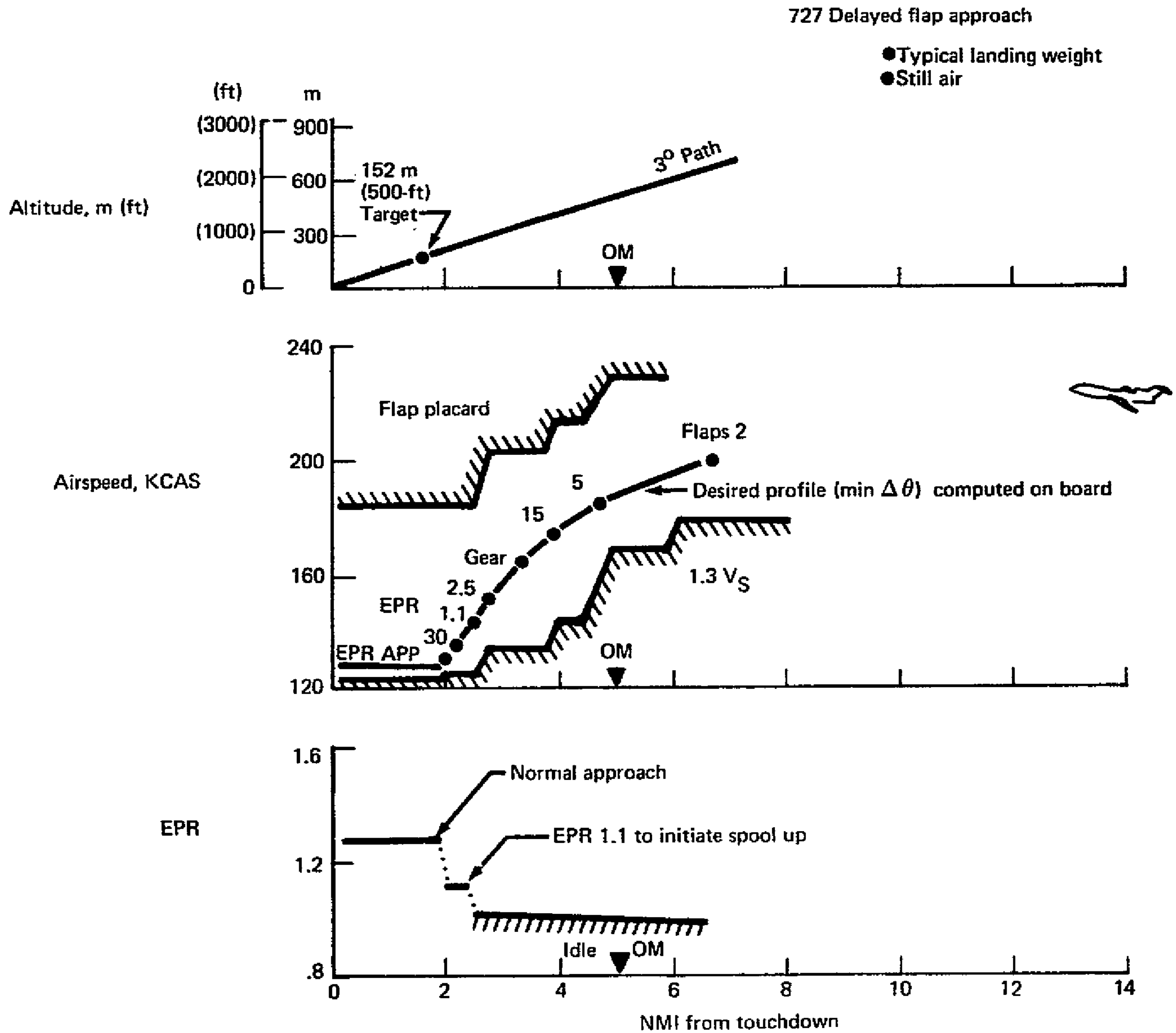


Figure A-1.—Desired Deceleration Profile for 727 DFA Procedure

The preferred flight profile for nonicing conditions begins in a clean configuration at a speed of 220 kn. However, flaps 2 (at a lower speed) can be used with little reduction in benefits, and the AEMS will adjust to any initial flap-speed combination that might be required in the operational environment. Thrust is reduced to idle at a point determined by the AEMS. Flaps, gear, and thrust are then sequenced as indicated by the displays to stabilize at a target altitude above 152m (500 ft) selected by the pilot for the particular approach conditions. As indicated, the nominal profile provides reasonable speed margins relative to the flap placards and minimum approach speeds. This allows the commands to be given at higher or lower speeds if necessary to hit the target.

Piloted simulator data for a typical delayed flap approach are presented in figure A-2. The precomputed nominal profile from figure A-1 is shown for reference.

A-3. BENEFITS AND PILOT EVALUATION

The piloted simulator data in figure A-3 compare the delayed flaps approach (DFA-1) to another procedure (A-1) which is representative of an approach procedure currently used by some ATA member airlines. Disadvantages of the delayed flaps procedure include increased cockpit activity at low altitude and delayed checklist completion. The higher initial approach speeds may cause problems for ATC but, in combination with the cleaner configuration, will provide reductions in approach time, fuel, and noise. The higher initial approach speeds also allow flying much of the final approach at idle power, which further enhances the community noise benefit.

As part of the Boeing engineering and simulator study, approach time, fuel, and noise were estimated for several types of procedures in still air, headwind, and tailwind conditions. Descriptions of the procedures and discussions of the potential benefits are contained in reference 1. Comparisons of the delayed flaps procedure (DFA-1) against two reduced flap procedures considered typical of current ATA airline operations indicate the AEMS concept could substantially reduce approach time, fuel, and noise. The benefits for still air, VFR conditions were estimated to be as follows for the 727-200/JT8D-9:

- Flight time reduction: 2 min
- Fuel savings: 1420 to 1750 N (320 to 395 lb) per approach (depending on current airline procedure)
- Centerline noise reduction beyond 2 nmi relative to the A-1 procedure: more than 10 EPNdB for untreated nacelles, and 6 EPNdB for quiet nacelles
- 90 EPNdB contour area reduction: comparable to nacelle treatment

Pilot comments indicated the workload is higher than for current ILS procedures but reasonable, being comparable to an IFR nonprecision approach. Minimum stabilization heights of 152m (500 ft) for VFR conditions and 305m (1000 ft) for IFR conditions were selected as realistic for comparing time, fuel, and noise benefits. This height could be selectable by the aircrew within limits specified by the customer airline.

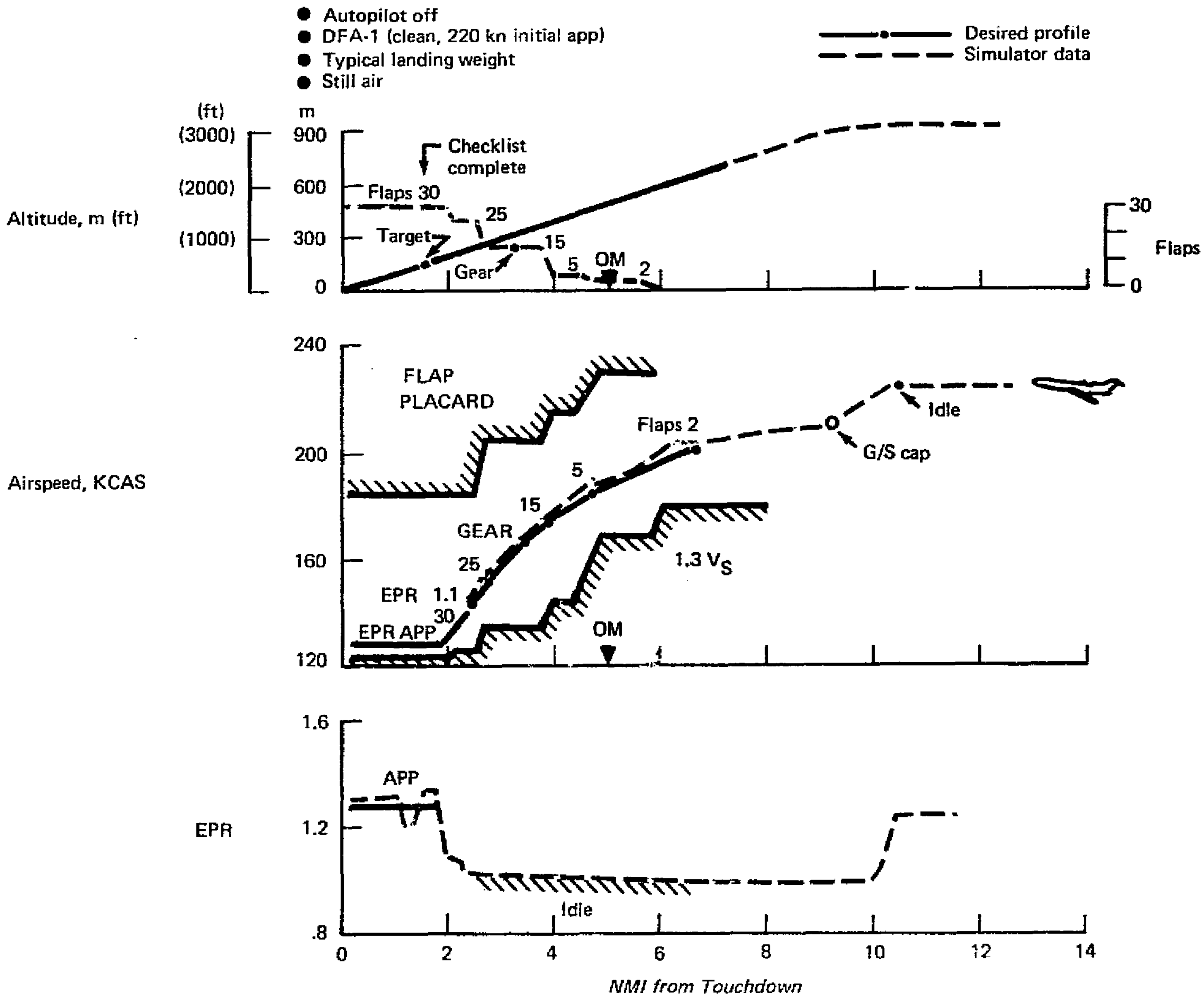


Figure A-2.–Piloted Simulation Flight Profile for 727 DFA

- Typical landing weight
- Still air
- Autopilot off
- DFA-1 (clean, 220 kn initial app)
- A-1 (procedure used by some ATA airlines)

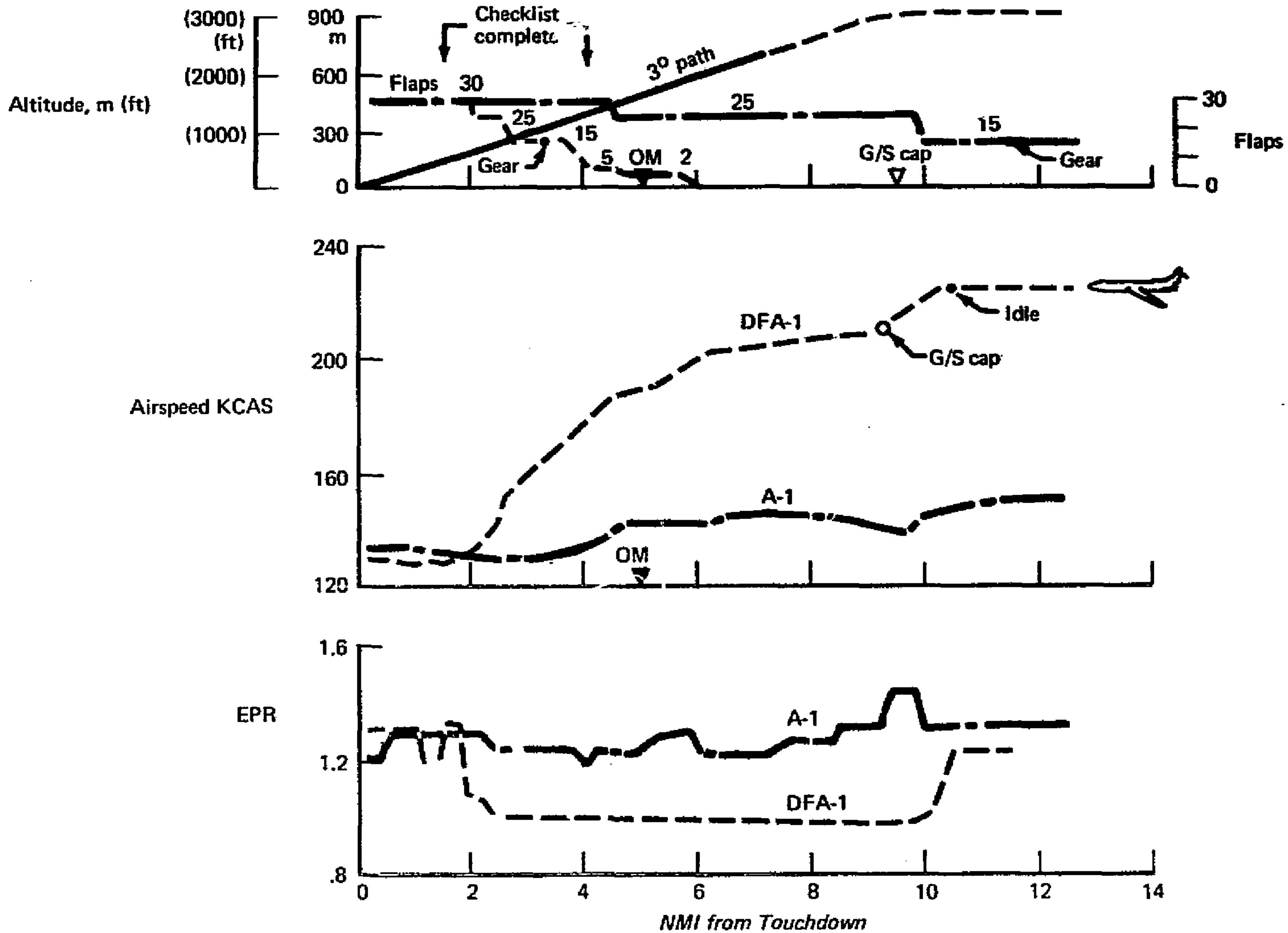


Figure A-3.—Piloted Simulator Comparisons for DFA and Current Airline Procedures

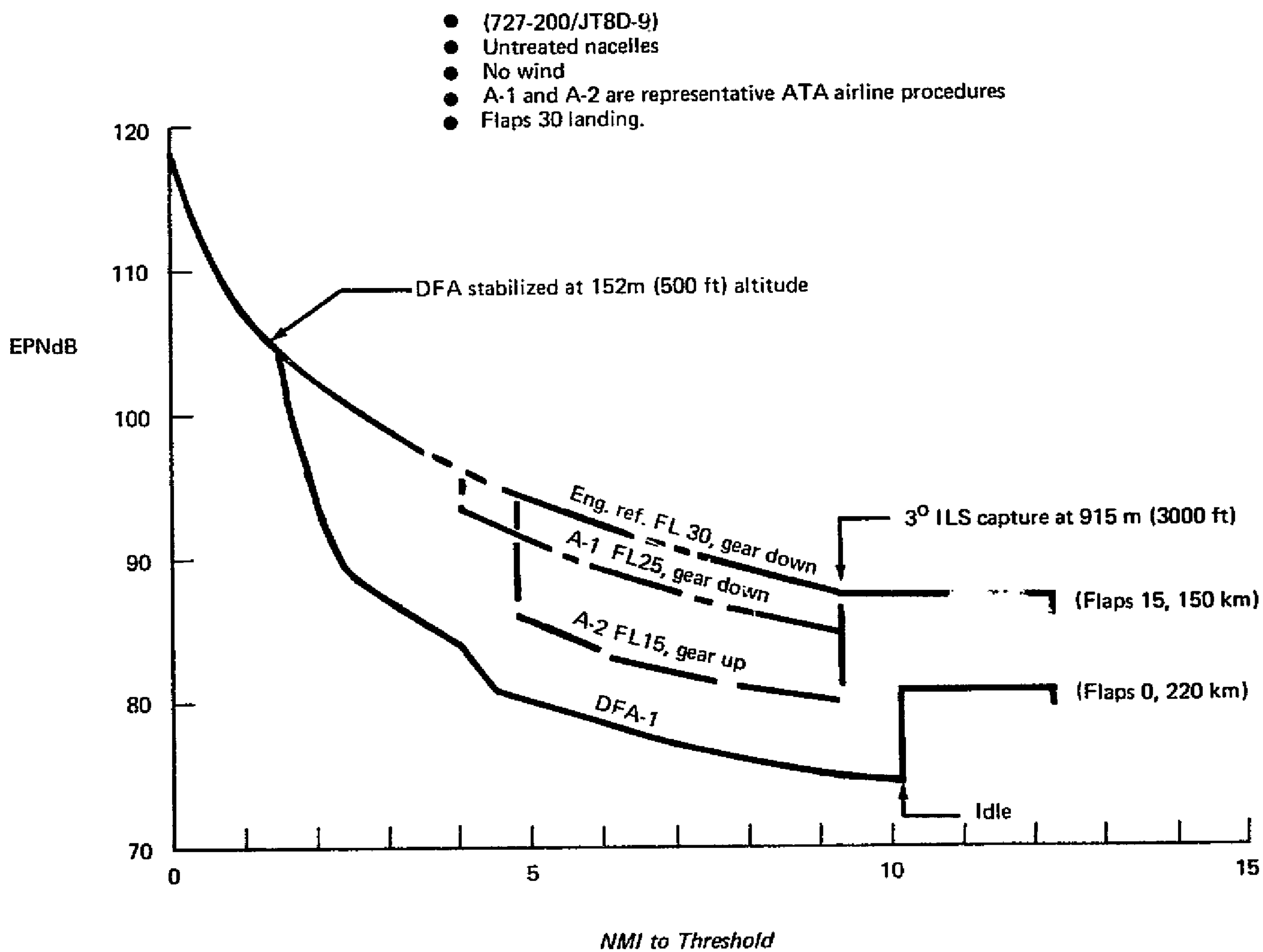


Figure A-4. Computed Centerline Noise Comparisons

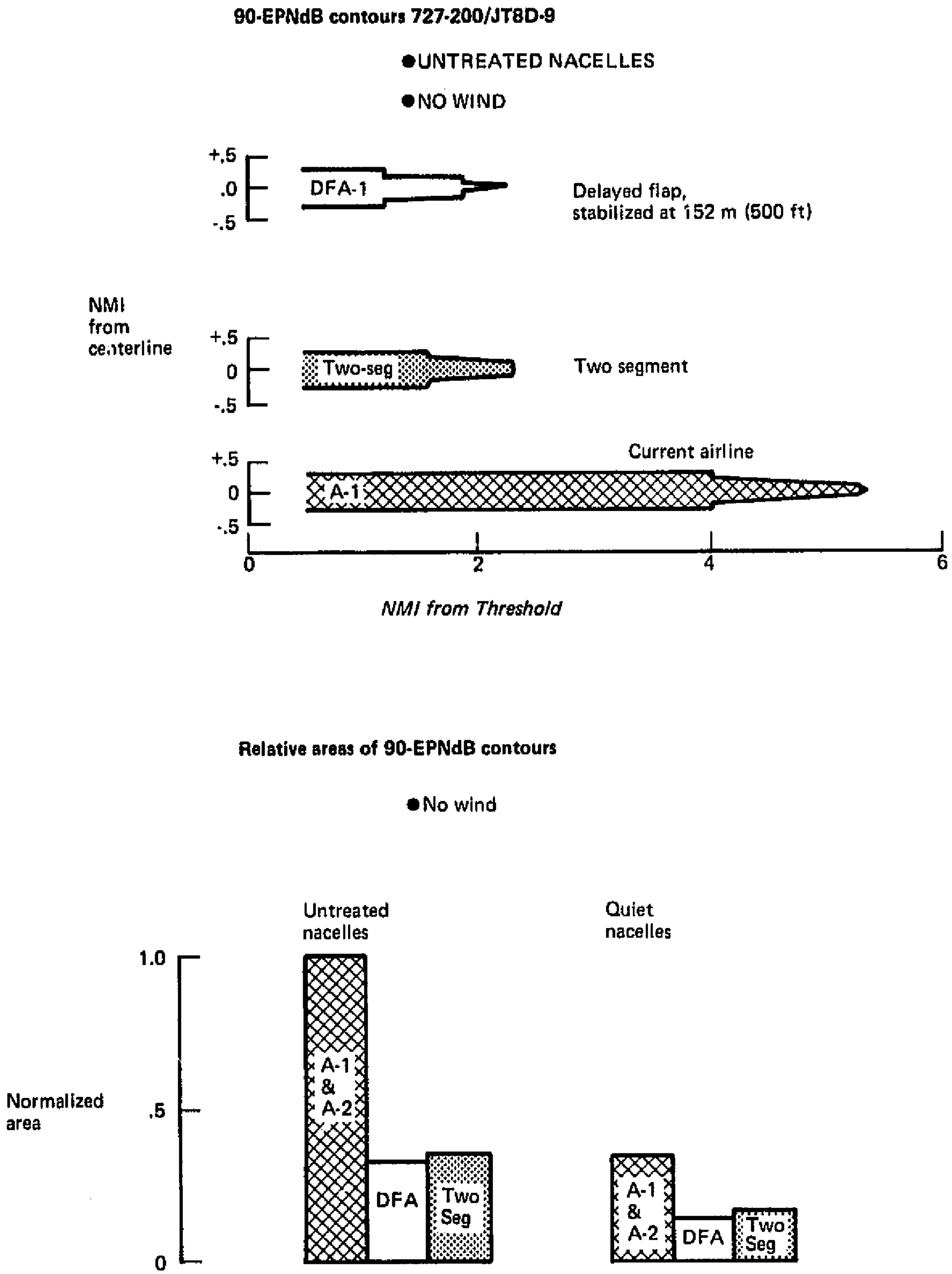


Figure A-5.—Noise Contour Comparisons

The procedures are compatible with current 727 systems. No modifications would be required to the current autopilot or flight director, except for installation of a fast/slow indicator. Current autopilot trim motor rates are adequate. Compatibility with icing conditions is provided by automatically selecting alternate flight profiles using higher power settings ($N_1 \geqslant 55\%$) when the inlet anti-ice switch is activated. The profile compensates for wind velocity (computed onboard using DME ground speed) so no operational restrictions on usage in tailwinds are needed.

APPENDIX B

AIRPORT 727 TRAFFIC ACTIVITY

Prepared by: Martin J. Omoth

727-100 and 727-200 AIRPORTS RANKED ACCORDING TO THEIR ACTIVITY
(approaches per week)

Airport	Operator	Approaches Per Week
1. Chicago, Illinois (O'Hare)	Northwest	223
	TWA	432
	Braniff	157
	Continental	50
	Delta	166
	Eastern	72
	American	546
	United	628
		2,274
2. Dallas/Ft. Worth, Texas	American	460
	Air Canada	7
	Alaska	7
	Braniff	918
	Continental	98
	Delta	63
	Eastern	7
	Western	7
		1,567
3. Atlanta, Georgia	Braniff	14
	Delta	523
	Eastern	710
	Northwest	41
	United	94
		1,382
4. New York, New York (LaGuardia)	American	535
	Braniff	21
	Delta	109
	Eastern	161
	National	43
	Northwest	43
	TWA	214
	United	84
		1,210

Airport	Operator	Approaches Per Week
5. Los Angeles, California	American	77
	Continental	78
	Delta	17
	Eastern	14
	National	14
	PSA	396
	TWA	97
	United	287
	Western	126
		1,106
6. Washington, D.C. (National Airport)	American	238
	Braniff	47
	Delta	104
	Eastern	189
	National	159
	Northwest	124
	TWA	114
	United	105
		1,080
7. San Francisco, California	American	49
	Continental	21
	National	21
	Northwest	7
	PSA	286
	TWA	76
	United	299
	Western	103
		862
8. Denver, Colorado	Braniff	88
	Continental	267
	Eastern	14
	TWA	42
	United	322
	Western	91
		824
9. Miami, Florida	Braniff	42
	Delta	91
	Eastern	333
	Lan Chile	1
	National	205
	Northwest	20
	Air Panama	7
	TWA	21
	United	49
		769

Airport	Operator	Approaches Per Week
10. Houston, Texas	American	35
	Air Canada	7
	Alaska	7
	Braniff	221
	Continental	105
	Delta	110
	Eastern	132
	National	77
		694
11. Boston, Massachusetts	American	152
	Delta	222
	Eastern	173
	National	14
	Northwest	21
	TWA	41
	United	28
		651
12. Kansas City, Missouri	Braniff	284
	Continental	70
	Delta	28
	TWA	159
	United	42
		583
13. Tampa, Florida	Braniff	42
	Delta	126
	Eastern	154
	National	175
	Northwest	34
	TWA	28
	United	7
		566
14. Minneapolis/St. Paul, Minnesota	Braniff	88
	Eastern	7
	Northwest	304
	United	74
	Western	81
		554
15. St. Louis, Missouri	American	109
	Braniff	13
	Delta	21
	Eastern	91
	TWA	285
		519

Airport	Operator	Approaches Per Week
16. New York, New York (JFK)	American	36
	Braniff	54
	Delta	70
	Eastern	151
	Lan Chile	1
	National	143
	Northwest	7
	Air Panama	7
	TWA	21
	United	20
		510
17. Philadelphia, Pennsylvania/ Wil ngton, Delaware	American	1
	Delta	105
	Eastern	145
	National	42
	Northwest	45
	TWA	61
	United	87
		486
18. Detroit, Michigan (Metropolitan)	American	136
	Braniff	20
	Delta	63
	Eastern	43
	Northwest	153
	TWA	7
	United	56
		478
19. Cleveland, Ohio	American	87
	Eastern	14
	Northwest	92
	TWA	7
	United	239
		439
20. Seattle-Tacoma International, Washington	Alaska	34
	Braniff	21
	Continental	70
	Eastern	35
	Northwest	63
	United	124
	Western	70
		417

Airport	Operator	Approaches Per Week
21. New York, New York (Newark)	American	13
	Braniff	51
	Delta	35
	Eastern	179
	National	48
	Northwest	24
	TWA	42
	United	21
		413
22. Ft. Lauderdale, Florida	Braniff	21
	Delta	154
	Eastern	112
	National	78
	Northwest	21
	United	14
		400
23. Portland, Oregon	Braniff	28
	Continental	105
	Eastern	28
	Northwest	42
	United	138
	Western	35
		376
24. Pittsburgh, Pennsylvania	American	28
	Eastern	58
	Northwest	65
	TWA	74
	United	150
		375
25. San Diego, California	American	56
	Delta	5
	National	7
	PSA	182
	United	29
	Western	77
		356
26. Oklahoma City, Oklahoma	American	84
	Braniff	159
	Continental	49
	Eastern	7
	TWA	56
		355

	Airport	Operator	Approaches Per Week
27.	New Orleans, Louisiana	Braniff	56
		Continental	28
		Delta	84
		Eastern	70
		National	91
		United	14
			343
28.	Memphis, Tennessee	American	131
		Braniff	75
		Delta	77
		Eastern	14
		United	28
			325
29.	Tulsa, Oklahoma	American	48
		Braniff	134
		Continental	63
		TWA	42
			287
30.	San Antonio, Texas	American	35
		Braniff	137
		Continental	63
		Eastern	42
			277
31.	Phoenix, Arizona	American	42
		Continental	35
		Delta	7
		TWA	123
		Western	65
			272
32.	Cincinnati, Ohio	American	149
		Delta	76
		TWA	34
			259
33.	Columbus, Ohio	American	41
		Delta	49
		Eastern	14
		TWA	133
		United	7
			244

Airport	Operator	Approaches Per Week
34. Jacksonville, Florida	Delta	35
	Eastern	77
	National	130
		242
35. Wichita, Kansas	Braniff	86
	Continental	77
	TWA	69
		232
36. Omaha, Nebraska	Braniff	56
	Eastern	28
	United	147
		231
37. Albuquerque, New Mexico	Continental	147
	TWA	83
		230
38. Orlando, Florida	Delta	28
	Eastern	105
	National	91
		224
39. West Palm Beach, Florida	Delta	84
	Eastern	49
	National	75
	United	7
		215
40. Nashville, Tennessee	American	108
	Braniff	47
	Eastern	49
		204
41. Charlotte, North Carolina	Delta	35
	Eastern	147
	United	21
		203
42. San Jose, California	American	21
	Continental	35
	PSA	110
	United	28
		194

Airport	Operator	Approaches Per Week
43. Milwaukee, Wisconsin	Northwest	164
	United	28
		192
44. El Paso, Texas	American	56
	Continental	133
		189
45. Burbank, California	Continental	42
	PSA	141
		183
46. Dayton, Ohio	American	42
	Delta	21
	TWA	99
	United	21
		183
47. Las Vegas, Nevada	National	21
	TWA	63
	United	47
	Western	32
		163
48. Spokane, Washington	Northwest	105
	United	56
		161
49. Baltimore, Maryland	American	14
	Delta	35
	Eastern	41
	National	21
	TWA	6
	United	42
		159
50. Indianapolis, Indiana	American	56
	Delta	35
	TWA	67
		158
51.. Washington, D.C.	American	14
	Braniff	68
	Eastern	28
	TWA	7
	United	35
		152

Airport	Operator	Approaches Per Week
52. Oakland, California	American	7
	PSA	79
	TWA	14
	United	49
		149
53. Louisville, Kentucky	American	62
	Delta	49
	Eastern	28
	TWA	7
		146
54. Des Moines, Iowa	Braniff	41
	United	100
		141
55. Raleigh/Durham, North Carolina	Eastern	112
	United	21
		133
56. Salt Lake City, Utah	American	27
	United	77
	Western	28
		132
57. Ontario, California	American	21
	Continental	49
	PSA	28
	United	30
		128
58. Lubbock, Texas	Braniff	41
	Continental	84
		125
59. Norfolk, Virginia	National	75
	United	48
		123
60. Hartford, Connecticut	American	21
	Delta	42
	Eastern	37
	TWA	7
	United	13
		120

	Airport	Operator	Approaches Per Week
61.	Rochester, New York	American	55
		United	62
			117
62.	Colorado Springs, Colorado	Braniff	39
		Continental	77
			116
63.	Sacramento, California	PSA	79
		United	28
		Western	7
			114
64.	Buffalo, New York	American	40
		Eastern	23
		United	42
			105
65.	Midland/Odessa, Texas	Continental	105
66.	Shreveport, Louisiana	Braniff	21
		Delta	84
			105
67.	Charleston, South Carolina	Delta	8
		Eastern	21
		National	70
			99
68.	Boise, Idaho	United	98
69.	Tucson, Arizona	American	35
		Continental	21
		TWA	42
			98
70.	Austin, Texas	Braniff	67
		Continental	28
			95
71.	Little Rock, Arkansas	American	68
		Braniff	26
			94
72.	Birmingham, Alabama	Delta	49
		Eastern	14
		United	28
			91

	Airport	Operator	Approaches Per Week
73.	Sarasota/Bradenton, Florida	Eastern	42
		National	49
			91
74.	Daytona Beach, Florida	Eastern	49
		National	41
			90
75.	Madison, Wisconsin	Northwest	85
76.	Anchorage, Alaska	Alaska	49
		Braniff	7
		Continental	7
		Western	21
			84
77.	Providence, Rhode Island	American	21
		Eastern	28
		National	21
		United	13
			83
78.	Knoxville, Tennessee	American	14
		Delta	28
		United	41
			83
79.	Billings, Montana	Northwest	77
80.	Jackson/Vicksburg, Mississippi	Delta	77
81.	Pensacola, Florida	Eastern	28
		National	49
			77
82.	Amarillo, Texas	Braniff	34
		Continental	14
		TWA	28
			76
83.	Rochester, Minnesota	Northwest	72
84.	Reno, Nevada	United	70
85.	Savannah, Georgia	Delta	35
		National	35
			70

	Airport	Operator	Approaches Per Week
86.	Fresno, California	PSA	40
		United	23
			63
87.	Melbourne, Florida	Eastern	42
		National	21
			63
88.	Mobile, Alabama/Pascagoula, Mississippi	Eastern	7
		National	56
			63
89.	Richmond, Virginia	Eastern	49
		United	14
			63
90.	Corpus Christi, Texas	Braniff	47
		Eastern	14
			61
91.	Toledo, Ohio	Delta	21
		Eastern	7
		United	33
			61
92.	Cedar Rapids/Iowa City, Iowa	United	56
93.	Fargo, North Dakota	Northwest	56
94.	Greensboro/High Point, North Carolina	Eastern	35
		United	21
			56
95.	Moline, Illinois	United	50
96.	Chattanooga, Tennessee	Delta	14
		Eastern	14
		United	21
			49
97.	Fort Myers, Florida	National	49
98.	Newport News, Virginia	National	35
		United	14
			49
99.	Portland, Maine	Delta	48

Airport	Operator	Approaches Per Week
100. Syracuse, New York	American Eastern	27 21 48
101. Tallahassee, Florida	Eastern National	28 19 47
102. Monterey, California	United	44
103. Bismarck, North Dakota	Northwest	42
104. Huntsville/Decatur, Alabama	Eastern United	7 35 42
105. Lincoln, Nebraska	United	42
106. Missoula, Montana	Northwest	42
107. Allentown, Pennsylvania	Eastern United	14 26 40
108. Juneau, Alaska	Alaska	40
109. Stockton, California	PSA	40
110. Columbia, South Carolina	Delta	36
111. Butte, Montana	Northwest	35
112. Bozeman, Montana	Northwest	35
113. Great Falls, Montana	Northwest Western	28 7 35
114. Helena, Montana	Northwest	35
115. Monroe, Louisiana	Delta	35
116. Panama City, Florida	National	35
117. Bangor, Maine	Delta	34
118. Ft. Wayne, Indiana	Delta United	7 27 34

Airport	Operator	Approaches Per Week
119. Albany, New York	American	28
120. Ft. Smith, Arkansas	Braniff	28
121. Grand Rapids, Michigan	United	28
122. Lansing, Michigan	United	28
123. Saginaw, Michigan	United	28
124. Santa Barbara, California	United	28
125. Sitka, Alaska	Alaska	28
126. Brownsville, Texas	Braniff	27
127. Akron/Canton, Ohio	United	27
128. Fairbanks, Alaska	Alaska Braniff	17 7 24
129. Long Beach, California	PSA	23
130. Augusta, Georgia	Delta Eastern	7 14 21
131. Charleston, West Virginia	American United	14 7 21
132. Evansville, Indiana	Eastern	21
133. Sioux Falls, South Dakota	Western	21
134. Grand Forks, North Dakota	Northwest	21
135. Gainesville, Florida	Eastern	21
136. Greenville/Spartanburg, South Carolina	Eastern	21
137. Lexington/Frankfort, Kentucky	Delta Eastern	14 7 21

	Airport	Operator	Approaches Per Week
138.	South Bend, Indiana	United	19
139.	Youngstown, Ohio	United	19
140.	Wilkes-Barre/Scranton, Pennsylvania	Eastern	14
141.	Bakersfield, California	United	14
142.	Baton Rouge, Louisiana	Delta	14
143.	Alexandria, Louisiana	Delta	14
144.	Flint, Michigan	United	14
145.	Grand Junction, Colorado	United	14
146.	Jamestown, North Dakota	Northwest	14
147.	Ketchikan, Alaska	Alaska	14
148.	Lawton, Oklahoma	Continental	14
149.	Pendleton, Oregon	United	14
150.	Wichita Falls, Texas	Continental	14
151.	Harrisburg, Pennsylvania (International Airport)	TWA	13
152.	Beaumont/Pt. Arthur, Texas	Delta	7
153.	Gustavus, Alaska	Alaska	7
154.	Islip, New York	American	6
155.	Valdez, Alaska	Alaska	5

APPENDIX C

ISL, VASI, AND DME AVAILABILITY AT 727 AIRPORTS

Prepared by Martin J. Omoth

	Airport	Runway	ILS	Glideslope	DME	VASI
(1)	O'Hare	4R	Cat I	3.00°		
		4L				x
		22R	Cat I	3.00°		
		9R	Cat I	2.90°		
		27L	Cat I	3.00°		
		9L	Cat I	3.00°		
		27R	Cat I	3.00°		
		14R	Cat II	3.00°		
		32L	Cat I	3.00°		
		14L	Cat II	3.00°		
		32R	Cat I	3.00°		
(2)	Dallas-Ft. Worth	31R	Cat I	3.00°		
		17R	Cat I	3.00°		
		35L	Cat I	3.00°		
		17L	Cat II	3.00°		
		35R	Cat I	3.00°		
(3)	Atlanta (The Hartsfield) International	8	Cat II	3.00°		
		26	Cat I	2.94°		
		9R	Cat IIIa	3.00°		
		27L	Cat I	3.00°		
		27R				x
(4)	LaGuardia	4	Cat I	3.00°		
		22	Cat II	3.00°		x
		13	Cat I	3.00°		x
		31				x

Airport	Runway	ILS	Glideslope	DME	VASI
(5) Los Angeles International	6R	Cat I	3.00°	x	x
	24L	Cat I	3.00°	x	
	6L				x
	24R	Cat II	3.00°	x	
	7R				x
	25L	Cat I	3.00°	x	
	7L	Cat I	3.00°	x	x
	25R	Cat I	3.00°	x	
(6) Washington National	3				x
	21				x
	15				x
	33				x
	18				x
	36	Cat II	3.00°		
(7) San Francisco International	19L	Cat I	3.00°		
	10R				x
	28L	Cat I	2.70°		
	28R	Cat IIIa	3.00°		
(8) Denver Stapleton	8R				x
	26L	Cat I	2.75°		
	26R				x
	17R				x
	35L	Cat I	3.00°		
	35R	Cat IIIa	3.00°		

Airport	Runway	ILS	Glideslope	DME	VASI
(9) Miami International	9R	Cat I	3.00°		x
	27L	Cat I	2.90°		
	9L	Cat I	3.00°		
	27R	Cat I	3.00°		x
	12				x
	30				x
(10) Houston Intercontinental	14	Cat I	2.92°		x
	8	Cat II	2.80°		
	26	Cat I	3.00°		x
(11) Logan International Boston	4R	Cat I	3.03°		
	22L				x
	27				x
	15R	1	3.00°		x
	33L	Cat I	3.00°		
(12) Kansas City International	1	Cat I	2.50°		
	19	Cat II	3.00°		
	9	Cat I	2.95°		
	27				x
(13) Tampa International	9				x
	27				x
	18R				x
	36L	Cat I	2.75°		x
	18L	Cat I	3.00°		x
	36R				x

1 Needs approach lights for Cat I

	Airport	Runway	ILS	Glideslope	DME	VASI
(14)	Minneapolis-St. Paul International	4	Cat I	3.00°		
		29L	Cat II	3.00°	x	
		11L				x
		29R	[1]	3.00°		
(15)	St. Louis - Lambert	24	Cat I	2.90°		
		12R	Cat I	3.00°		
		30L	Cat I	3.00°		
		12R				x
		30R				x
(16)	John F. Kennedy	4R	Cat II	2.75°	x	
		22L	Cat I	3.00°		
		4L	[1]	2.87°		
		22R	[1]	3.00°		
		13R				x
		31L	[1]	3.00°		
		13L	Cat I	3.00°		x
		31R	[1]	3.00°		
(17)	Philadelphia International	9R	Cat II	3.00°		
		27L	[1]	3.00°		
		27R	[1]	3.00°		
(18)	Detroit Metro-Wayne County	3L	Cat II	3.00°		
		21R	Cat I	2.80°		
		27	[1]	3.00°		
(19)	Cleveland-Hopkins	5R	Cat I	3.00°		
		23L	Cat I	3.00°	x	
		28R	Cat I	3.00°		

[1] Needs approach lights for Cat I

	Airport	Runway	ILS	Glideslope	DME	VASI
(20)	Seattle-Tacoma International	16R	Cat II	3.00°		
		34L				x
		16L				x
		34R	Cat I	3.00°		
(21)	Newark	4R	Cat II	3.00°		
		22L	Cat I	3.00°		
		4L	Cat I	2.60°		
		22R				x
		29				x
(22)	Ft. Lauderdale	9R				x
		9L	[1]	2.75°		x
		27R				x
		13				x
(23)	Portland International	10R	Cat II	3.00°		
		28R	Cat I	3.00°		
(24)	Greater Pittsburgh	28L	Cat I	3.00°		
		10L	Cat II	3.00°		
		28R				x
(25)	San Diego (Lindbergh)	9	Cat I	3.22°	x	
		27				x
(26)	Oklahoma City	35R	Cat II	2.90°		
		17R	Cat I	3.00°		
(27)	New Orleans	10	Cat II	2.80°		
		1	1	3.00°		

[1] Needs approach lights for Cat I

	Airport	Runway	ILS	Glideslope	DME	VASI
(28)	Memphis International	35L	Cat II	3.00°		
		9	[1]	2.50°		
		35R	Cat I	2.81°		
		17L	Cat I	3.00°		
(29)	Tulsa	35R	Cat II	3.00°		
		17L	Cat I	2.50°		
(30)	San Antonio	12R	Cat II	3.00°		
		3R	Cat I	3.00°		
		30L	Cat I	3.00°		
(31)	Phoenix	8R	Cat I	3.00°		
(32)	Greater Cincinnati	36	Cat II	3.00°		
		18	Cat I	2.50°		
		9R	Cat I	3.00°		
		27L	Cat I	3.00°		x
(33)	Port Columbus International	38L	Cat I	3.00°		
		10L	Cat I	3.00		
(34)	Jacksonville International	7	Cat II	3.00°		
		13	Cat I	3.00°		
(35)	Wichita Mid-Continent	1R	Cat I	2.70°		
		19R	Cat I	3.00°		
(36)	Omaha (Eppley)	14R	Cat I	3.00°		
(37)	Albuquerque International	35	Cat 1	2.60°		

[1] Needs approach lights for Cat I

	Airport	Runway	ILS	Glideslope	DME	VASI
(38)	Orlando Jetport at McCoy	36L	Cat I	2.50°		
(39)	Palm Beach International	9L	Cat I	3.00°		
(40)	Nashville Metro	2L	Cat I	2.67°		
(41)	Charlotte (Douglas)	5	Cat I	2.65°		
(42)	San Jose	30L	Cat I	3.00°		
		12R	Cat I	3.00°		
(43)	Milwaukee (Mitchell)	19R	Cat I	3.00°		
		7R	[1]			
		1L	Cat II			
(44)	El Paso International	22	Cat I	3.00°		
(45)	Hollywood-Burbank	7	Cat I	3.00°		
(46)	Dayton (Cox-Dayton)	6L	Cat II	3.00°		
		18	Cat I	3.00°		
		24L	Cat I	3.00°		
(47)	Las Vegas (McCarran)	25	Cat I	3.00°		
(48)	Spokane International	21	Cat I	2.75°		
(49)	Baltimore-Washington International	10	Cat II	3.00°		
		15R	Cat I	2.85°		
		28	Cat I	3.00°		x

[1] Needs approach lights for Cat I

	Airport	Runway	ILS	Glideslope	DME	VASI
(50)	Indianapolis Municipal	4L	Cat II	3.00°		
		22R	Cat I	3.00°		
		31	Cat I	2.63°		
(51)	Dulles International	1R	Cat IIa	2.75°		
		19R	Cat I	2.50°		
		19L	Cat I	3.00°		
(52)	Oakland International	29	Cat II	3.00°		
		27R	Cat I	2.90°		
(53)	Louisville (Standiford)	1	Cat II	2.92°		
		29	Cat I	2.98°		
(54)	Des Moines Municipal	30R	Cat I	3.00°		x
		12L	Cat I	3.00°		
(55)	Raleigh/Durham	5	Cat I	2.57°		
		23	Cat I	3.00°		x
(56)	Salt Lake City International	34L	Cat II	3.00°		
		16L	Cat I	3.00°		
(57)	Ontario International	25	Cat I	2.75°		
(58)	Lubbock Regional	17R	Cat I	2.90°		
(59)	Norfolk International	5	Cat I	2.50°		
		23	Cat I	3.00°		
(60)	Hartford (Bradley International/Windsor Locks)	6	Cat II	3.00°		

	Airport	Runway	ILS	Glideslope	DME	VASI
(61)	Rochester-Monroe County	4	Cat I	3.00°		
		28	Cat I	2.95°		
		22	Cat I	3.00°		x
(62)	Colorado Springs Municipal	35	Cat I	2.70°		x
(63)	Sacramento Metro	16	Cat II	3.00°		
(64)	Greater Buffalo International	23	Cat I	3.00°		
		5	Cat I	3.00°		
(65)	Midland Regional	10	Cat I	2.50°		
(66)	Shreveport Regional	13	Cat I	3.00°		
		31	Cat I	3.00°		
(67)	Charleston AFB/Municipal	15	Cat I	3.00°		x
(68)	Boise Air Terminal	10R	Cat I	3.00°		
(69)	Tucson International	11L	[1]			
(70)	Austin (Mueller)	30L	Cat I	2.50°		
(71)	Little Rock (Adams)	4	Cat I	3.03°		
(72)	Birmingham Municipal	5	Cat I	2.81°		x
(73)	Sarasota/Bradenton	31	Cat I	3.00°		
(74)	Daytona Beach Reg.	6L	Cat I	2.62°		

[1] Needs approach lights for Cat I

Airport	Runway	ILS	Glideslope	DME	VASI
(75) Madison-Dane County	36	Cat I	3.00°		
(76) Anchorage International	6R	Cat II	3.00°		
(77) Providence (Green)	5R	Cat I	3.00°		
(78) Knoxville (McGhee-Tyson)	4L	Cat I	2.70°		
	22R	1	2.00°		
(79) Billings (Logan)	9	Cat I	3.00°		
(80) Jackson (Thompson) (Miss.)	15L	Cat I	3.00°		
	33L	Cat I	3.00°		
(81) Palestine Municipal	(VFR)				
(82) Amarillo	3	Cat I	2.52°		
(83) Rochester Municipal	31	Cat I	2.75°		
(84) Reno International	16	Cat I	3.00°	x	
(85) Savannah Municipal	9	Cat I	2.65°		
(86) Fresno	29R	Cat I	3.00°		
(87) Melbourne Regional	9	Cat I	2.80°		
(88) Mobile (Bates)	14	Cat I	2.60°		

	Airport	Runway	ILS	Glideslope	DME	VASI
(89)	Richmond (Byrd International)	33	Cat I	3.00°		
		6	Cat I	2.90°		
		15	Cat I	3.00°		x
(90)	Corpus Christi International	13	Cat I	2.50°		
		35	Cat I	3.00°		
(91)	Toledo Express	7	Cat I	2.50°		
(92)	Cedar Rapids	8	Cat I	2.50°		
(93)	Fargo (Hector)	35	Cat I	2.66°		x
(94)	Greensboro-HighPoint Winston-Salem Reg.	14	Cat I	2.53°		
		23	Cat I	3.00°		
		5				x
(95)	Moline (Quad-City)	9	Cat I	2.50°		
(96)	Chatanooga (Lovell)	20	Cat I	3.00°		
(97)	Ft. Myers (Page)	5	Cat I	3.00°		x
(98)	Newport News	6	Cat I	3.00°		
(99)	Portland International	11	Cat I	3.00°		
(100)	Syracuse (Hancock International)	28	Cat I	3.00°		
		10	Cat I	3.00°		
(101)	Tallahassee Municipal	36	Cat I	2.80°		
(102)	Monterey (Peninsula)	10	Cat I	3.00°		

	Airport	Runway	ILS	Glideslope	DME	VASI
(103)	Bismarck Municipal	31	Cat I	2.57°		
(104)	Huntsville (Madison Co.)	18R	Cat I	2.82°		
		36L	Cat I	3.00°		
(105)	Lincoln Municipal	35L	Cat I	2.68°		x
(106)	Missoula	11	Cat I	3.00°		
(107)	Allentown-Bethlehem	6	Cat I	3.00°		
(108)	Juneau	8	LDA*		x	x
(109)	Stockton	29R	Cat I	2.90°		
		11L				x
(110)	Columbia Metro	11	Cat I	3.00°		
		29	Cat I	3.00°		
(111)	Butte-Silver Bow	11	(No ILS, VORTAC at field)			x
		15				x
(112)	Bozeman (Gallatin)	12	Cat I	3.00°		x
(113)	Great Falls International	34	Cat I	3.00°		
(114)	Helena	26	Cat I	3.00°		x
(115)	Monroe Municipal	4	Cat I	2.50°		

*LDA is a localizer type directional aid

	Airport	Runway	ILS	Glideslope	DME	VASI
(116)	Panama City-Bay	14	1	2.75°		
(117)	Bangon International	33	Cat I	2.60°		
(118)	Ft. Wayne Municipal	31	Cat I	2.93°		
		4	Cat I	3.00°		x
(119)	Albany Co.	19	Cat I	3.05°		
		1	Cat I	3.00°		
(120)	Ft. Smith Municipal	25	Cat I			
(121)	Grand Rapids	26L	Cat I	3.00°		
(122)	Lansing (Capital)	27	Cat I	2.82°		
(123)	Saqinaw (Tri-City)	5	Cat I	2.50°		
(124)	Santa Barbara	7	Cat I	3.00°	x	
(125)	Sitka	11	(Localizer-DME)		x	x
(126)	Brownsville International	13R	Cat I	2.75°		
(127)	Akron-Canton Regional	1	Cat I	2.95°		
		23	Cat I	3.00°		x
(128)	Fairbanks International	19R	Cat I	3.00°		x
		1	Cat II	3.00°	x	
(129)	Long Beach	30	Cat I	2.75°		

1 Approach lights needed for Cat I operations

	Airport	Runway	ILS	Glideslope	DME	VASI
(130)	Augusta (Bush)	35	Cat I	3.00^0		
		17	Cat I	3.00^0		
(131)	Charleston (Kanawha)	23	Cat I	2.95^0		x
(132)	Evensville Dress	22	Cat I	2.78^0		
(133)	Sioux Falls (Foss)	3	Cat I	2.70^0		x
(134)	Grand Forks International	35	Cat I	2.50^0		
(135)	Gainesville Municipal	28	Cat I	3.00^0		
(136)	Greenville/Spartanburg	3	Cat I	3.00^0		
(137)	Lexington (Blue Grass)	4	Cat I	2.80^0		
(138)	South Bend (Michiana)	27	Cat I	3.00^0		
(139)	Youngstown Municipal	32	Cat I	2.98^0		
(140)	Wilkesbarre/Scranton	4	Cat I	3.00^0		
(141)	Bakersfield (Meadows)	30R	Cat I	3.00^0		
(142)	Baton Rouge (Ryan)	13	Cat I	3.00^0		
(143)	Alexandria (Esler)	26	Cat I	2.50^0		
(144)	Flint (Bishop)	9	Cat I	2.70^0		
(145)	Grand Junction	11	Cat I	2.75^0		

	Airport	Runway	ILS	Glideslope	DME	VASI
(146)	Jamestown Municipal	30	Cat I	3.00^{0}		
(147)	Ketchikan (Wfnt)	30	Cat I	3.37^{0}	x	x
(148)	Lawton Municipal	35	Cat I	3.00^{0}		
(149)	Pendleton Municipal	25R	Cat I	2.75^{0}		
(150)	Wichita Falls AFB/ Municipal	33L	Cat I	2.50^{0}		x
(151)	Harrisburg	13	Cat I	3.00^{0}		x
(152)	Beaumont-Port Arthur	11	Cat I	2.50^{0}		
(153)	Gustavus		(NDB at field) (LRCO* Juneau FSS)			
(154)	Islip (Mac Arthur)	6	Cat I	2.80^{0}		
(155)	Valdez #2		(Unattended, VFR, No Navigation Aid)			

*Limited remote communication outlet

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3. *Airways Facilities Sector Level Maintenance Staffing Criteria and Standards.* FAA Order 1380.9D, August 8, 1973.

4. Fiscal Year 1976 FAA Budget Hearings (F&E).

5. Lambregts, A. A. and Svensson, C. I.: *Engineering Evaluation of 727 Approach Energy Management System Using Distance Derived from the ILS.* Boeing Document D6-44215, January 1977.