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Application of the Microwave Landing System to Helicopter Operations

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Final Report

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16. Abstract

This report identifies ways in which the Microwave Landing System (MLS) can be utilized to aid helicopter operations. Consideration is given to the following study areas:

- helicopter instrument approach requirements by type of operation
- helicopter instrument approach requirements by operational area
- types of potential approach procedures that could be used by helicopters
- helicopter performance considerations during approach, landing and missed approach procedures
- ground and airborne MLS equipment
- benefits and costs associated with the use of MLS in helicopter operations

The operational areas considered in the study are: city centers, major hub airports, non-hub airports, remote areas, and offshore oil rig support. MLS procedures can be applied to each of these operational areas. From an economic standpoint, operations at city center heliports, major hub airports, non-hub airports, and remote areas will have benefits that exceed costs if operations counts are sufficiently large. Offshore operations will not have benefits that exceed costs due to the availability of alternative approach procedures.

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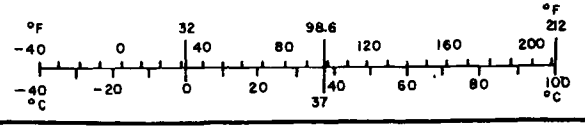
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 EXECUTIVE SUMMARY

At the present the number of heliports in the United States is about 3300. Many helicopter tasks require the use of IFR equipment to operate in all weather conditions. The growing need for IFR procedures at these heliports has prompted the development of navigation systems and procedures specifically tailored for helicopter operations.

1.1 BACKGROUND

There are at least three primary reasons to investigate the application of MLS to helicopter approach and landing operations. First, pilot workload during approach and landing is intense and the use of MLS could reduce workload, thus, enhance safety. Second, MLS permits helicopter operators to continue flight during non-VFR operating conditions. Finally, the unique capabilities of helicopters have prompted the development of terminal procedures utilizing the maneuverability of helicopters.

Recently MLS has moved from a research and development activity to a test and evaluation activity. The FAA's major activity in this area is the Service Test and Evaluation Program (STEP). The STEP program calls for initial operations with FAA and user owned aircraft supplemented by FAA aircraft and FAA ground facilities, transitioning in the second phase to user aircraft with government furnished airborne receivers flying to ground facilities owned and operated by FAA. These operations will take place at both hub and small community airports in the north-eastern U.S. Initial runways to be outfitted with MLS are as follows:

Airports	Runways
Washington National	18 and 33
Philadelphia International	17
Clarksburg, West Virginia	21
Atlantic City FAATC (Test Site)	31

These operations will demonstrate the suitability of MLS in the day-to-day service environment.

1.2 OPERATIONAL REQUIREMENTS

Approach procedures are developed with specific airspace boundaries. Aircraft staying within these boundaries are protected from trees, towers, mountains and other obstacles that can be hazardous to safety of flight.

The basic requirements to perform an instrument approach procedure are:

- approach guidance
- fix identification
- vertical guidance

One additional requirement is sometimes imposed in congested terminal areas. This requirement is that of aircraft separation to aid air traffic control.

1.2.1 Approach Course Guidance

Approach course guidance provides the pilot with an indication of the position of the aircraft with respect to the desired approach path. This guidance may be in the form of a course deviation indicator for VOR, MLS, and ILS approach procedures, a DME distance value for DME Arc procedures, or a radar map and a compass reading for ARA procedures. To the trained instrument pilot, each of these presentations can be interpreted to determine the aircraft position with regard to the approach couse and determine what, if any, steering inputs are necessary to keep the aircraft on the approach course.

1.2.2 Fix Identification

Fix identification provides the pilot with an indication of how position along the final approach course is progressing. The alongtrack position is used to identify points on the approach path where altitude changes or course changes should be made. Fix identification is provided by any one of a number of techniques. These techniques include:

- facility crossing (NDB or VOR)
- time measured after crossing a facility
- VOR radial
- NDB bearing
- DME or DME/P* distance
- marker beacon indicator
- range mark on an airborne radar display

1.2.3 Vertical Guidance

Vertical guidance is generally provided in one of four ways:

- electronic glide slope (ILS or MLS)
- radar altimeter
- baro altimeter
- 3D-RNAV (VNAV)

In an ILS or MLS approach, vertical guidance is provided by a vertical deviation indicator measured from an electronic glide path. In approaches over seawater or smooth terrain, vertical guidance is often provided by the use of a radar (or radio) altimeter. This device measures height above the terrain over which the aircraft if flying. In most non-precision approach procedures, vertical guidance is provided by a barometric altimeter. The baro altimeter measures height with respect to a standard atmospheric pressure profile. At specific points in the procedure, usually identified by a position fix, the procedure calls for the pilot to descend to a lower altitude as determined from the baro altimeter. The lowest such altitude in the procedure is called the minimum descent altitude (MDA). The altimeter must be corrected in flight for pressure

*NOTE: DME/P is precision DME which is currently being considered by the International Civil Aviation Organization (ICAO) as an international standard for MLS facilities.

variations from the profile. The 3D-RNAV, or VNAV, guidance method is a combination of the baro altitude and area navigation systems. An electronically computed glide path is utilized to provide guidance signals to the pilot or autopilot. This system allows the pilot to select altitudes at waypoints and descent gradients that are compatible with the aircraft capability.

1.2.4 Aircraft Separation Requirements

In congested terminal areas, the instrument approach procedure is being used to aid air traffic control. This can be achieved because airspace protection limits for precision approach procedures are less than those required by ATC radars. Typically, a terminal radar route width is ±1.5 nm while aircraft on parallel ILS approach paths can be separated by as little as 4300 ft, which is equivalent to a route width of ±2150 ft. This represents a 4.2 to 1 improvement in airspace utilization on final approach.

This same separation capability plus increased operational flexibility is expected from MLS. Additional ATC benefits can be derived by using this landing system. Some of the MLS features that can be utilized are offset radial approach paths, different approach descent angles for aircraft with differing performance capabilities, and segmented or curved approach paths using MLS/RNAV capabilities.

Procedures containing these capabilities of MLS have been demonstrated during the MLS development program. However, additional testing is required to establish a data base from which to develop standardized MLS approach criteria. This data base is being developed through continuing FAA research and development efforts.

1.3 HELICOPTER MLS OPERATIONAL ENVIRONMENT

Through an analysis of the various applications of helicopters and the types of operations that are performed, the user environments were divided into five specific areas. These are:

- city center
- major hub airport
- non-hub airport
- remote area
- offshore oil rig

1.3.1 City Center Operations

City center operations are typified by operations into and out of heliports which are located in the central core area of major cities. Four types of operators are generally associated with this type of operation; law enforcement, emergency medical service, business/executive, and scheduled air carriers. Law enforcement operators generally have little or no requirement to operate in an IMC environment and thus will not be considered in this section. Most business/executive operators and scheduled air carriers are currently conducting all-weather operations whenever ground based navigation transmitters and published

instrument procedures permit. Dependable, expeditious service is the economic cornerstone of these operations, and all weather capability enhances that dependability. Emergency medical service (EMS) operations fall into two categories; interhospital transfers, and on scene pickup and transfers. Interhospital transfers do not, in most cases, require operations in IMC. Currently, EMS operations are generally limited to VMC. However, expansion to all-weather operations might significantly increase their effectiveness.

1.3.2 Major Hub Airport Operations

The primary navigation aid currently used for precision approaches at major hub airports is ILS. Several of these airports have short STOL designated runways, alleviating the problem of integrating incompatible aircraft on final approach. Where precision navigation aids are provided for these commuter designated runways, a separate ground transmitter system must be installed. For economic reasons, most major airports are reluctant to provide independent runway and approach aids systems for helicopter and commuter traffic, requiring these aircraft to be integrated into the air carrier arrival stream in order to obtain final approach guidance. The use of MLS, either as an approach aid on the short runway or on the primary runway would significantly enhance helicopter and STOL operations. Conventional procedures would be used with ground installations placed at the STOL runway. Offset azimuth or MLS/RNAV procedures are desirable when the equipment is placed on the primary runway.

1.3.3 Non-Hub Airport Operations

Non-hub airport activity is primarily general aviation traffic. When instrument conditions prevail, flight operations at non-hub airports involve transient general aviation aircraft, air taxi flights, and occasional air transport flights. Terminal areas are relatively uncongested and thus inflight delays are minimal.

Many of these airfields are poorly equipped in terms of non-precision approach capability and very few have precision approach instrumentation. Some form of precision approach guidance would be of considerable benefit to aid all-weather operations for both helicopter and fixed-wing traffic.

The most likely MLS ground system candidate for non-hub airports is the small community system with ±10° of azimuth coverage and 1° to 15° in elevation coverage. The use of DME or DME/P could be optional depending upon the specific navaids currently available in the area that could be used for fix identification. This type of ground system would provide users with centerline guidance, vertical guidance, and a means of fix identification. With these capabilities, approach minimums on the order of 200 feet ceilings and 0.5 mile visibilities would be attained at many non-hub airport facilities.

1.3.4 Remote Area Operations

The helicopter is an ideal vehicle for transport into and out of remote areas. Additionally, once at the remote site, helicopters can perform many tasks more effectively and efficiently than possible by any other means. The heavy lift capability of the helicopter is used by logging companies to transport logs to the sawmill or to a nearby river. Fire fighters use this same capability to deliver fire retardants to the scene of forest fires. Utility companies and game management departments depend on rotorcraft maneuverability to patrol power lines and restock isolated lakes and streams. Survey crews can be transported from one location to another in a minimum amount of time, saving weeks of backpacking between remote sites over the period of a year. Wildlife management game counts can be accomplished more quickly and accurately through the use of helicopters. Men and equipment can be transported to remote locations for support of a variety of operations from mining to forest ranger resupply. Perhaps the greatest contribution the helicopter has made in this area is that of search and rescue.

The variety of operations mentioned above illustrate the versatility of the helicopter and its adaptability to the remote area environment. It should be noted, however, that these missions have one thing in common, they are almost exclusively VMC in nature. Almost all remote area missions require visual contact with the ground requiring little or no precision IFR capability.

Occasionally there are intensive remote area support operations for survey and exploration teams. These activities may last for a few days or may extend indefinitely. In these cases there are requirements for all-weather operations capability. At these locations the availability of transportable, ground-based MLS equipment would be of significant value. This type of system would have to have the following characteristics:

- easy set up of transmitters, antennas, and monitors
- operate on self contained power
- easily maintained
- reliable

1.3.5 Offshore Oil Rig Operations

Several of the operational environments discussed in this report are conducive to the application of helicopters in routine productive roles. The offshore oil rig environment, however, is heavily dependent on helicopter operations. The key to this development has been the dependable service provided by the helicopter, particularly in the Gulf of Mexico oil fields. Recent expansion to locations other than the Gulf of Mexico has revealed the necessity of developing improved IFR capability and procedures if historical dependability standards are to be maintained without degrading safety. Weather conditions off the New Jersey coast and in the North Sea are significantly worse than those found in the Gulf of Mexico. Conditions off the Massachusetts coast promise to be worse yet. Cost effective IFR procedures need to

be developed in offshore facilities if these regions are to be maintained with a high degree of dependability.

FAA approval of airborne radar directed approaches (ARA) using weather mapping radar[1] in the offshore environment has reduced the requirement for a precision ground/rig based approach navigation signal aid. The use of MLS without airborne radar cannot achieve low minimums due to obstructions such as the rig and ships in the approach airspace. The use of the ARA procedure can produce low minimums without the use of MLS. Therefore, while the use of MLS in the offshore areas could have some operational benefits to pilots, there appears to be little or no improvement in offshore, all-weather capability resulting from the use of MLS.

1.4 HELICOPTER MLS PROCEDURES

In the study program several approach procedures utilizing MLS were investigated. These include:

- MLS straight in
- MLS point in space
- MLS offset azimuth
- MLS/RNAV

1.4.1 MLS Straight In Procedure

Operational Areas

city center
non-hub airport
remote area (for long term, repetitive operations only)
offshore (stabilized platforms or installation)

Ground Equipment

azimuth coverage ±10° from centerline
elevation coverage 1° to 15°
collocated azimuth and elevation at helipads
split site installation at non-hub airports
DME or DME/P required at most installations
marker beacon, compass locator can be used in lieu of DME required at some non-hub airports
monitor equipment (may require non-standard installation in city center, remote area and offshore locations)

Airborne Equipment

MLS receiver with centerline guidance and selectable glide path angle
DME, marker beacon or automatic direction finding equipment depending upon ground installation

1.4.2 MLS Point In Space Procedure

Operational Areas

city center

Ground equipment

azimuth coverage ±10° from centerline
elevation coverage 1° to 15°
collocated azimuth and elevation
DME or DME/P required for fix identification
monitor equipment (may require non-standard installation)

Airborne equipment

MLS receiver with centerline guidance and selectable glide path angle
DME or DME/P receiver

1.4.3 MLS Offset Azimuth Procedure

Operational areas

major hub airports

Ground equipment

azimuth coverage ±40° to ±60° from centerline
elevation coverage 1° to 15°
split site azimuth and elevation
DME or DME/P required for fix identification and arc transitions
monitor equipment at standard locations

Airborne equipment

MLS receiver with selectable azimuth and selectable
DME or DME/P receiver

1.4.4 MLS/RNAV Procedure

Operational areas

major hub airports
areas requiring noise abatement procedures

Ground equipment

azimuth coverage ±40° to ±60° from centerline
elevation coverage 1° to 15°
split site azimuth and elevation
DME or DME/P required for RNAV position determination
monitor equipment at standard locations

1.5 SUMMARY OF HELICOPTER MLS BENEFIT/COST ANALYSIS

The analysis of helicopter MLS costs is broken down into the following categories:

1.5.1 Costs

- Ground system
  - Investment costs

    Equipment (MLS, DME or DME/P, and lighting)
    Site preparation
    Flight Inspection (facility commissioning)

- Annual costs

  Operating costs
  Maintenance costs
  Routine flight inspection

- Airborne system
  - Investment costs

    new aircraft installation
    retrofit installation
    equipment costs (centerline guidance, offset azimuth guidance, MLS/RNAV guidance)

  - Annual costs

    Maintenance

All costs are treated on a twenty-five year present value basis with costs for future years discounted at a 10% annual rate to 1980. The results of the MLS ground system cost analysis is shown in the following list:

Ground System Costs (25 year total, discounted to 1980)

Configuration	Total System Cost
Small Community MLS	$725,000
Basic I MLS	$1,029,000
Basic II MLS	$1,312,000
Expanded MLS	$1,746,000

Airborne System Costs

MLS airborne system descriptions and costs are presented in Table 1.1.

Table 1.1 MLS Airborne Systems

System Characteristic	System 1	2	3	4
Centerline guidance	Yes	Yes	Yes	Yes
Selectable glide path	Yes	Yes	Yes	Yes
Selectable azimuth angle	No	Yes	Yes	Yes
MLS/RNAV guidance	No	No	No	Yes
Separate control panel	No	No	Yes	Yes
Auxiliary data display	No	No	No	Yes
Panel/remote electronics	Panel	Panel	Remote	Remote
Single/dual installation	Single	Single	Single	Single
Precision(P)/Nonprecision(N)DME	Non-precision	Non-precision	Non-precision	Precision
Cost* (25 year total, discounted to 1980)	$1,891	$2,221	$12,800	$26,769

*Cost does not include conventional DME but does contain a cost differential for DME/P on System 4.

1.5.2 Benefits

Helicopter MLS benefits are broken down into the following categories:

Safety Benefits (from averted accidents)

- Aircraft damage reduction
- Human lives saved
- Serious injuries averted

Efficiency Benefits (from averted flight disruptions)

- Reduced delays
- Averted cancellations
- Fewer diversions
- Reduced number of overflights of destination

Evaluation of safety benefits requires substantial analysis of IFR accident records. Since helicopter IFR records are limited, fixed-wing accident statistics were utilized. These analyses produced differing benefits for each aircraft size category. These individual benefits were weighted by size category percentages and accumulated to produce the following average value for safety benefits:

Average safety benefit - $42 per IFR approach

Evaluation of efficiency benefits requires an evaluation of helicopter direct operating costs, revenue lost due to cancellations, value for lost passenger time, and passenger handling costs when confronted with a flight disruption. These values differ for different operational areas and helicopter types. The results of this analysis, also obtained by weighting the benefits by size category percentages, produced the following average efficiency benefits:

Operational Area	Average Efficiency Benefit
City center	$290 per IFR approach
Major hub airport	$350
Non-hub airport	$240
Remote area	$190
Offshore	$210

1.5.3 Number of MLS Operations

The number of MLS operations at a heliport is computed as a percentage of current annual itinerant operations. This percentage is developed from the following factors:

- Current helicopter special VFR or non-precision approach
- Estimated MLS minimums
- Percentage use of the approach procedure
- Growth in operations over the time period of the analysis
- MLS equippage rate

Two of these terms, growth and equippage rate, change depending upon the year in which the benefit occurs. In addition benefits for future years are discounted at a 10% per year rate. These time varying terms were accumulated to a constant multiplier.

1.5.4 Helicopter MLS Benefits

Combination of all these benefit and operations factors produced the benefit values by operational area shown in Table 1.2. The daily operations include both current VFR and IFR itinerant operations. The results are very sensitive to the minimums (VFR, special VFR or IFR) currently in effect at the heliport. Therefore three levels of minimums are shown in the Table.

Table 1.2 Helicopter MLS Benefits ($ Million) 25 Years Discounted to 1980

BENEFITS ($ MILLION)	Helicopter Special VFR or Non-Precision Approach Minimums								
	1000 - 1½			700 - 1½			500 - 1		
	Daily Operations			Daily Operations			Daily Operations		
Operational Area	50	100	200	50	100	200	50	100	200
City center	1.32	2.64	5.29	.83	1.66	3.32	.41	.82	1.64
Major Hub Airport	1.60	3.20	6.40	1.01	2.01	4.02	.50	.99	1.99
Non-hub Airport	1.12	2.23	4.46	.70	1.40	2.80	.35	.69	1.38
Remote Area	.92	1.84	3.68	.58	1.16	2.31	.29	.57	1.14
Offshore	.98	1.96	3.92	.62	1.23	2.46	.30	.61	1.22

Note: Minimums are interpreted as ceiling (feet) - visibility (miles)

1.5.5 Benefit/Cost Ratio

Two types of benefit to cost ratios were considered. The first is analogous to ILS establishment criteria and does not consider costs for airborne equipment. This analysis is valid when MLS is available at a large number of airfields and is represenative of a long term consideration of helicopter MLS costs.

The second analysis considers that users will have to install MLS on their aircraft and these costs must be attributed to the specific heliport under consideration. This analysis is representative of the near term when MLS will be available at only one heliport used by the operator.

Table 1.3 presents the benefit to cost ratio values when only ground system costs are considered. Small Community MLS installations are assumed for all operational areas except the major hub airport where a Basic I system is utilized. Both systems include azimuth, elevation, and heliport lighting. The Small Community MLS has conventional DME, the Basic I MLS has DME/P. Table 1.4 presents the same information when airborne system costs are assigned to the heliport under consideration. Inclusion of airborne system costs seriously affects the benefit to cost ratio in areas that have relatively low minimums at the present time, as shown in the columns with current minimums of 500 - 1. Therefore it is apparent that in general the most favorable locations for MLS, in a cost-benefit sense, are those areas that do not have low minimums but yet do have high demand in terms of daily operations.

1.5.6 Alternative Approach Procedures

In the onshore areas where alternative non precision approach procedures can be flown to minimums of 500 - 1 and less, the cost of the MLS ground system will usually mean that costs will outweigh benefits except in areas with very high operations counts. For areas where non-precision approach minimums are on the order of 700 - 1½, benefits will begin to exceed costs with moderate operations counts (16,000 to 23,000 annual itinerant operations). Typical areas which would be initial candidates for MLS installations would be:

- airports/heliports in mountainous areas
- city center areas with tall buildings and narrow corridors
- major hub airport areas where airspace is limited
- remote heliports supporting active helicopter operations

In the offshore areas the presence of the rig and possible presence of ships in the area require the use of airborne radar for obstacle avoidance. Without radar, MLS minimums will necessarily be high. With radar and no MLS, the ARA procedure can be flown to minimums that are as low as most anticipated MLS minimums. Therefore in the offshore environment MLS procedures are not considered to be economically feasible.

1.6 CONCLUSIONS

The major conclusions developed in this study are divided into two categories, operational and economic. These conclusions are presented in the following sections.

1.6.1 Operational Results

- Five types of helicopter MLS approach procedures were identified in the study. They are:
  - MLS straight in
  - MLS point in space
  - MLS azimuth only
  - MLS offset azimuth
  - MLS/RNAV

Table 1.3 Helicopter MLS Benefit/Cost Ratio (Ground System Costs Only)

BENEFIT/COST RATIO	Helicopter Special VFR or Non Precision Approach Minimums								
	1000 - 1½			700 - 1½			500 - 1		
	Daily Operations			Daily Operations			Daily Operations		
Operational Area	50	100	200	50	100	200	50	100	200
City Center	1.8	3.6	7.3	1.1	2.3	4.6	.6	1.1	2.3
Major Hub Airport	1.6	3.1	6.2	1.0	2.0	3.9	.5	1.0	1.9
Non-hub Airport	1.5	3.1	6.2	1.0	1.9	3.9	.5	1.0	1.9
Remote Area	1.3	2.5	5.1	.8	1.6	3.2	.4	.8	1.6
Offshore	1.4	2.7	5.4	.8	1.7	3.4	.4	.8	1.7

Note: Minimums are interpreted as ceiling (feet) - visibility (miles)

Table 1.4 Helicopter MLS Benefit/Cost Ratio (Estimated Ground and Airborne System Costs)

BENEFIT/COST RATIO	Helicopter Special VFR or Non Precision Approach Minimums								
	1000 - 1½			700 - 1½			500 - 1		
	Daily Operations			Daily Operations			Daily Operations		
Operational Area	50	100	200	50	100	200	50	100	200
City Center	1.8	3.4	6.5	1.1	2.2	4.1	.5	1.1	2.0
Major Hub Airport	1.5	2.8	5.1	.9	1.8	3.2	.5	.9	1.6
Non-hub Airport	1.5	2.8	5.0	.9	1.7	3.1	.5	.9	1.5
Remote Area	1.2	2.3	4.1	.8	1.4	2.6	.4	.7	1.3
Offshore	1.2	2.3	4.0	.8	1.4	2.5	.4	.7	1.2

Note: Minimums are interpreted as ceiling (feet) - visibility (miles)

- The MLS straight in approach is generally equivalent procedurally to the current ILS approach. Lateral and vertical guidance is provided by the MLS azimuth and elevation scanning beam signals. Fix identification for alongtrack position keeping can be provided by DME, DME/P, marker beacons, or other navigation aids. Glide path angle can be fixed, as it is with ILS, or variable to suit the helicopter performance capabilities or landing area operational environment.

- The MLS point in space procedure is essentially the same as the MLS straight in procedure, except the approach terminates at a point greater than 2600 ft from the landing area for operational or safety reasons. At the missed approach point the pilot continues VFR to the landing area or performs the missed approach procedure. Point in space procedures are often used in city center areas where multiple landing areas are located around bridges, buildings and other obstructions. DME, DME/P or other navaids are used for fix identification.

- MLS azimuth only approaches are non-precision procedures that are procedurally equivalent to ILS localizer approaches. This procedure would be used when MLS elevation is not available or inoperative. Vertical guidance is provided by barometric altitude. Fix identification for letdown purposes may utilize DME, DME/P, or other navaids.

- MLS offset azimuth approaches utilize an azimuth radial other than centerline (0° azimuth) for all or part of the approach. This type of approach procedure could be used at MLS equipped airports that have wide angular coverage in azimuth (±40° to ±60°) at the primary runways. The offset azimuth procedure can be used to provide helicopters with approach paths that are independent of fixed-wing traffic. This procedure can also be used to avoid noise sensitive areas. DME, DME/P or other navaids are used for fix identification.

- The MLS/RNAV procedure combines the capability of MLS and RNAV to provide terminal area routes that are virtually independent of MLS location so long as the aircraft operates within the MLS proportional coverage area. This capability provides operational advantages similar to these of the offset azimuth procedure, but it has the additional flexibility of not being constrained to azimuth radials. This procedure does require additional airborne equipment capability to generate MLS/RNAV waypoints and guidance.

- MLS offset azimuth procedures or MLS/RNAV can be used in congested terminal areas to enhance ATC operations by permitting helicopters to operate on routes that are independent of fixed-wing traffic. The helicopters can utilize the MLS transmitter facilities intended for operations on the primary runways.

- MLS has substantial operational potential for helicopter operations at city center locations, major hub airports, and non-hub airport locations.
- Many remote area operations need VFR conditions as a mission requirement. These operations generally will not benefit substantially from the use of MLS procedures. However intensive remote area operations to a specific area over long periods of time could benefit from MLS procedures.
- Use of MLS in the offshore oil rig environment requires stabilized platforms or stabilized antenna structures for the azimuth transmitter. MLS elevation signals are probably unusable on a pitching, heaving platform.
- MLS straight in, MLS point in space, and MLS azimuth only approaches can be developed using ground facilities ranging from the ±10° coverage system to the expanded ±60° coverage system. MLS offset azimuth and MLS/RNAV procedures can be developed using the ±40° and ±60° azimuth coverage ground facilities.

1.6.2 Economic Results

- MLS benefits will accrue to most multiengine turbine helicopters and IFR equipped single engine turbine helicopters. Very few piston engine helicopters will be IFR qualified over the next 15 years.
- The data base describing or forecasting helicopter operations at specific airports and landing areas is not readily available. The analysis of user costs and benefits requires this data base. Estimates of operations counts were necessary in order to complete the analyses. The results are therefore based upon these estimates.
- Twenty-five year accumulated MLS ground system costs, discounted at a 10% rate to 1980, were obtained through an analysis of previous MLS studies. These costs include MLS azimuth, elevation, and monitor equipment; site preparation; helicopter approach lighting; operating and maintenance costs. The following system cost data were obtained:

Configuration	Proportional Coverage	Total System Cost (25 year, discounted 10% to 1980)
Small Community MLS	±10°	$725,000
Basic I MLS	±40°	$1,029,000
Basic II MLS	±40°	$1,302,000
Expanded MLS	±60°	$1,746,000

- Twenty-five year accumulated MLS airborne system costs, discounted to 1980, were obtained through an analysis of previous MLS studies, manufacturers' inputs, and current avionics costs. These costs include airborne equipment, installation (for retrofit in older helicopters), and annual maintenance. The following user costs data were obtained:

Airborne System Cost (25 year, discounted 10% to 1980)

System		Cost (per unit)
1	Low-performance GA	$1,891
2	Intermediate-performance GA	$2,221
3	High-performance GA	$12,800
4	Integrated MLS/RNAV	$26,769

- Safety benefits obtained by averting approach and landing accidents were estimated to be as follows:

Type of Helicopter	Safety Benefit per IFR Approach
Single engine turbine	$50
Light twin turbine	$20
Medium twin turbine	$20
Heavy turbine	$40
Very heavy turbine	$80
Weighted average	$42

- Efficiency benefits obtained by averted flight disruptions (delays, diversions, cancellations and overflights) vary depending upon the type of operation in which the aircraft is engaged. The following data is an estimate of efficiency benefits based upon a weighted average of helicopter types:

Operational Area	Efficiency Benefits per IFR Approach
City center	$290
Major hub airport	$350
Non-hub airport	$240
Remote area	$190
Offshore	$210

- The accumulated twenty-five year helicopter MLS benefits are very sensitive to current VFR or IFR approach minimums without MLS. The following numbers of daily flight operations are required to produce benefits which equal the cost of MLS ground system costs.

Operational Area	MLS Ground System	Average Daily Operations (Takeoffs + Landings)		
		1000-1½	700-1½	500-1
City center	Small Community MLS	28	43	90
Major hub airport	Basic I MLS	32	51	104
Non-hub airport	Small Community MLS	33	52	105
Remote area	Small Community MLS	40	64	124
Offshore	Small Community MLS	37	58	117

Note: Minimums are interpreted as ceilings in feet - visibility in miles.

- Based upon a current operational count (1980) of 100,000 operations per year, an MLS point in space approach to the Manhattan heliports has a benefit to cost ratio exceeding unity. The ratio is very sensitive to current assumed Helicopter Special VFR (HSVFR) Minimums. The benefit estimate and benefit to cost ratio are as follows:

Assumed HSVFR Minimums	Benefit Estimate	Benefit/Cost Ratio*
1000 ft - 1½ mile	$6,500,000	9.0
700 ft - 1½ mile	$3,900,000	5.4
500 ft - 1 mile	$1,600,000	2.2

*Based on the use of a Small Community MLS

- In the offshore environment the use of airborne radar is necessary in IFR to avoid the rig and ships operating in the area with or without MLS guidance. With airborne radar and radar altimetry, minimums of 200 ft ceiling and 3/4 mile visibility are attainable with or without MLS. Therefore MLS is not economically feasible in the offshore environment.

2.0 BACKGROUND

2.1 THE HELICOPTER IFR NAVIGATION NEED

At present the number of heliports in the United States is about 3300. This has increased from only 400 in 1960. Of these 3300, nearly 300 are rooftop, the rest being ground level. More than 400 are public-use, many of which are commercial use, fixed base operations. Hospital heliports number almost 700. The largest contributors are the private or personal-use heliports numbering more than 2300[2].

The viability of many emerging helicopter operations depends on the ability to perform all-weather operations at these heliports. Until about five years ago the helicopter was considered basically a VFR vehicle. A few IFR operations were performed but these were basically fixed-wing procedures flown with two pilots on large helicopters. Recent innovations in both the handling characteristics of helicopters and in the demand by operators for IFR route structures has prompted considerable interest in instrument approach and landing procedures that are specifically tailored for helicopters. Evidence of the seriousness with which helicopter operators view IFR operations can be seen by their willingness to spend large amounts of money ($50,000 to $150,000) on stability augmentation systems (SAS) which allow helicopters to obtain single pilot IFR certification. Other indicators of the need for IFR in helicopters are the interest in RNAV in the Northeast corridor areas and the interest in Loran-C in the offshore and land areas. Still other indicators are the increased development and sales of twin turbine helicopters outfitted in both executive and working cabin design. With this growing requirement for IFR operations there follows a need to develop IFR navigation systems and procedures for helicopters.

There are at least three primary reasons to investigate the application of MLS to helicopter approach and landing operations. First, it is a well known fact that workload is highest and the accident rate is greatest during approach and landing. Safety considerations during this phase of flight create a need to examine new technological advances like MLS and to assess their capability for improving the safety of flight. The second reason is economic in nature. Without IFR procedures and approved landing aids many flights would be delayed or even cancelled, producing an economic burden upon the helicopter operator. Many times, a go/no-go decision on a given flight is directly predicated on the type of landing system that is available at the intended point of arrival. Reserve fuel and alternate airport selections are also directly affected by existing or forecast weather conditions considered in conjunction with the availability of ground based landing aids and airborne avionics capability. The availability of lower MLS minimums will increase the reliability of flight for operators who equip their fleet. The third reason for investigating MLS for helicopters is for improving the utility of these aircraft. This can be done by designing approach procedures around the helicopter's capabilities and not constraining it to fized-wing procedures. Approach procedures have been developed for the Instrument Landing System (ILS) and the ATC radar. All of these

approach procedures have been designed around fixed-wing aircraft. Only recently have the Terminal Instrument Procedures[3] (TERPS) recognized the unique capabilities of helicopters. Chapter 11 in TERPS is specifically developed for helicopters. However, the procedures that have been developed up to this time still do not permit the helicopter to fully utilize its unique flight characteristics in the approach and landing phase of flight. New navigation equipment and new procedures are needed to make use of these characteristics. The newly adopted Time Reference Scanning Beam Microwave Landing System (TRSB MLS or simply MLS) has many features which makes it a very strong contender for fulfilling this role. The basic design concept of the MLS system was to inherently provide the flexibility that is so greatly needed in helicopter IFR operations.

2.2 THE MLS SYSTEM

MLS is composed of ground based transmitters and airborne receivers. The ground station can be configured in several ways depending on the needs of the specific site or the complexity of operations at the site. In the simplest configuration planned for use by the FAA at this time, the ground station consists of azimuth, elevation, and DPSK (differential phase shift keying) transmitters. The DPSK provides digital data to the receiver telling it of an impending azimuth or elevation transmission, time synchronization, and data link capabilities. The azimuth portion of MLS is composed of two basic elements, proportional and clearance guidance. In a standard installation the area in a sector on each side of the extended runway centerline is called the proportional guidance region. In this area angular information relative to the runway centerline is provided by a scanning beam signal. A narrow scanning beam sweeps from one side of the coverage area to the other and returns. On each side of the proportional guidance area there may exist a clearance guidance region. The clearance guidance signal can be processed by the receiver to indicate that the aircraft is either left or right of the runway centerline. In this region proportional angular guidance is not provided.

The elevation part of MLS operates in a manner that is similar to the proportional azimuth function. A scanning beam sweeps from the minimum elevation angle up to the vertical coverage limit and back down again to provide a proportional elevation guidance signal. The lateral extent of this elevation signal may or may not cover the same angular area as the proportional azimuth scanning beam. The DPSK signal is broadcast throughout the MLS coverage area and provides acquisition and timing information (preamble) for the scanning beam signals and data link messages that take the form of basic data which will be broadcast at all MLS sites, or auxiliary data which may be broadcast at sites with expanded operational capability. Other extended features of the MLS systems provide for DME, flare and back-azimuth functions. Flare is provided at sites that may have autoland capabilities. The back-azimuth feature can be used for missed approach and departure procedures.

Standardization of the DME part of MLS has not occurred at this time. The civil aviation community tends to favor continued use of the present L-band DME. Tests have been performed using a precision

DME that is capable of providing higher accuracy than the standard DME signal but yet remains compatible with existing airborne DME receivers. Military users of MLS tend to prefer a new DME system operating at C-band. Differences between the civil and the military positions on DME are being considered at the present time.

The proportional coverages areas of MLS may vary from site to site depending upon the operational requirements of the users and the availability of equipment. At the present time several ground station configurations are under consideration by FAA planners. These systems include:

Configuration	Proportional Coverage	ICAO Operational Category
Small Community MLS (no DME)	±10°	I
Small Community MLS (DME/P)	±10°	I
Basic MLS I	±40°	I
Basic MLS II	±40°	II
Expanded MLS	±60°	III

The benefits to the operators is using MLS rather than ILS will come from the ability to use the extended proportional coverage areas in both azimuth and elevation. If ways and procedures can be devised to make use of these areas, MLS can be of benefit to helicopter operators. Benefits to the FAA in using MLS occur due to reduced installation costs for MLS and potential airport capacity improvement from the MLS operational flexibility.

2.3 THE STATUS OF MLS

Recently MLS has moved from a research and development activity to a test and evaluation activity. The FAA's major activity in this area is the Service Test and Evaluation Program (STEP). The STEP program calls for initial operations with user owned aircraft supplemented by FAA aircraft and FAA ground facilities, transitioning in the second phase to user aircraft with government furnished airborne receivers flying to ground facilities owned and operated by FAA. These operations will take place at both hub and small community airports in the northeastern U.S. Initial installation of MLS systems area as follows:

Airports	Runways
Washington National	18 and 33
Philadelphia International	17
Clarksburg, West Virginia	21
Atlantic City NAFEC (Test Site)	31

These operations will demonstrate the suitability of MLS in the day-to-day service environment. It is intended that commuter and other operators that regularly use these airfields will be supplied with MLS receivers for evaluation.

Several activities are taking place with MLS in the area of standards development. A major international activity has led to the development of Standards and Recommended Practices (SARPS) for the ICAO. This activity has been handled by the All-Weather Operations Panel (AWOP) of ICAO. This work mainly concerns the standardization of ground stations for MLS throughout the world. For airborne equipment in the U.S. the Radio Technical Commission for Aeronautics (RTCA) has formed Special Committee SC-139 to develop standards for MLS angle receivers. This activity has produced RTCA Report No. DO-177 entitled "Minimum Operational Performance Standards For Microwave Landing System (MLS) Airborne Receiving Equipment". Additional activities on MLS airborne systems are being undertaken by ARINC-AEEC. On the international front the European counterpart of RTCA called EUROCAE is developing airborne standards for its member nations. Developments in EUROCAE were regularly reported at SC-139 meetings so international coordination was maintained for both ground and airborne systems.

3.0 STUDY OUTLINE

3.1 STUDY METHODOLOGY

The method of approach selected for performing this study is referred to as a case study approach. In this type of approach a quantity of background data and cost/performance relationships are developed to the point where they can be applied to a number of specific locations and operational applications. This study will define the potential application of MLS approach procedures to five specific helicopter user environments. These are:

- city center operations
- major hub airport operations
- non-hub airport operations
- remote area operations
- offshore oil rig operations

The data requirements for developing cost/performance relationships for use in the trade-off analysis have been categorized accordingly into the following eight study areas:

Task 1. helicopter approach and landing operations
Task 2. MLS approach types
Task 3. MLS airborne equipment
Task 4. MLS ground equipment
Task 5. helicopter approach and landing characteristics
Task 6. utilization forecasts
Task 7. cost projections
Task 8. alternatives to MLS approaches

To adequately perform this work, emphasis has been placed on collecting data and reports of other organizations that have actual experience in using MLS for helicopter approaches. Three organizations which provided data in this area are the U.S. Army, Aviation Research and Development Command, Fort Monmouth, New Jersey; NASA Ames Research Center, Sunnyvale, California; and FAA Aeronautical Center, Oklahoma City, Okahoma, as well as RTCA SC-139, of which representatives of these organizations are active.

The specific methodology used in the trade-off analysis for the eight tasks mentioned previously is described in detail in the following paragraphs.

Task 1. Generate a realistic characterization of the operational requirements for helicopter IFR approaches and landings. Also describe the areas in which IFR approaches will be required or desirable, and identify the constraints imposed upon both the helicopter and the approach and landing aids.

Task 2. Define the extent of MLS approach procedures pertinent to helicopter operations. Characterize MLS operational and technical problems and limitations. In this task the various approach procedures postulated for MLS are described. Among these approach procedures are straight-in MLS approaches at various elevation angles, azimuth function only approaches, offset MLS azimuth radial approaches (both with and without elevation), 2D RNAV-MLS approaches, and 3D RNAV-MLS approaches. Both collocated and split site transmitter locations are considered.

Task 3. Compare the results of Tasks 1 and 2 and match operational requirements with approach procedures. Identify those requirements which may be satisfied by more than one procedure and also identify those procedures where MLS is not capable of meeting the operational requirements. Identify the airborne equipment required for each procedure. The purpose of this task is to tie together the helicopter approach and landing requirements with the MLS approach capabilities. In many instances it is expected that more than one MLS procedure may apply. In other instances, MLS may not be capable of meeting the full operational requirements for the approach and landing. In these instances, MLS may have to be supplemented with additional ground or airborne equipment in order to meet the full operational requirement. For this reason Task 8 has been provided to consider non-MLS type approaches and to determine their cost effectiveness relative to the inclusion of MLS in the procedure.

Task 4. Determine the ground and airborne equipment required to perform the approaches and landings described in Task 3. Examine the MLS parameter ranges for required coverage and accuracy. Many of the approach procedures described in Task 3 can be performed with both limited and full capability MLS ground systems. Additionally, these approaches can be flown using MLS airborne equipment with a wide variety of operational capabilities as far as producing analog outputs, digital data outputs, DPSK data link outputs, etc. The most basic category of capability required to perform the approach will be postulated in this task.

Task 5. Since helicopters have different flight characteristics, evaluate the utility of the approach procedures described in Task 3 over a range of helicopter approach and landing capabilities. Evaluate the impact of the approach decision height and visibility minimums. The versatility of the helicopter also permits a wide range of approach speeds to be used. The exact descent profile may well depend on pilot preference and passenger comfort considerations as well. It is desirable to keep this flexibility in the

instrument approach procedure also. This capability, however, may produce requirements for additional flight control instrumentation. In addition, the approach speed and approach angle may directly affect the decision height and visibility minimums of the approach. The relationships between these parameters will have an effect on the overall cost performance trade-off.

Task 6. Obtain forecasts of helicopter operations for the next ten to twenty years for the various approach and landing operations in Task 1. Consider these forecasts in light of appropriate traffic and aircraft characteristics and determine the sensitivity of operations to approach minimums. In Tasks 1 thru 5 the case study approach provides the capability to treat each of the approach procedures and operational requirements as a separate entity. Task 6 develops the methodology for combining the various operations into an overall cost vs. performance trade-off. The relative importance of each of the helicopter approach and landing operations will be evaluated based on the projected number of approaches performed annually and on the basis of passenger numbers and payload considerations. Projections over a twenty-five year period are used. This time period is consistent with current FAA planning analysis procedures[4,25].

Task 7. Relate MLS coverage, accuracy and reliability to cost of equipment. Include the cost of purchase, installation, and maintenance for both ground and airborne hardware. In this task equipment costs are associated with each of the performance levels of the MLS ground and airborne equipment. When related to the MLS approach procedures for each of the operational applications as produced by Task 3, and when varied over the range of helicopter performance capabilities described in Task 5, the cost vs. capability range for each of the MLS approach procedures is determined. At this point there is produced a cost vs. performance relationship for each of the case studies that is analyzed. In cases where traffic forecasts are available, specific benefit/cost ratios and benefit quantification are determined. In cases where traffic forecasts are not available, the relationship between benefits and benefit/cost ratios versus traffic levels are presented graphically.

Task 8. Determine qualitatively the limitations and/or benefits of using alternate procedures. For some applications, MLS may require a significant number of modifications and enhancement in order to operate in a satificatory manner. In these instances, alternate approach and landing procedures may be more cost effective than MLS by itself. Operations that are included are VFR approaches, VOR approaches, VOR/DME approaches, RNAV appraoches, Loran-C approaches, and ARA approaches. To fully analyze each of these approach procedures would take a considerable amount of effort and is beyond the

scope of this investigation. Therefore, these analyses are treated in a subjective rather than quantitative manner.

3.2 REPORT ORGANIZATION

The products of the work performed in the eight tasks are presented in Sections 4 through Section 6 of this report. Section 4 contains a discussion of the operational requirements for helicopter approach procedures. This discussion is primarily the output of Task 1.

The results of Tasks 2, 3, 4 and 5 are contained in Section 5. These results are organized first, according to types of approach procedure and second, according to typical applications in the five helicopter user environments. Discussions of airborne and ground equipment requirements for each type of approach are contained in the section. Finally, limitations or constraints upon the procedure design as a result of the physical characteristics and operating characteristics of the helicopter are discussed.

The benefit/cost aspects of the study are contained in Section 6. In this section are described the costs of ground and airborne MLS equipment, the costs of weather related delays, and MLS utilization forecasts. Also discussed in Section 6 are approach procedures based on alternative navigation aids to MLS. Included in these discussions is an analysis of the relative merits of MLS procedures versus alternative procedures in terms of costs and benefits.

4.0 OPERATIONAL REQUIREMENTS FOR HELICOPTER IFR APPROACHES AND LANDINGS

4.1 BACKGROUND

Instrument approach procedures are designed and developed to help pilots make safe and efficient approaches and landings in weather conditions of limited ceilings and/or visibility. The TERPS[3] document contains standardized approach criteria that have been approved by the FAA and the U.S. Armed Forces. These criteria were developed to meet the requirements of both civil and military aviation. Recently, it has become increasingly evident that in some instances helicopters have requirements and performance characteristics that allow them to have instrument approach procedure standards that are different from those that apply to fixed-wing aircraft. Those unique helicopter standards which have been adopted to date are contained in Chapter 11 of TERPS. This section describes many of the approach requirements and the approach criteria that have been developed to meet these requirements as they apply to helicopter operations.

4.2 INSTRUMENT APPROACH REQUIREMENTS

Approach procedures are developed with specific airspace boundaries. Aircraft staying within these boundaries are protected from trees, towers, mountains and other obstacles that can be hazardous to flight.

The basic requirements to perform an instrument approach procedure are:

- approach course guidance
- fix identification
- vertical guidance

One additional requirement is sometimes imposed in congested terminal areas. This requirement is that of aircraft separation to aid air traffic control.

4.2.1 Approach Course Guidance

Approach course guidance provides the pilot with an indication of the position of the aircraft with respect to the desired approach path. This guidance may be in the form of a course deviation indicator for VOR and ILS approach procedures, a DME distance value for DME Arc procedures, or a radar map and a compass reading for ARA procedures. To the trained instrument pilot, each of these presentations can be interpreted to determine the aircraft position with regard to the approach course and determine what, if any, steering inputs are necessary to keep the aircraft on the approach course.

4.2.2 Fix Identification

Fix identification provides the pilot with an indication of how position along the final approach course is progressing. The alongtrack

position is used to identify points on the approach path where altitude changes or course changes should be made. Fix identification is provided by any one of a number of techniques. These techniques include:

- facility crossing (NDB or VOR)
- time measured after crossing a facility
- VOR radial
- NDB bearing
- DME distance
- marker beacon indicator
- range mark on an airborne radar display

4.2.3 Vertical Guidance

Vertical guidance is generally provided in one of four ways:

- electronic glide slope
- radar altimeter
- baro altimeter
- 3D-RNAV (VNAV)

In an ILS approach, vertical guidance is provided by a vertical deviation indicator measured from an electronic glide path. In approaches over seawater or smooth terrain, vertical guidance is often provided by the use of a radar (or radio) altimeter. This device measures height above the terrain over which the aircraft is flying. In most non-precision approach procedures, vertical guidance is provided by a barometric altimeter. The baro altimeter measures height with respect to a standard atmospheric pressure profile. At specified points in the procedure, usually identified by a position fix, the procedure calls for the pilot to descend to a lower altitude as determined from the baro altimeter. The lowest such altitude in the procedure is called the minimum descent altitude (MDA).

The altimeter must be corrected in flight for pressure variations from the standard profile. Altitude minimums are stated in terms of height above mean sea level to account for the height of the surrounding terrain and obstacles. When sources of barometric altimeter corrections are remote from the airport of intended landing, minimum descent altitudes are increased to account for possible atmospheric pressure variations between the remote facility and the airport. The rate of increase of the minimums is 5 feet of altitude for each mile in excess of 5 miles from the remote source to the airport.

The 3D-RNAV, or VNAV, guidance method is a combination of the baro altitude and area navigation systems. The 3D area navigation system allows the pilot to select an altitude associated with each waypoint. The pilot also selects the descent/ascent angle he wishes to fly to the waypoint. Three degree descents are typical for fixed-wing aircraft and descents of five to eight degrees are possible with helicopters. The navigation computer combines the desired waypoint altitude, the descent/ascent angle, measured baro-altitude and distance to waypoint data and determines a vertical deviation signal which is presented to the pilot on

a vertical deviation indicator. VNAV guidance has the same problems that affect baro altitude plus inaccuracies introduced in the distance to waypoint computation caused by navigation system errors.

4.2.4 Aircraft Separation Requirements

In congested terminal areas, the parallel ILS approach procedure is being used to aid air traffic control. This can be achieved because airspace protection limits for precision approach procedures are less than those required by ATC radars. Typically, a terminal radar route width is ±1.5 nm while aircraft on parallel ILS approach paths can be separated by as little as 4300 ft, which is equivalent to a route width of ±2150 ft. This represents a 4.2 to 1 improvement in airspace utilization on final approach.

This same separation capability plus increased operational flexibility is expected from MLS. Additional ATC benefits can be derived by using this landing system. Some of the MLS features that can be utilized are offset radial approach paths, different approach/descent angles for aircraft with differing performance capabilities, and segmented or curved approach paths using MLS/RNAV capabilities.

Procedures utilizing the capabilities of MLS have been demonstrated during the MLS development program. However, additional testing is required to establish a data base from which to develop standardized MLS approach criteria. This data base is being developed through continuing FAA research and development efforts.

4.3 INSTRUMENT APPROACH AIRSPACE

The airspace utilized in an instrument approach procedure is divided into four segments. These segments are:

- initial approach
- intermediate approach
- final approach
- missed approach

Each of these segments is used for specific purposes in the approach procedure. The orientation and size of each segment is determined by the geography in the approach area and the navaids utilized for the procedure. Each segment contains a primary area and a secondary area. The primary area is located along each side of the segment centerline. The secondary area is located between the primary area and the airspace not utilized for the procedure. The obstacle clearance requirements in the primary area are more stringent than those of the secondary area. Specific details on these requirements are described in the following paragraphs.

Figure 4.1 shows a typical approach procedure airspace diagram. This procedure is based on straight courses such as could be flown using VOR radials, NDB bearings, or localizer courses. Specific details on the criteria used to establish approach airspace are found in TERPS[3] and in Reference 5.

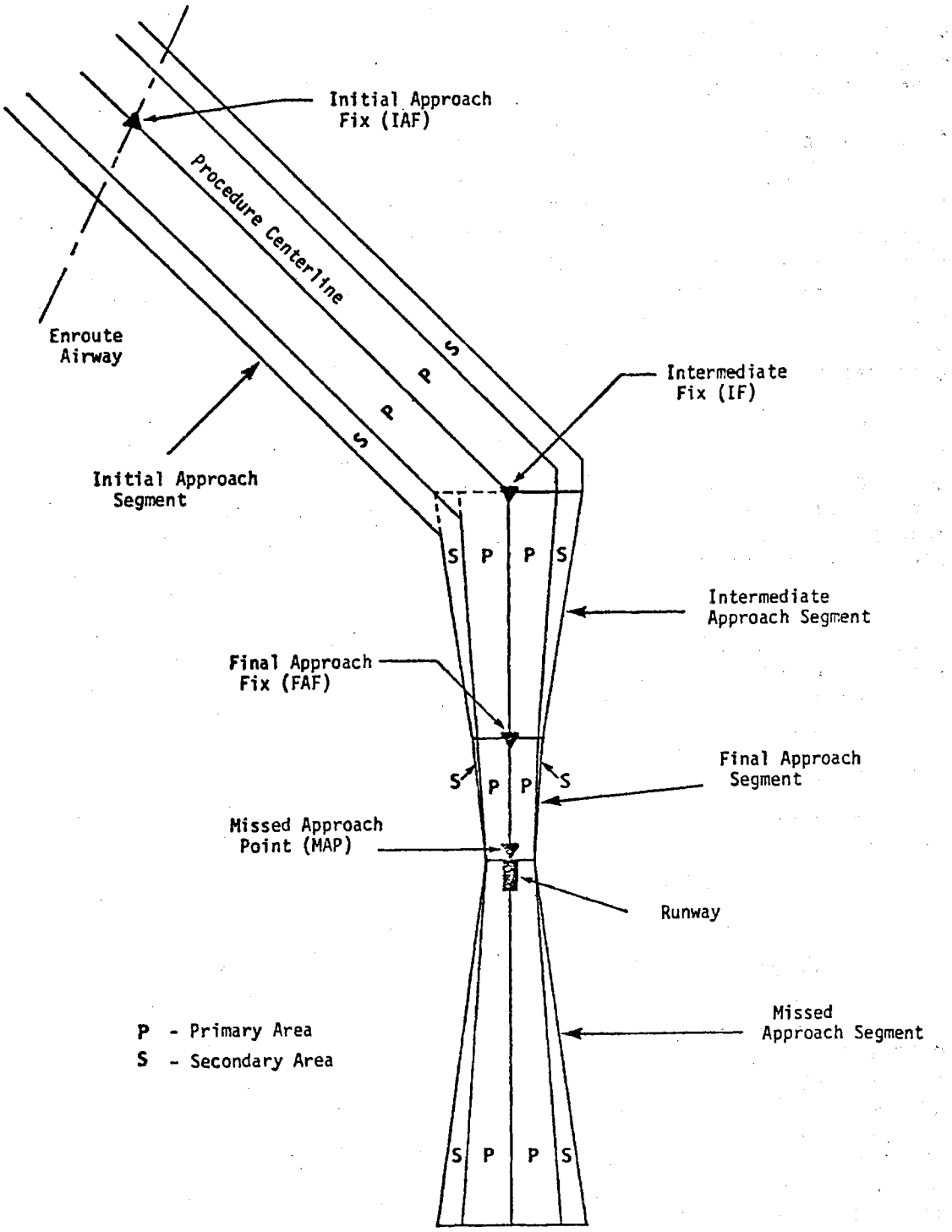


Figure 4.1 Approach Airspace

4.4 CURRENT HELICOPTER IFR OPERATIONAL ENVIRONMENTS

This section will describe IFR approach and landing characteristics for each of the operational environments listed below:

- city center
- major hub center
- non-hub airports
- remote area
- offshore oil rig

4.4.1 City Center Operations

City center operations are typified by operations into and out of heliports which are located in the central core area of major cities. Four types of operators are generally associated with this type of operation; law enforcement, emergency medical service, business/executive, and scheduled air carriers. Law enforcement operators generally have little or no requirement to operate in an IMC environment and thus will not be considered in this section. Most business/executive operators and scheduled air carriers are currently conducting all-weather operations whenever ground based navigation transmitters and published instrument procedures permit. Dependable, expeditious service is the economic cornerstone of these operations, and all weather capability enhances that dependability.

Emergency medical service (EMS) operations fall into two categories; interhospital transfers, and on scene pickup and transfers. Interhospital transfers generally involve the transfer of a patient from one hospital to another specialty hospital. Although this situation is technically critical, the patient is under medical supervision, and during periods of low visibility and/or ceilings can be sustained at the original hospital. Thus, interhospital transfers do not, in most cases, constitute an immediate life or death situation. On the other hand, on scene pickup operations almost always involve a life and death situation and speed is a primary concern. Hospitals which have developed EMS helicopter programs, either independently or in conjunction with local law enforcement agencies, are primarily interested in getting the accident victim into a controlled hospital environment as soon as possible. Weather conditions which impede helicopter operations during an EMS emergency tend to increase the shock-trauma fatality rate[24].

Currently, EMS operations are generally limited to VMC but expansion to all-weather operations might significantly increase their effectiveness. On scene pickup of victims requires VFR weather conditions at the accident scene since it is highly unlikely that instrument navigation aids will be available at the pickup site. A highly portable, quickly deployed, precision transmitter system has not yet been designed and even if developed, probably could not be certified under current standards without extensive site surveys and obstacle clearance evaluation.

Shown in Figure 4.2 is an approach to a typical city center operation. This figure details a Copter RNAV Special Instrument Approach procedure to the Downtown Manhattan Heliport. This approach begins at the NESOM

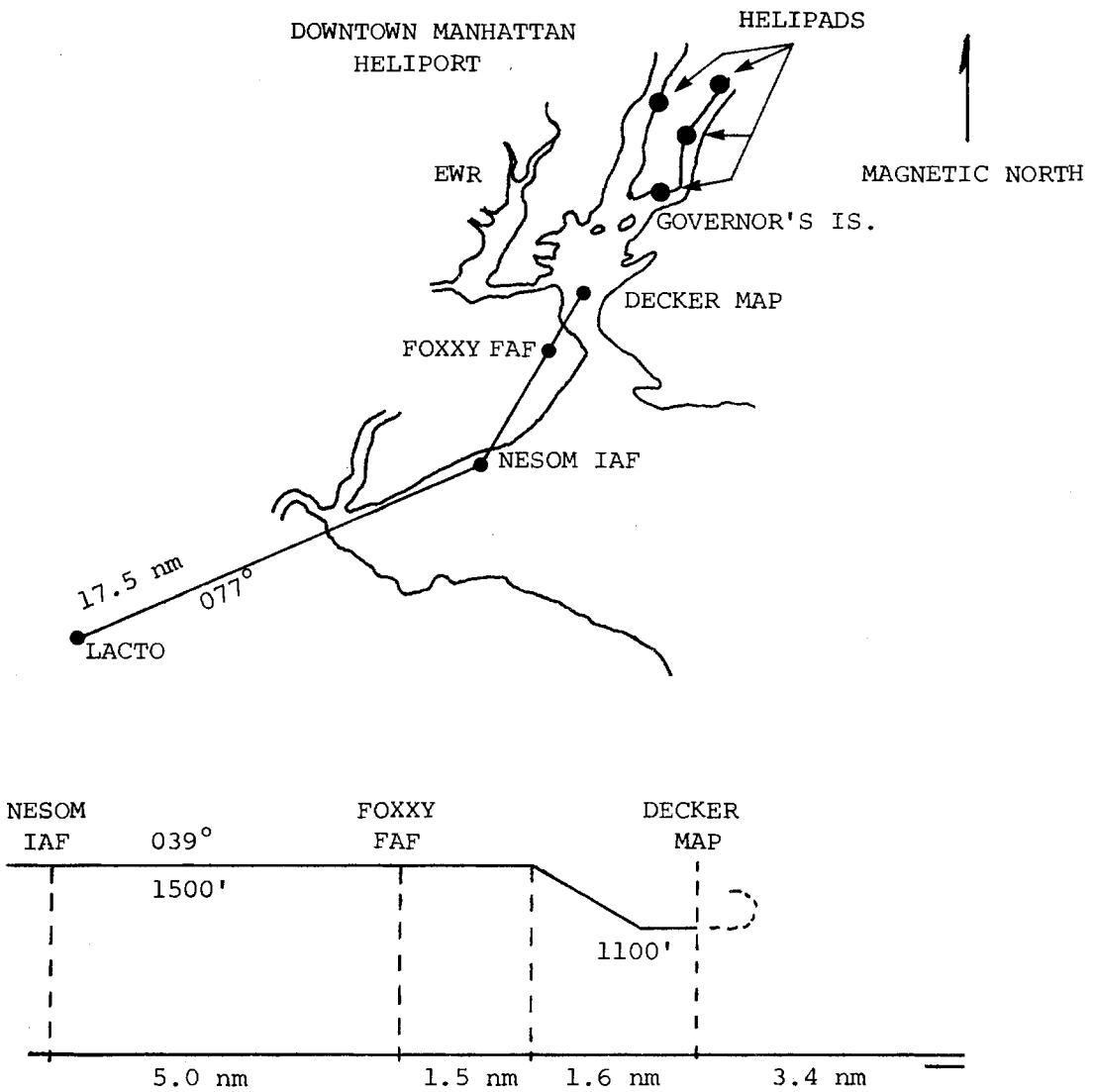


Figure 4.2 City Center Copter RNAV Special Instrument Approach Procedure

IAF and ends at a point in space MAP at DECKER. At MAP the approach to land is continued if visibility permits, otherwise a missed approach climbing right turn is executed to 1700 feet direct to hold at FOXXY. It should be noted that the best this procedure can provide is to bring the aircraft to 3.4 nm from the helipad at MAP.

4.4.2 Major Hub Center Operations

The primary navigation aid currently used for precision approaches at major hub airports is ILS. Several of these airports have short commuter designated runways, alleviating the problem of integrating incompatible aircraft on final approach. Where precision navigation aids are provided for these commuter designated runways, a separate ground transmitter system must be installed. For economic reasons, most major airports are reluctant to provide independent runway and approach aids systems for helicopter and commuter traffic, requiring these aircraft to be integrated into the air carrier arrival stream in order to obtain final approach guidance.

Major hub airports are characterized by heavy traffic demands and strict airspace usage procedures. Airports such as Kennedy and LaGuardia in New York and Los Angeles International in California operate at capacity levels during peak hours. Operation at these levels requires a smooth steady flow of traffic. When weather conditions become IMC, final approach spacing requirements are increased, effectively lowering rate of acceptance of arriving aircraft. Delays of one to two hours are not unusual when a major airport drops below VFR minimums during peak hours. Smooth aircraft flow is dependent not only upon controller and pilot skill and judgement, but also upon the relative performance capabilities of successive aircraft in the arrival stream. Dissimilar final approach speeds require additional spacing to assure that minimum standards are not violated during the course of the approach. Increased spacing means greater delays for all other aircraft in the arrival stream. How much greater these delays will be is directly dependent on two factors; relative speed differential and the length of the common routing. A third factor, aircraft spacing standards, are regulatory and will be assumed to be a constant for the foreseeable future. As the speed differential between two successive aircraft is increased, spacing requirements are increased. Additionally, as the length of the common routing segment is incrased, spacing requirements are increased.

By its nature, the ILS signal must be aligned to a single azimuth and a single glide slope, thus requiring every aircraft to follow the same path on final approach. Although this path can be theoretically intercepted at any distance from the touchdown point, no precision guidance is afforded until interception. Thus, an aircraft intercepting a standard 3° glide slope ILS course two miles from touchdown would not have precision guidance until it was effectively at 600 feet above touchdown. Additionally, azimuth capture would be difficult because of the apparent increased sensitivity of angle measurement systems close to the transmitter. Without precision guidance during the intercept maneuver, an undesirably high cockpit workload situation is introduced.

Illustrated in Figure 4.3 is a typical ILS approach for Philadelphia International to runway 9R. The Initial Approach Fix (IAF) is identified by either the MODENA or NEW CASTLE VORTAC and the localizer centerline at an altitude of not below 1900 feet. The glide slope is captured just prior to the CLAYMONT outer marker (or final approach fix). At the middle marker, if minimums are below 200 feet and ½ mile visibility, a missed approach would be executed; otherwise, the approach would be continued through the inner marker to land.

4.4.3 Non-hub Airport Operations

Non-hub airport activity is primarily general aviation traffic. When instrument conditions prevail, flight operations at non-hub airports involve transient general aviation aircraft, air taxi flights, and occasional air transport flights. Terminal areas are relatively uncongested and thus inflight delays are minimal. Navigation guidance is generally provided by either VORTAC transmitters (non-precision approaches) or ILS transmitters (precision approaches). Where VORTAC stations are not readily available, non-precision guidance can be provided by non-directional beacons (NDB).

An example of a typical non-precision approach is shown in Figure 4.4. This approach is indicative of a standard NDB approach where the NDB station coincides with the initial approach point. The approach is relatively straightforward. It should be noted that LULU Intersection can also be used as an initial approach fix. In general this approach can be considered to be an example of a typical NDB Approach.

4.4.4 Remote Area Operations

The helicopter is an ideal vehicle for transport into and out of remote areas. Additionally, once at the remote site, helicopters can perform many tasks more effectively and efficiently than are possible by any other means. The heavy lift capability of the helicopter is used by logging companies to transport logs to the sawmill or to a nearby river. Fire fighters use this same capability to deliver fire retardants to the scene of forest fires. Utility companies and game management departments depend on rotorcraft maneuverability to patrol power lines and restock isolated lakes and streams. Survey crews can be transported from one location to another in a minimum amount of time, saving weeks of backpacking between remote sites over the period of a year. Wildlife management game counts can be accomplished more quickly and accurately through the use of helicopters. Men and equipment can be transported to remote locations for support of a variety of operations from mining to forest ranger resupply. Perhaps the greatest contribution the helicopter has made in this area is that of search and rescue.

The variety of operations mentioned above illustrate the versatility of the helicopter and its adaptability to the remote area environment. It should be noted, however, that these missions have one thing in common; they are almost exclusively VMC in nature. Almost all remote area missions require visual contact with the ground requiring little or no precision IFR capability. Associated terminal areas are typified

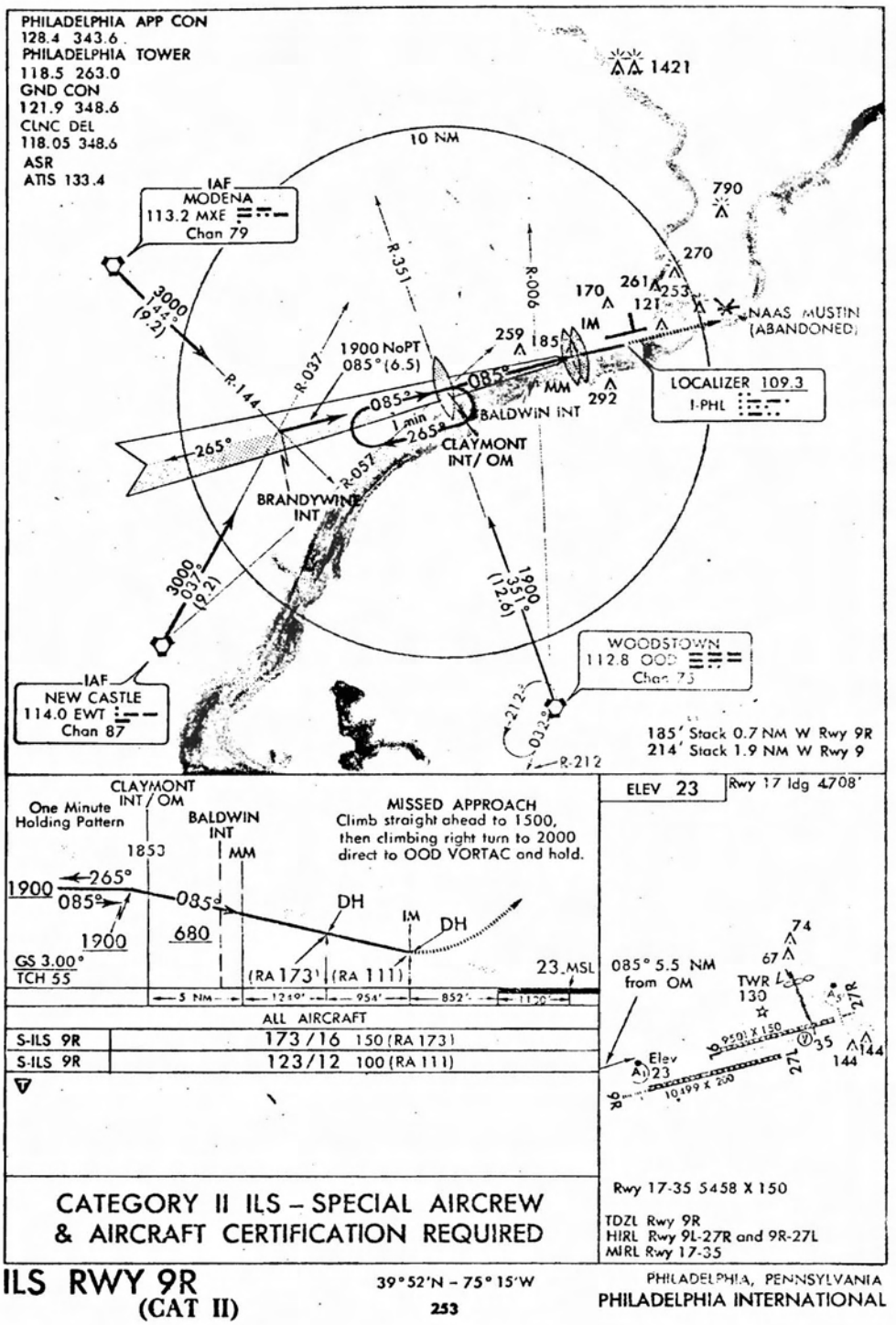


Figure 4.3 ILS Approach to Philadelphia International Airport, Runway 09R

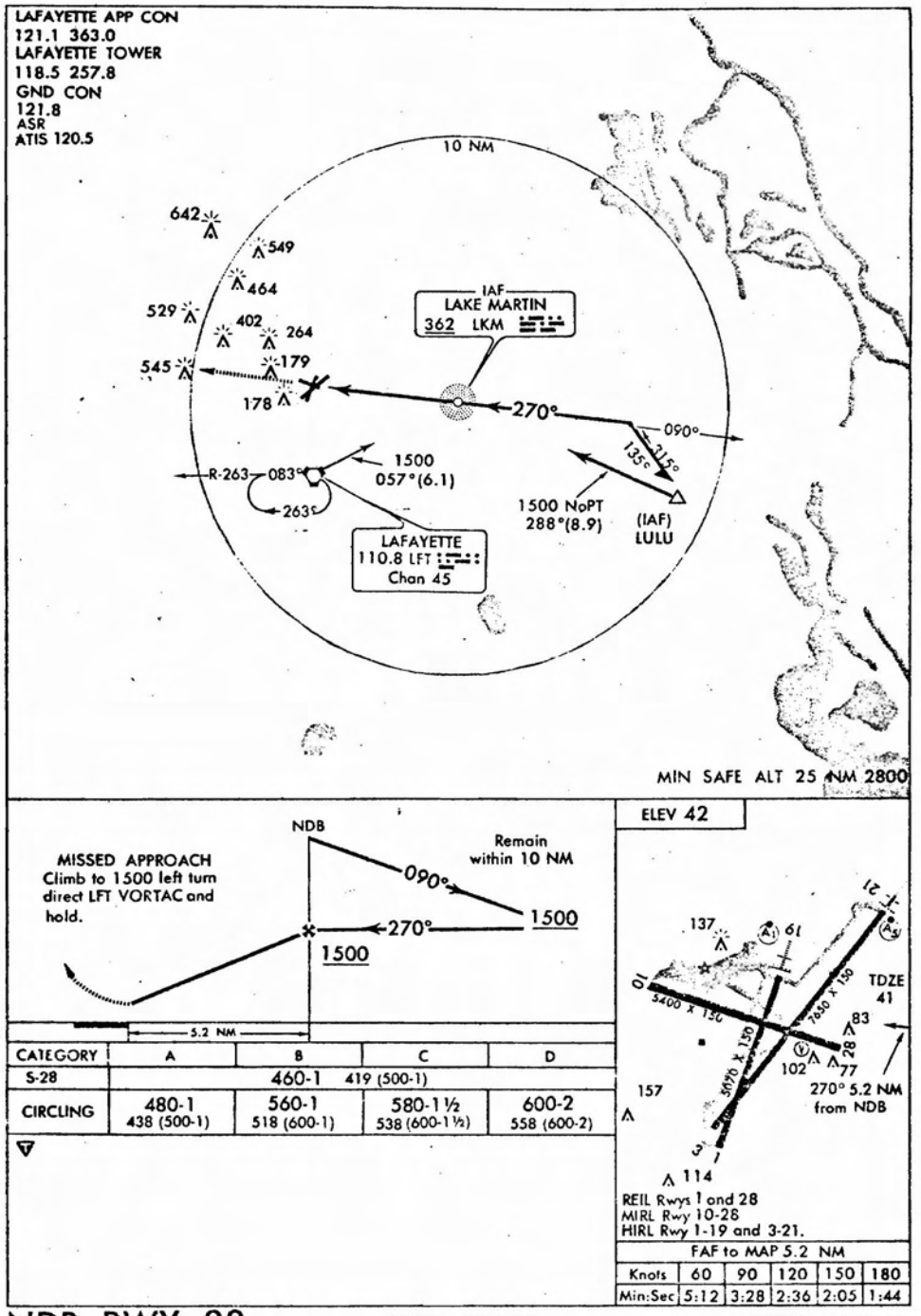


Figure 4.4 NDB Approach to Layfayette Regional Airport, Runway 28.

by low traffic counts again indicating no current requirement for expensive precision navigation landing aids.

4.4.5 Offshore Oil Rig Operations

Several of the operational environments discussed in this report are conducive to the application of helicopters in routine productive roles. The offshore oil rig environment, however, is completely dependent on helicopter operations. The key to this development has been the dependable service provided by the helicopter, particularly in the Gulf of Mexico oil fields. Recent expansion to locations other than the Gulf of Mexico has revealed the necessity for developing improved IFR capability and procedures if historical dependability standards are to be maintained without degrading safety. Weather conditions off the New Jersey coast and in the North Sea are significantly worse than those found in the Gulf of Mexico. Conditions off the Massachusetts coast promise to be even worse. Cost effective IFR procedures need to be developed in offshore facilities if these regions are to be maintained with a high degree of dependability.

FAA approval of airborne radar directed approaches (ARA) using weather mapping radar[1] in the offshore environment has reduced the requirement for a precision ground/rig based approach navigation signal aid. The ARA with required minimums of 200 feet/3/4 nm (with radio altimeter) and obstacle height + 250 feet/1/2 nm (without radio altimeter) is shown in Figures 4.5 and 4.6. The approach shown in Figure 4.5 is a relatively straightforward ARA approach to a single platform. Figure 4.6 is an example of an ARA approach to a platform cluster, depicting individual platforms. Platform coordinates and identification are found on the reverse side of the approach plate.

4.5 SUMMARY

In summary it is quite evident that there is a growing interest and requirement for helicopter IFR operations in many applications. There is also increasing recognition that helicopter operations are different from fixed-wing operations and that these differences should be reflected in the instrument approach procedures.

Specifically, with reference to the five operational environments considered in this study, there is a requirement for IFR approach procedures in city center, major hub airports, non-hub airports and offshore areas. Only remote area operations appear to have a lesser need for IFR approach procedures.

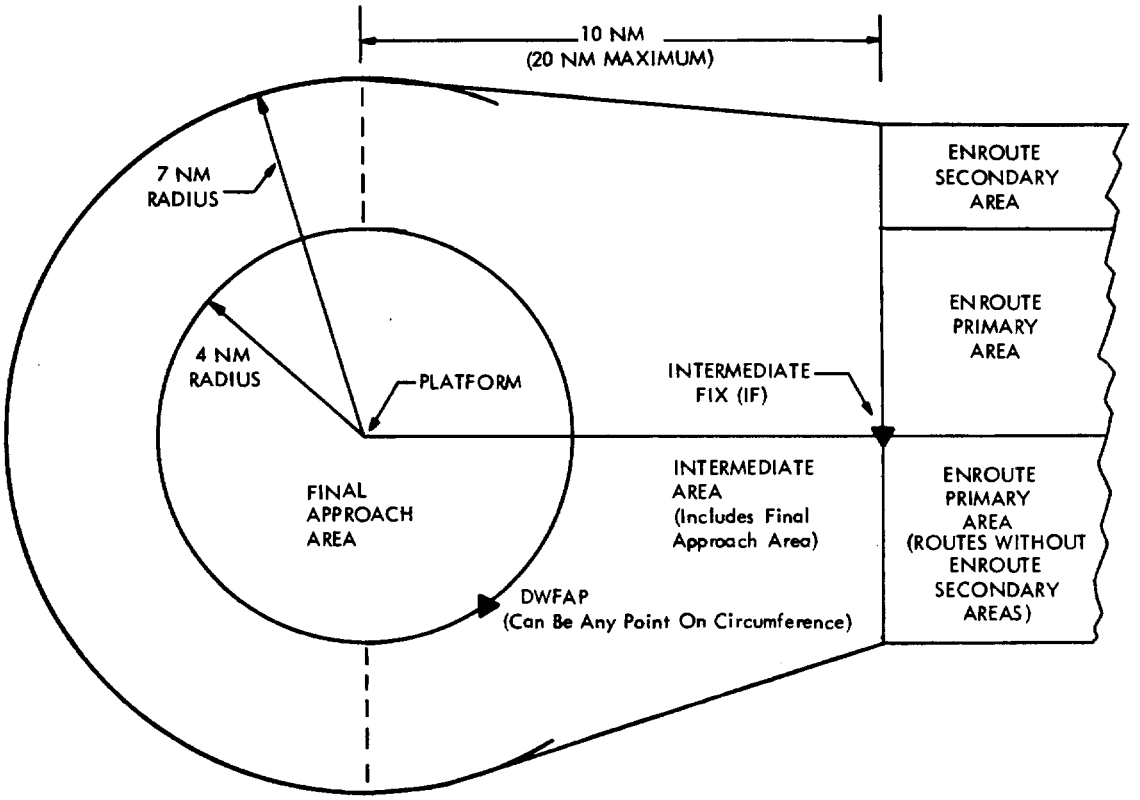


Figure 4.5 Single Platform Airborne Radar Approach Procedure

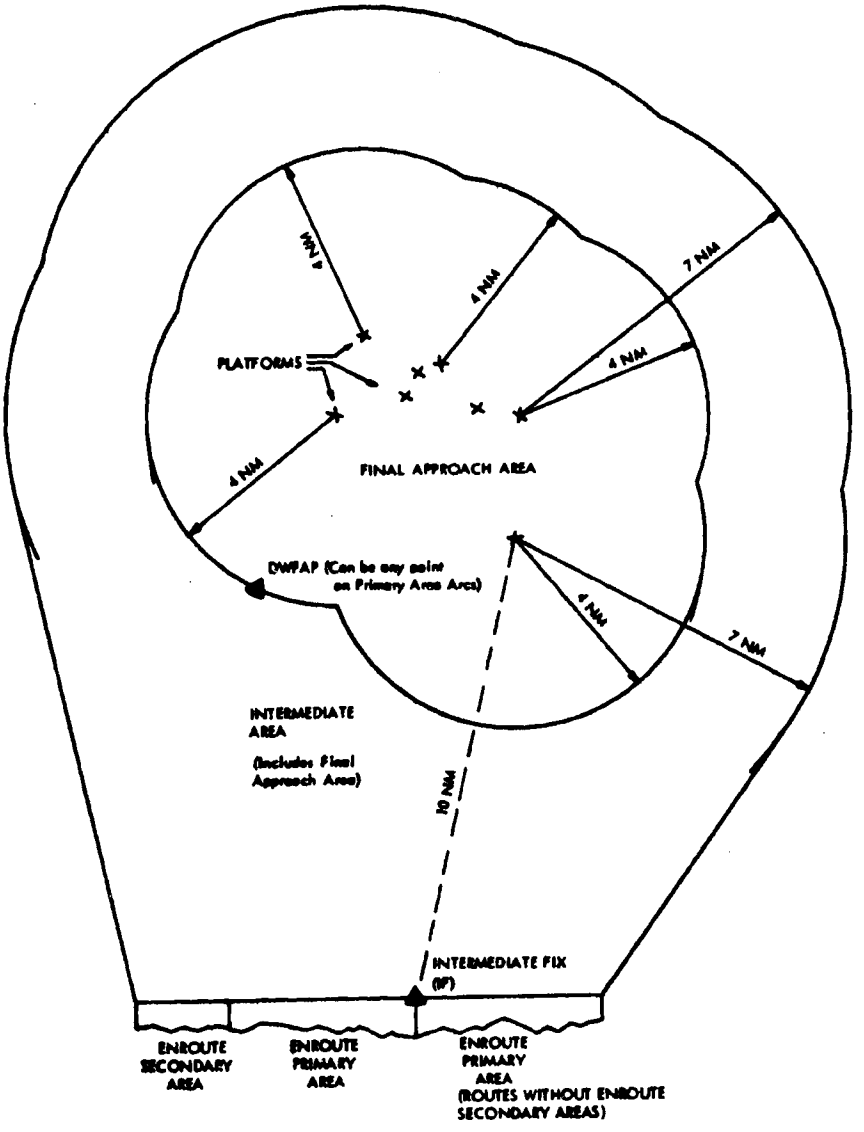


Figure 4.6 Platform Cluster Airborne Radar Approach Procedure

5.0 HELICOPTER MLS APPROACH PROCEDURES

Previously discussed in Section 4.0 were the IFR approach requirements for the various helicopter operations now in use. This section will proceed in the method of approach a step further to postulate six helicopter MLS approach procedures. These procedures will then be evaluated against the types of operations discussed in Section 4.0, to determine any operational and technical problems and limitations. Once this has been determined, a candidate MLS approach procedure will be presented for each of the types of operations described in Section 4.0 along with the airborne and ground MLS equipment required to satisfy the approach procedures. This section will then discuss the operational utility of these MLS approach procedures as a function of helicopter approach and landing characteristics. These relationships provide the basis for the MLS cost benefit analysis of Section 6.0.

5.1 POSTULATED MLS APPROACH PROCEDURES

The attractiveness of MLS as a precision landing aid for helicopter operations is its ability to increase and enhance the operational utility of the helicopter with precision approach capability in a number of locations not suitable to ILS. The following paragraphs will present six postualated helicopter MLS approaches.

5.1.1 Straight In Procedures

The straight in MLS approach procedure is essentially identical to an ILS approach, using a single glide path and a single approach course. Shown in Figure 5.1 is an example straight in MLS approach. The placement of the azimuth and elevation antennas is conventional, with the azimuth on the centerline beyond the stop end and elevation beside the runway 1000 feet from the approach end. Fix identification is provided by marker beacons or intersections formed by enroute navigation aids and the azimuth approach course.

In order to transition to MLS approach guidance at the final approach fix five nm from the runway threshold, some other navigation course is necessary. Guidance can be provided by using enroute navigation aids such as VOR, DME, Loran-C or Omega/LVF. Loran-C and Omega/VLF would be more commonly used in offshore environments, although VOR or DME could be used if the offshore operation is within line-of-sight signal reception.

Typically the missed approach point (MAP) is positioned 0.63 nm from the touchdown zone where the 3° glide path reaches 200 feet above the runway elevation. If the field were in sight, the pilot would continue the approach. If not, he would execute a missed approach with a climbing turn or straight ahead, depending on terrain clearance.

This type of MLS installation could be suitable for center city, major hub, non-hub, remote area and offshore operations. Of course, suitability at hubs is dependent on how many helicopter operations can be effectively integrated with fixed-wing on the MLS approach segment during peak IMC conditions and still offer an improvement over ILS procedures. Any MLS installation in remote areas would most probably

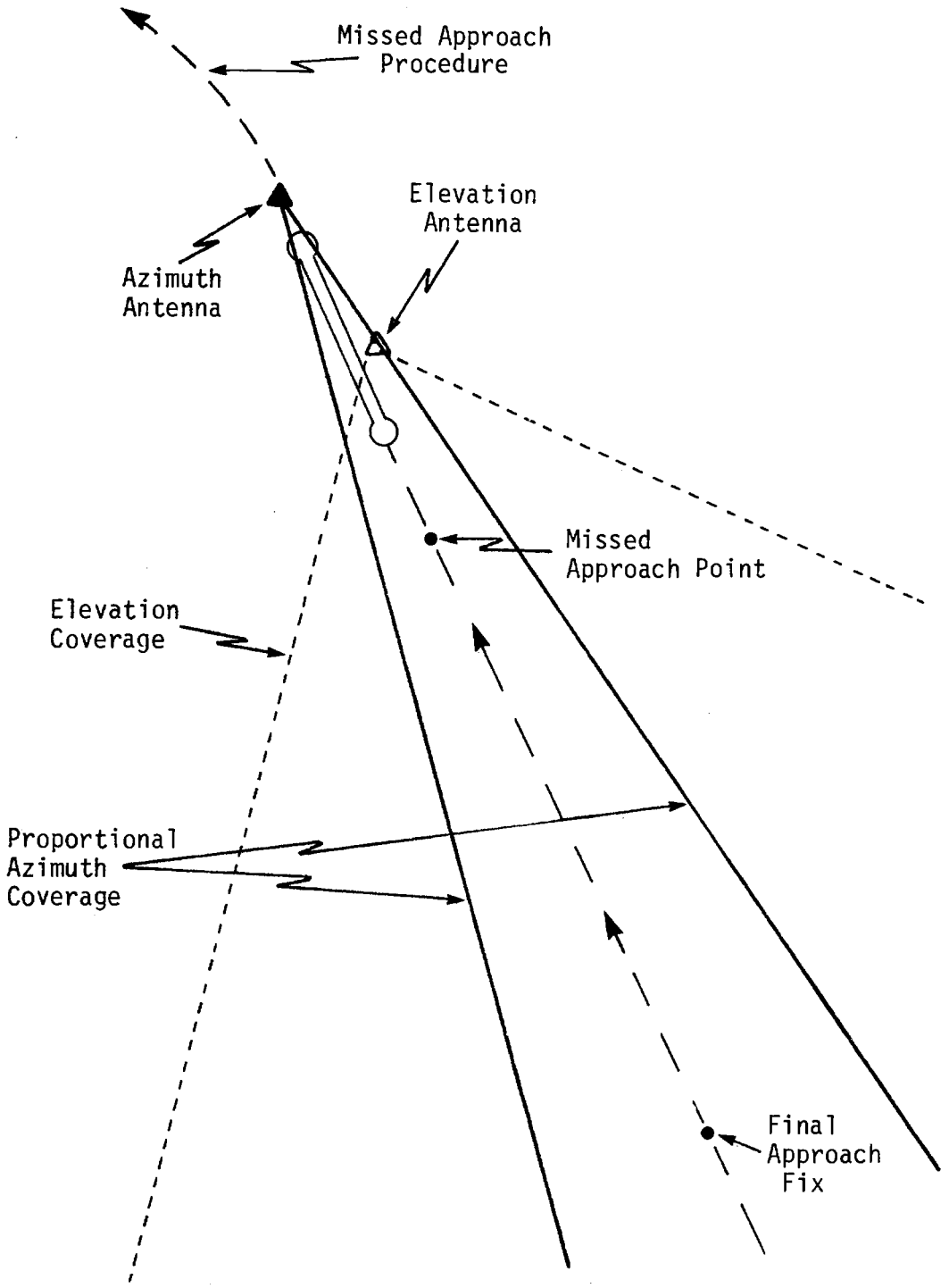


Figure 5.1 Straight-In MLS Approach Procedure

be on a temporary basis, with the installation cost offset by the remote area operations worth.

This MLS installation would be configured with ±10° azimuth proportional coverage, ±10° elevation coverage, and 1° to 15° glide path coverage. Broader coverage could be provided if desired.

5.1.2 Variable Elevation Angle Procedures

Variable MLS elevation angle procedures are also similar to the straight in MLS and ILS procedures. The primary difference is the ability to select a particular glide slope approach angle. The angle of possible glide path angles available with MLS will encompass the requirements and capabilities of fixed-wing jets, STOL aircraft, conventional single or twin engine aircraft, helicopters and military aircraft. Variable elevation angle procedures would then prove applicable to both major hub and non-hub airport operations.

Selection or adjustment of glide path angles may be automatic or manual. As specified in Reference 6, automatic glide path selection will provide vertical guidance along the minimum selectable glide path angle as transmitted on the basic data message by the MLS ground station. The angle receiving equipment may automatically adjust to provide deviation signals with respect to the transmitted glide path angle. Manual selection overriding automatic selection will provide a warning if a glide path is selected below the transmitted glide path angle.

A typical application of variable elevation angle procedures is illustrated in Figure 5.2. In hub airport operations where helicopters are mixed with higher performance aircraft, it would be possible to make simultaneous approaches along the same approach course. This could be accomplished by directing the slower helicopter to fly the approach course at a higher altitude, 1,000 to 2,000 feet above the approach course of the faster, fixed-wing aircraft. This would allow the faster aircraft to overtake the helicopter and begin its normal MLS 3° glide slope approach. Depending on the performance capability of the helicopter it would continue at altitude until the angle receiver equipment prompts the pilot to execute a 6° to 8° MLS glide slope approach, as selected by the pilot.

Helicopter and higher performance aircraft need not necessarily be at different altitudes in the traffic pattern, as shown in Figure 5.3. This is accomplished by ATC timing the approach of both aircraft such that the helicopter would transition to the approach course after the fixed-wing aircraft has begun its 3° MLS approach and with proper separation assurance. At the proper, time the helicopter would be cleared to begin its 6° to 8° MLS approach.

In both examples, transition to approach course can be accomplished by using VOR, DME, or some other approved enroute navigation aid.

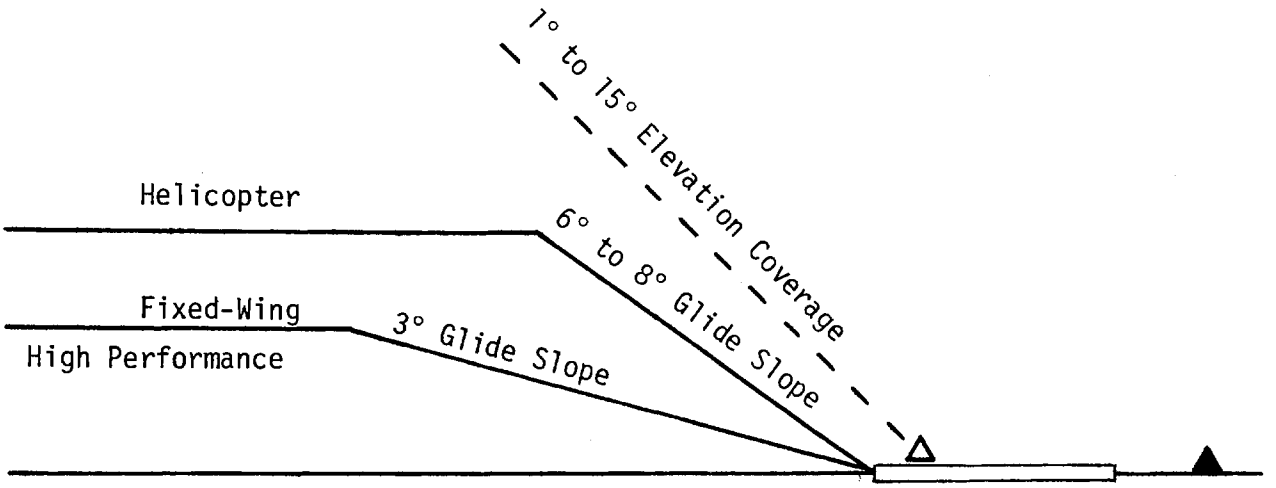


Figure 5.2 Variable Elevation Angle Procedure - Same approach course, different altitudes

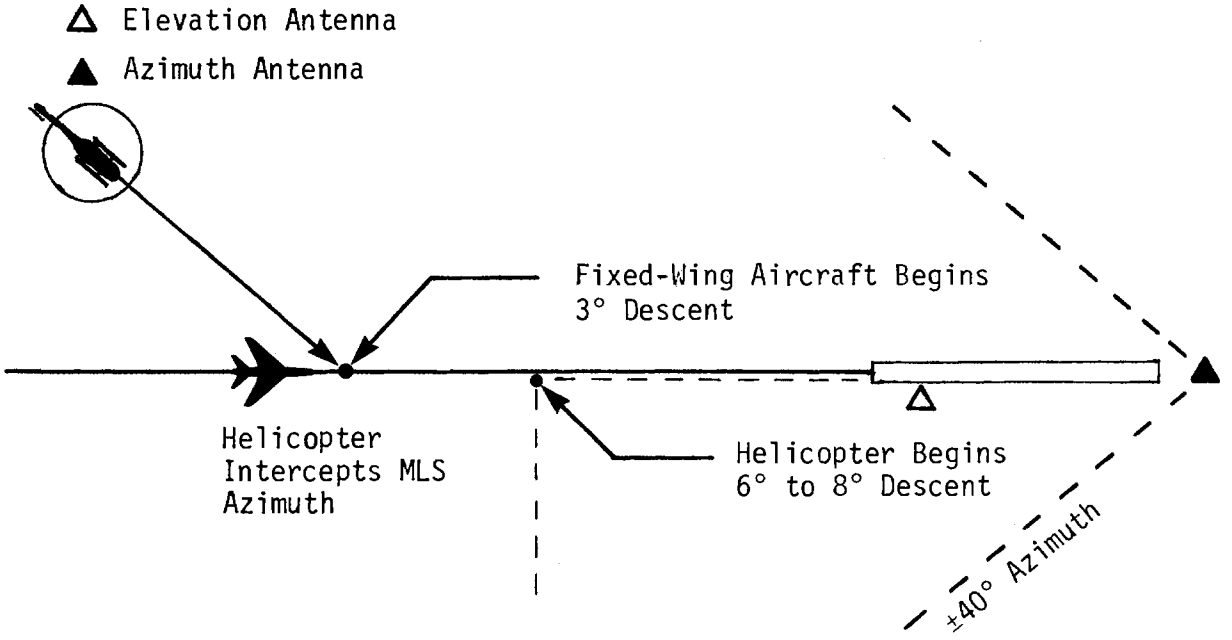


Figure 5.3 Variable Elevation Angle Procedure - Same approach course, same altitude (Planview)

5.1.3 Variable Azimuth Angle Procedures

With variable azimuth angle procedures the aircraft is not limited to centerline approaches, but can select an approach course in degrees right or left of centerline up to 60°. The published aircraft approach chart would specify the various selectable azimuth angle approaches available. Glide paths would be fixed at an elevation angle that is operationally suitable.

This MLS procedure is most likely to be flown with a DME arc transition as described in Figure 5.4. This procedure would easily allow for efficient separation of high performance aircraft and helicopter operations to avoid aircraft mixing on a common approach course. To perform this procedure an azimuth angle would be selected from this azimuth angle, e.g., 20°, until it reaches a published DME distance from the airport. At this point, a DME arc would be flown at constant altitude until a zero azimuth angle is acquired, at which time a 3° MLS descent would begin on a centerline (zero azimuth) approach course.

5.1.4 Azimuth Only Procedures

Azimuth only procedures are essentially identical to localizer procedures since no elevation angle guidance would be used by the aircraft. As with any other MLS approach configuration, the MLS centerline signal does not have to be aligned to the runway centerline, but can be offset, if terrain is an obstruction on the runway centerline extension.

To fly the azimuth only procedure, the MLS signal would be intercepted using conventional navigation sources from eight-to-five nm depending on the descent gradient. For a conventional 300 ft/mile descent rate the FAF would be placed at five nm from the runway. For steeper approaches the FAF would be positioned about three nm from the runway and used by V/STOL aircraft only. Since no MLS glide slope information would be available to the pilot, elevation for stepdown descent would be provided by either a barometric or radar altimeter. Marker beacons, non-directional beacons, VOR, DME or ADF could provide the initial, final and missed approach fixes. Approach lights would aid transition from IFR to visual guidance.

An example of an existing MLS azimuth only approach is shown in Figure 5.5, for Tuktoyaktuk, Canada in the Northwest Territory. The MLS azimuth path is intercepted by flying an eight nm DME arc at 1400 feet. Once the azimuth path is acquired the aircraft is flown to the FAF measured at five nm with the aircraft's DME. Just prior to crossing the FAF, the aircrafts begins its descent to level-off at 300 feet at about one nm DME. If the field is not in-sight, a climbing left turn missed approach would be executed, otherwise the pilot would continue the approach to land.

Azimuth only MLS configurations would be most useful on locations where localizer installations would be impossible or difficult due to the lack of level terrain at the non-hub airport or heliport. Another

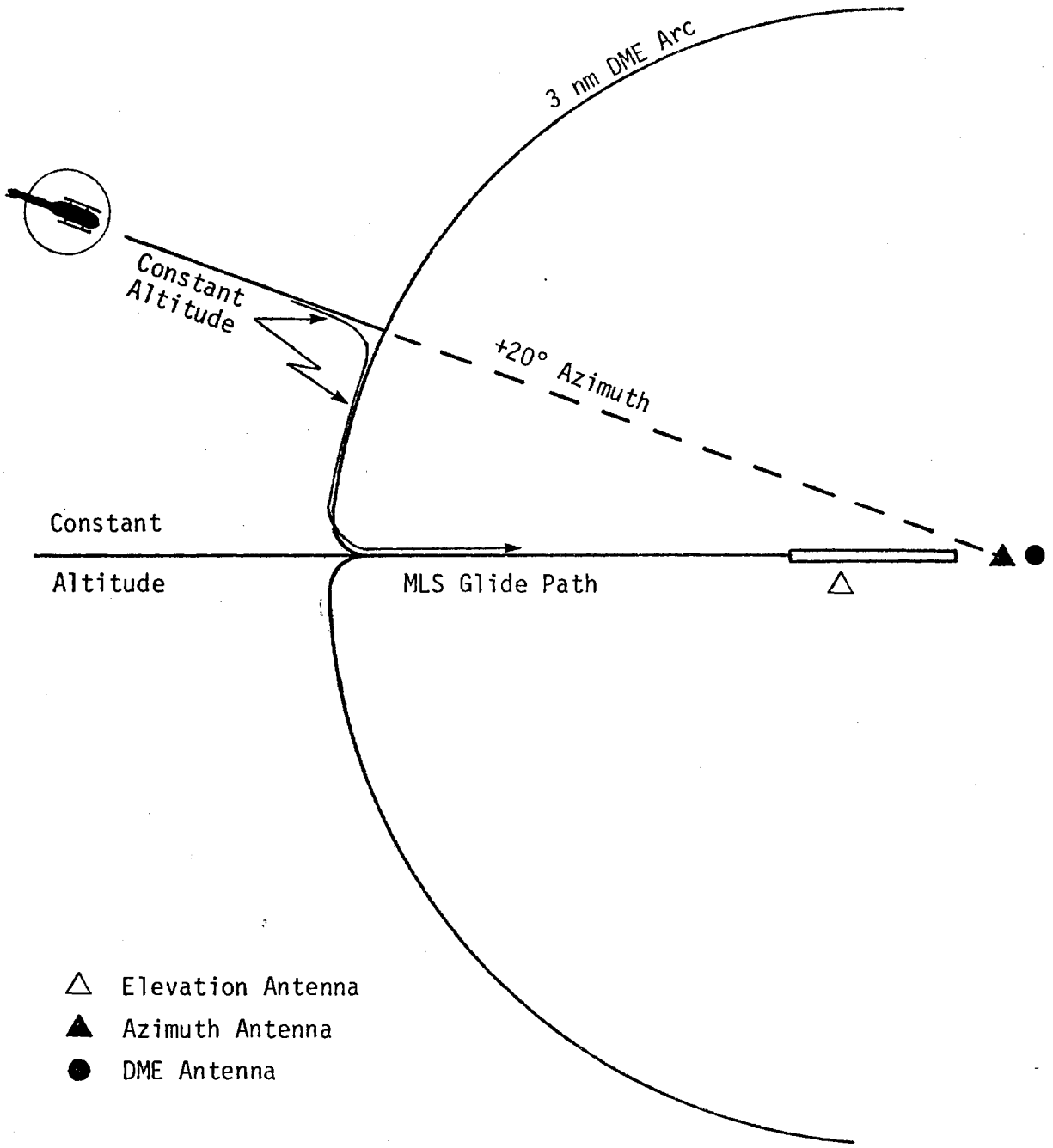
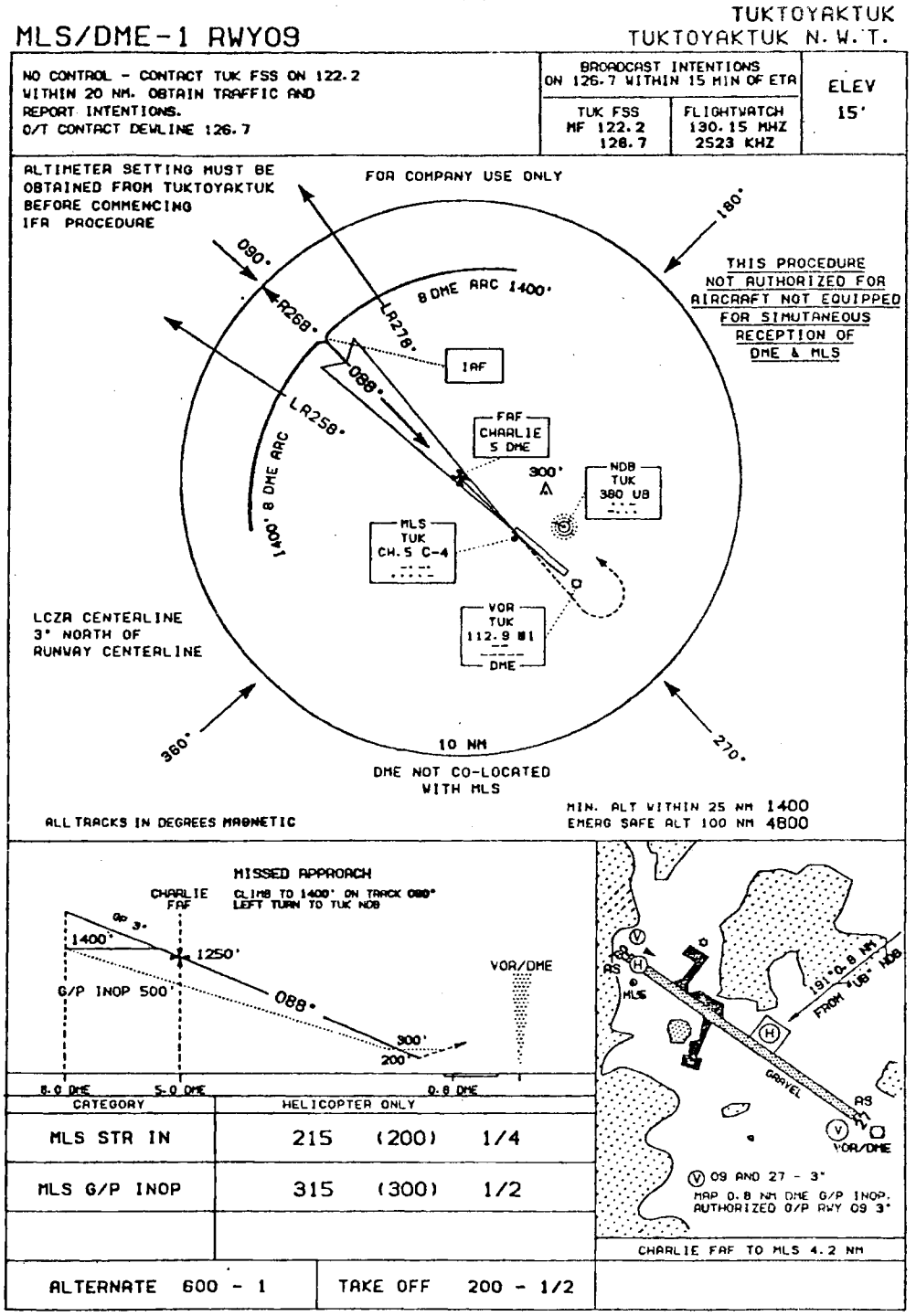


Figure 5.4 Variable Azimuth Angle Procedure (Planview)



NOTE: VOR Decommissioned

Figure 5.5 MLS Azimuth Only/DME Approach

possible application would be natural to remote areas where a temporary landing aid is necessary for several weeks or months. Another application would be for offshore oil rigs if altitude were not critical to the approach.

5.1.5 Azimuth, Elevation and DME Procedures

These procedures would be identical to those for the straight in MLS approach described in Section 5.1.1. As in those procedures the initial approach fix for the approach course would be acquired using conventional navigation, an eight nm DME arc in this case, as shown in Figure 5.6. The other use of DME would be to identify position fixes for the final approach and missed approach points.

These procedures would prove most advantageous for locations where approaches must be made over precipitous terrain or water, where it would be impossible to install marker or non-directional beacons. Such locations would include major hub and non-hub airports, heliports with very limited real estate as in city centers, as well as oil rig applications.

5.1.6 MLS/RNAV Procedures

After examining some typical visual approaches into high density, metroplex airports, some understandable similarities emerge.

The primary impetus to develop the approaches appears to have been noise abatement. In all the subject approaches (JFK, LaGuardia, Washington National, and Philadelphia) all possible use is made of over-water tracking, expressways, and parks.

There are, however, some attendant disadvantages. To begin with, minima for all these approaches are necessarily well above precision IFR minima. Ceilings range from 1,000 to 3,500 feet and visibilities range from 1 to 5 miles.

At some of the airports the physical proximity of waterways to the airfield, as well as their orientation relative to desirable runways, have forced final approach course interceptions much closer to the touchdown zones than usual and at much more severe angles (90° and more in final turn).

It is hypothesized that MLS/RNAV will be most advantageous to major hub airports and city center heliports.

Two example airports which will be discussed, JFK and Philadelphia, require final approach segments which do not follow straight in final approach paths. The following MLS/RNAV approaches were designed to overlie the existing visual approach procedures so that the noise abatement path could be used even in times of IMC.

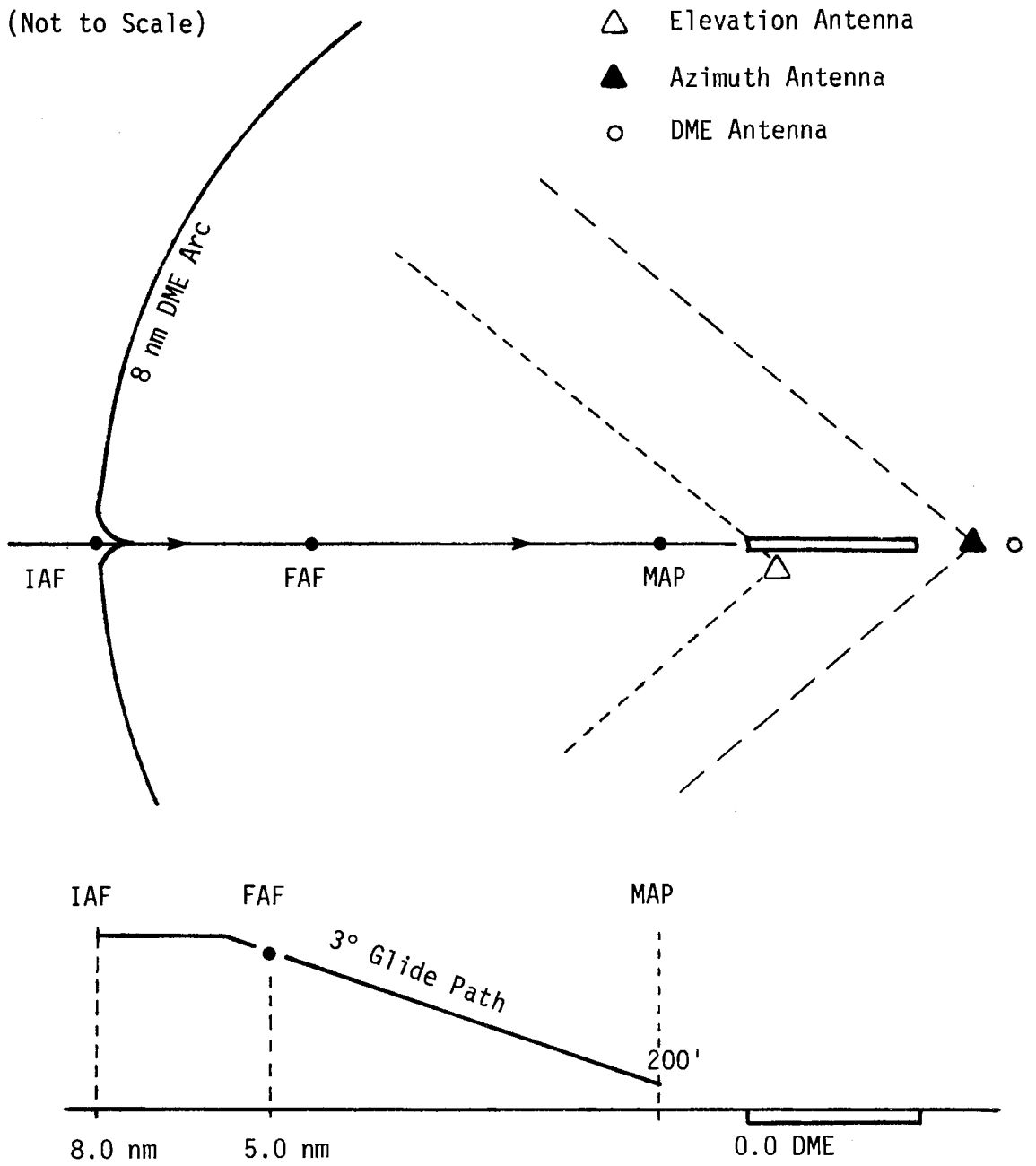


Figure 5.6 MLS Azimuth, Elevation and DME Procedures

- New York JF Kennedy

At JFK, the only approach to runway 13R (the longest runway) is the visual approach (3000-3, MDA 100') shown in Figure 5.7. There is a published ILS approach to runway 13L (DH-212', minima 200-½) which poses no noticable problems except that the entire approach takes place over high density population areas adjacent to the airport (Brooklyn).

Two runways, 13L and 13R, are served by the Canarsie VOR approach at JFK. In addition to higher minima, the salient characteristic of these approaches are their relatively short, curved final turns. Sequenced flashing lights are used to guide the pilot during the turns to final (the turns begin at the MAP and are 4.7 nm long for 13L and 3.7 nm long for 13R), but the distances from the TDZ are too short to incorporate an ILS from the present MAP.

The noise abatement value of these approaches is obvious since the common portion is, for the most part, offshore until the MAP. However, further restrictions prohibit descent below 500' until the R/W threshold is in sight. MLS/RNAV would allow a curved VNAV approach and descent to 200' at MAP.

- Philadelphia International

At Philadelphia, an ILS/CAT II approach is available for runway 09R. The approach itself is typical and presents no unusual problems for the pilot. The straight in ILS approach path does, however, overfly both suburban and urban Philadelphia, both high density population areas.

The visual approach to the airport from the west-southwest is also straightforward. The Delaware River curves gently eastward toward the airport which sits on the northern bank. Minima for the visual approach are 3500 feet ceiling and 3/4 mile visibility. The visual approach path is delineated by the banks of the Delaware and is, overall, a gently curving arc eastward from 10 miles down river to the touchdown zone. An MLS/RNAV approach to runway 09R is shown in Figure 5.8. This approach has been has been configured to overlie the visual approach to be used during periods when minimums are below those necessary for the visual approach.

5.2 MLS OPERATIONAL AND TECHNICAL PROBLEMS AND LIMITATIONS

There are problems and limitations associated with the installation of an MLS at each of the operational areas discussed in Section 4.0. In some cases the problems are technical, relating to the physical installation, while others have operational limitations in adapting MLS to meet the operational requirements of the environment or application. The following paragraphs will discuss these problems and limitations for each operational area previously mentioned.

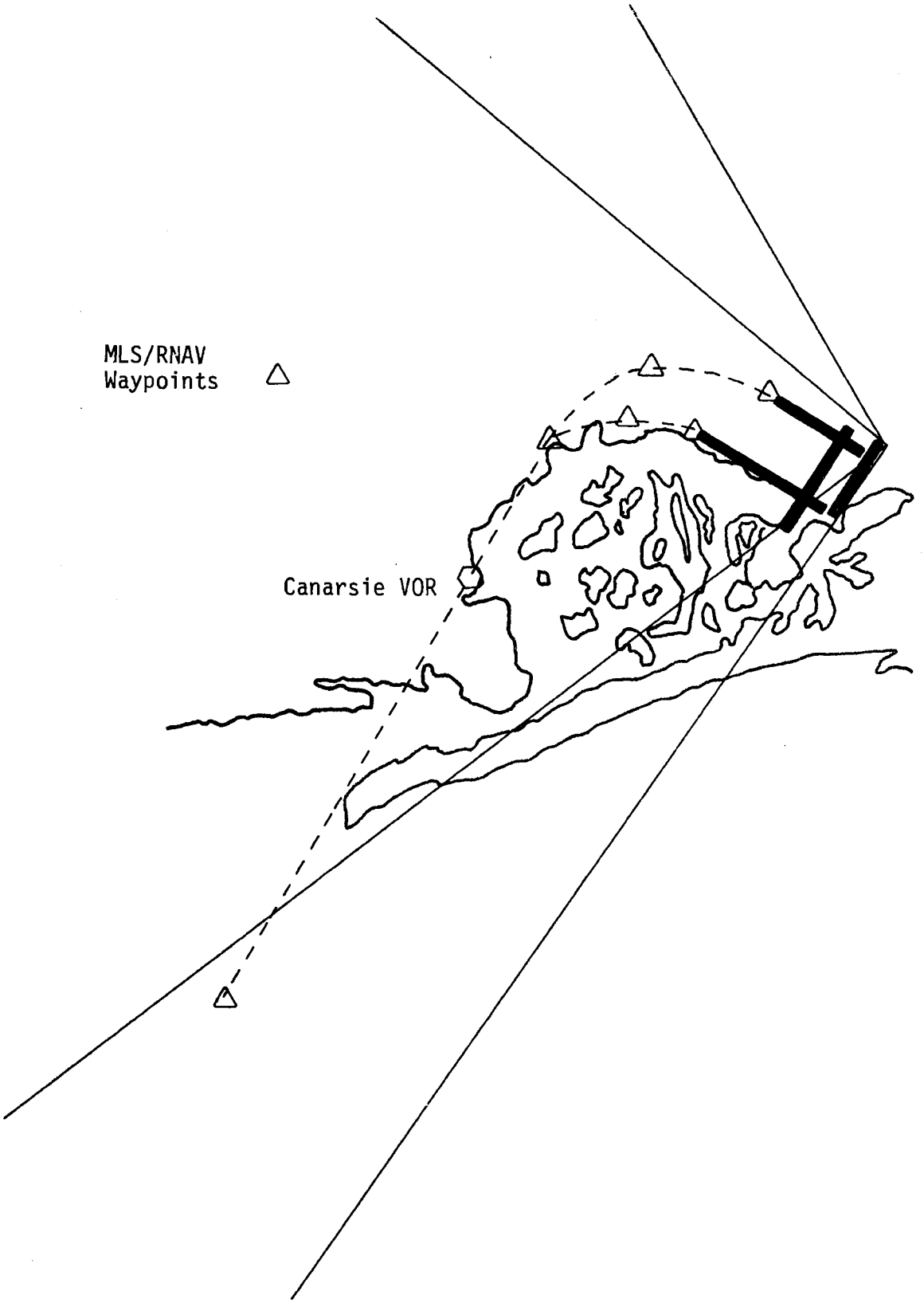


Figure 5.7 MLS/RNAV JFK Approach Overlying Canarsie VOR Approach to R/W 13 R/L

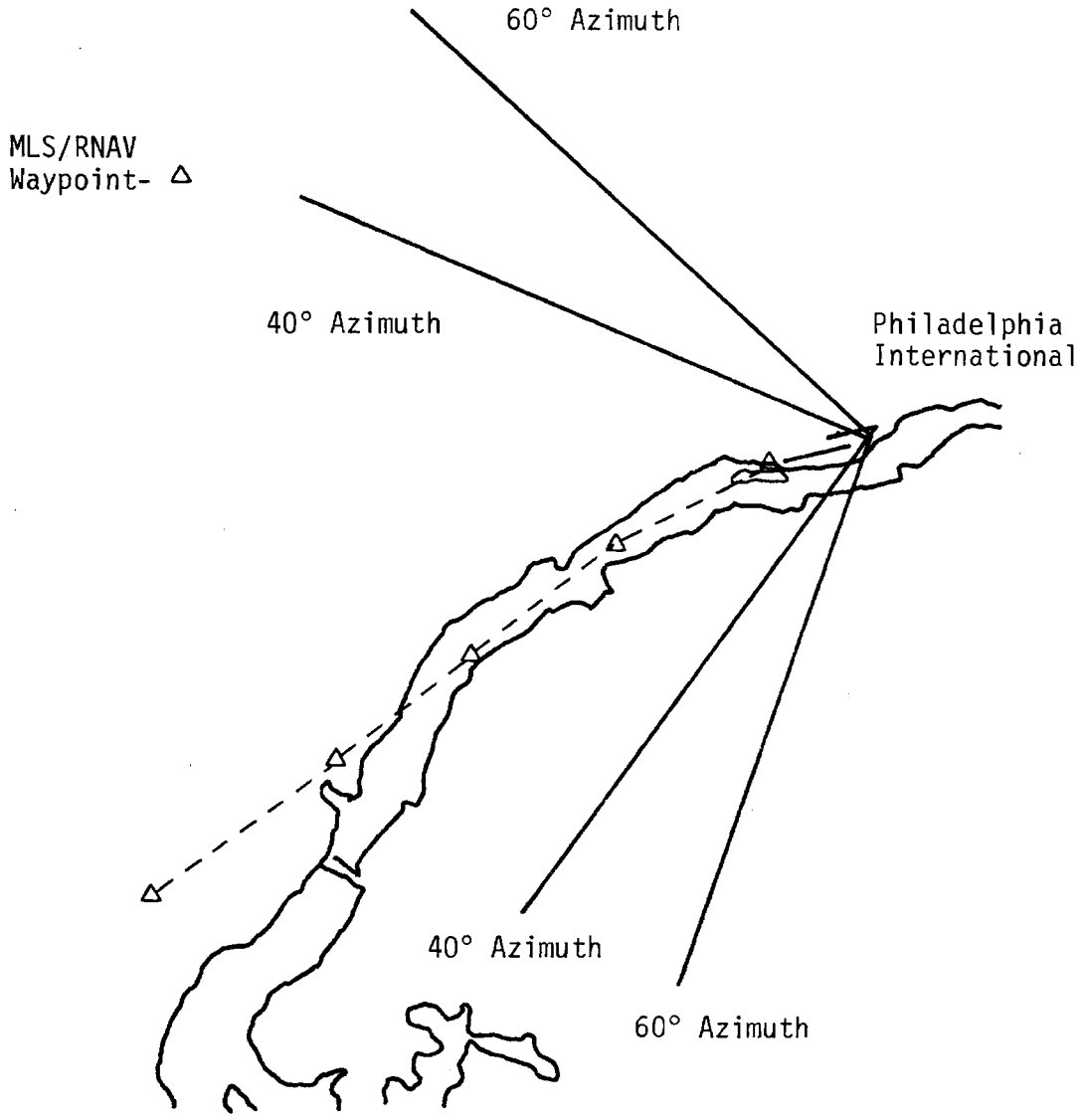


Figure 5.8 MLS/RNAV Approach to Philadelphia International Overlying the Visual Approach

- City Center Operations

The city center MLS application is among the most difficult of those discussed, both operationally and technically, insofar as IFR application is concerned. City center heliports, whether rooftop or ground level, are usually limited in real estate, making the installation of marker beacons and antenna arrays difficult if not impossible. Also, these heliports are often in close proximity to numerous obstacles such as buildings, bridges, towers, and powerlines. For this reason, if MLS where to be considered for a particular location to be the precision approach aid, elevation guidance would be required. Therefore, not all heliports could be approved for any precision instrument approach.

The city center user group to benefit most from MLS is the corporate/executive operators. In larger cities, charter or commercial operators are also active (i.e., New York Helicopter Corporation) between airport terminals and nearby heliports, often on a scheduled basis. Currently, most operators to city center heliports utilize single engine turbine helicopters. Recently, twin engine turbine rotorcraft, compatible in size with the corporate/executive requirements, have become available. These aircraft will be increasingly utilized in city center operations.

It is anticipated that the most likely MLS configurations for city center operations are a straight in approach path with elevation guidance or MLS combined with RNAV. Requirements for operating in the obstacle laden airspace must be considered in light of the rotorcraft performance limitations discussed in Section 5.4.

- Major Hub Center Operations

The major problem associated with major hub IFR operations is fixed-wing and rotorcraft separation and traffic congestion. An MLS configured airport would lessen this problem. Although there are generally no unusual technical problems associated with a major hub MLS configuration, there are operational limitations that must be considered. These fall into two general categories; fixed-wing and rotorcraft traffic integration conflict, and rotorcraft/rotorcarft conflict. The first type is more common, particularly where there are few or no dedicated helipads and the rotorcraft must be integrated into the common fixed-wing approach path. The latter category describes a terminal area such as New York where there are dedicated heliports and helipads and some non-conflicting routes with fixed-wing operations. During low visibility operations helicopters using these routes can experience condlicts with one another.

Even with MLS, separate approach paths are difficult to achieve without proper airspace planning. Wide angle MLS azimuth (±60°) configurations at major hubs appears to be the most attractive alternative. This would enable both fixed-wing and rotorcraft to make simultaneous approaches; the fixed-wing along a straight-in approach, and the rotorcraft along an offset azimuth radial or a MLS/RNAV route to a dedicated helipad. Separation would be maintained by airspace allocation or by ATC sequencing the aircraft.

There is a potential operational problem associated with variable elevation angle procedures. Since rotorcraft commonly operate at lower altitudes in the terminal area, to take advantage of a selectable MLS glide path (5° to 8°) the rotorcraft would be required to climb above the fixed-wing traffic to an altitude that assures separation above the fixed-wing 3° glide path prior to descending.

To resolve these problems, selectable azimuth approaches and/or selectable elevation approaches must be planned based on potential fixed-wing and rotorcraft conflict rate and the performance of aircraft involved.

- Non-hub Airport Operations

In general there are no unresolveable technical problems associated with an MLS installation in this environment. One possible operational problem could be encountered if winds disallow an approach to the MLS configured runway. In such a circumstance, it would be necessary to execute a circling approach to the opposite end of the runway after having overflown the airport along the MLS azimuth centerline.

- Remote Area Operations

Of the variety of remote area operations, the majority require visual contact with the ground, such as, search and rescue, pipeline and powerline survey, game management and logging. These operations require little or no precision IFR capability.

In order to be economically viable, a remote area operation would have to be performed for a prolonged duration to a specific site to benefit from MLS. Remote area operations are usually at temporary locations, therefore, a crew of technicians would be required on site to install equipment. In addition, regulatory approval would be required for each location and for the desired procedures.

If an MLS installation was required for a particular operation, there are no forseeable operational or technical problems out of the ordinary with which to contend. A straight in or offset azimuth approach with or without elevation and DME information would be the minimum configuration.

- Offshore Oil Rig Operations

Platform stability may prove to be a significant factor in determining the feasibility of using MLS as an approach aid in the offshore environment. There are basically three types of rigs in use; rigs which actually rest on the ocean floor (e.g., jack ups), floating rigs which use caissons for ballast, and drill ships. The first two types have the roll stability required to act as a base for a precision navigation sources in normal or even rough seas. Drill ships, on the other hand, can roll or pitch up to 10° in a heavy but not uncommon sea state. With approach glideslope values typically in the range of 2½° to 6°, this roll and pitch movement becomes several mangitudes

outside of acceptable tolerances. Even with roll or pitch movement on the order of 1°, the final approach glideslope is dramatically affected. Glideslope indications in an aircraft on 5 nm final will vary approximately ±500 feet with a ±1° transmitter pitch movement. In order to make MLS operationally usable for unstable platforms, some means of stabilizing the transmitter must be developed. One means of accomplishing this is through the application of gyro stabilization techniques which increases system costs. An alternate regulatory solution to the stability problem is the establishment of maximum pitch and roll limits whenever the propagated signal is being used as a precision approach aid. This of course would require the installation of on-site monitoring devices resulting, ultimately, in higher system costs.

For isolated unstable platforms, radar altimetry and a step down approach could be used in place of MLS elevation guidance. This procedure could only be used for rigs where precision altitude information is not critical to the approach.

Another consideration is that most IFR capable helicopters in the offshore environment are equipped with airborne radar and capable of executing ARA approaches. The advantage of airborne radar on final approach is the ability to see the rig or rigs as well as movement of ships. For this reason an ARA approach which combines DME, radar altimetry, and airborne radar can usually be made to the rig with lower minimums than can be achieved with MLS.

5.3 CANDIDATE MLS APPROACH PROCEDURES

In this section a candidate MLS approach procedure will be described for each of the operational areas described in Section 4.0. These procedures have been developed based on the operational needs and characteristics of each operational area, as well as, the operational and technical problems associated with MLS applications. In addition to candidate approach procedues, MLS airborne and ground equipment requirements will be specified.

Provided in Table 5.1, are the information and functional requirements for each MLS approach path capability by each operational application. The contents of this table represent the recommendation of RTCA Special Committee-139. The application categories of Table 5.1 follow closely the operational areas discussed previously. The low density or small community airport category parallels non-hub airports. The medium and high density airport category refers to major hub airports. The category for non-instrumented runways would also apply to city center heliports and rooftop helipads. The only area not specifically included in the table is offshore oil rig helipads although the remote area category could apply.

5.3.1 City Center MLS Approach Procedures

The candidate MLS approach selected is a straight in approach with elevation guidance. Because of the proximity of tall buildings, powerlines, towers, etc., in the vicinity of many helipads, approach

Table 5.1 Typical MLS Information/Functional Capabilities[6]

		REQUIREMENTS (R = REQUIRED, O = OPTIONAL)												
		INFORMATION								FUNCTIONAL				
APPLICATION	APPROACH PATH CAPABILITY	AZIMUTH	ELEVATION	BASIC DATA**	DISTANCE INFORMATION*	DME/P (PRECISION)	SELECTED PATH DEVIATION OUTPUT	AUXILIARY DATA**	MLS FLARE	MLS CHANNEL SELECT	AZIMUTH (OFFSET) SELECT	GLIDE SLOPE SELECT	WAYPOINT/FLIGHT PATH ENTRY	COMPUTATIONAL CAPABILITY
LOW DENSITY OR SMALL COMMUNITY AIRPORTS	STRAIGHT-IN ALIGNED WITH RUNWAY CENTERLINE	R	R	R	R	O	R			R		O		
	OFFSET AZIMUTH	R	R	R	R	O	R			R	R	O		
MEDIUM AND HIGH DENSITY AIRPORTS	STRAIGHT-IN ALIGNED WITH RUNWAY CENTERLINE	R	R	R	R	O	R			R		O		
	ABOVE PLUS SEGMENTED OR CURVED PATHS	R	R	R		R	R	R		R	O	O	R	R
MISSED APPROACH AND DEPARTURE	MLS RUNWAY CENTERLINE EXTENDED	R		R		O	R			R				
	SELECTED MLS MISSED APPROACH AZIMUTH	R		R		O	R			R	R			
	ABOVE PLUS SEGMENTED OR CURVED PATHS	R		R		R	R	R		R	O		R	R
SPECIAL APPLICATIONS: NON-INSTRUMENTED RUNWAYS	OFFSET AZIMUTH	R	R	R	R	O	R			R	R	O		
	ABOVE PLUS SEGMENTED OR CURVED PATHS	R	R	R		R	R	R		R	R	O	R	R
SPECIAL APPLICATIONS: REMOTE AREAS	STRAIGHT-IN	R	R	R	R	O				R		O		
AUTOMATIC LANDING AND ROLLOUT GUIDANCE		R	R	R		R		R	O	R		O		R

*SUCH AS MARKER BEACONS, DME/N OR OTHER POSITION FIX.
**IN SOME APPLICATIONS ONLY PORTIONS OF THE DATA MAY BE NEEDED.

minimums would prohibit, in many cases, the construction of primary and secondary airspace for an MLS approach to the helipad. For these heliports, a straight in MLS point in space approach appears to be best alternative.

The MLS ground equipment requirements include a ±10° proportional azimuth guidance. The elevation angle coverage would be 1° to 15°. DME is required to define fixes. The MLS airborne equipment requirements include a receiver capable of providing centerline azimuth guidance and selectable elevation guidance.

An example of a city center MLS approach configuration is shown in Figure 5.9. This MLS approach is based on the RNAV point in space approach to the downtown Manhattan Heliport previously shown in Figure 4.2. For the MLS configuration, the azimuth and elevation antennas are collocated on Governor's Island. The missed approach point, previously Decker, is now further alongtrack by 1.5 nm and at an altitude of 700 feet. At MAP, the rotorcraft would proceed visually 2.2 nm to the heliport, or execute a missed approach climbing right turn to 1700 feet direct to FOXXY and hold.

It should also be noted that the MLS signal monitor equipment is not placed according to standard airport configuration. In this case the monitor equipment would be located on Governor's Island in the path of the elevation and azimuth antennas. The purpose of the monitor equipment is to continuously evaluate the signals transmitted by the azimuth and elevation antennas. If invalid information is being transmitted, then the MLS will automatically be turned off.

5.3.2 Major Hub Center MLS Approach Procedures

The MLS approach procedure selected for the major hub airport is the MLS/RNAV approach. This is considered to be the minimum MLS approach procedure desirable in a high density, non-homogeneous aircraft environment.

The MLS approach configuration is shown in Figure 5.10. The ground configuration would take in an azimuth angle range of ±60°. The elevation angle range would be 1° to 15° over an azimuth coverage of ±60°. DME is required for the MLS/RNAV system. The airborne requirements include an MLS receiver capable of providing both angle and data information to the MLS/RNAV computer. The computer must be capable of accepting the MLS angle data, DME information and MLS site data and producing 3-D guidance.

An example of this candidate MLS procedure is shown in Figure 5.10, for Kennedy International. In this configuration, the elevation antenna is placed 1000 feet from the end of runway 13L. The DME and azimuth antenna are positioned at the opposite end of the runway collocated with the ILS localizer antenna. This configuration allows for fixed-wing traffic to fly RNAV to intercept the centerline or offset azimuth approach path for 13L or 13R. Rotorcraft would fly dedicated RNAV-copter routes to intercept the MLS/RNAV final approach paths.

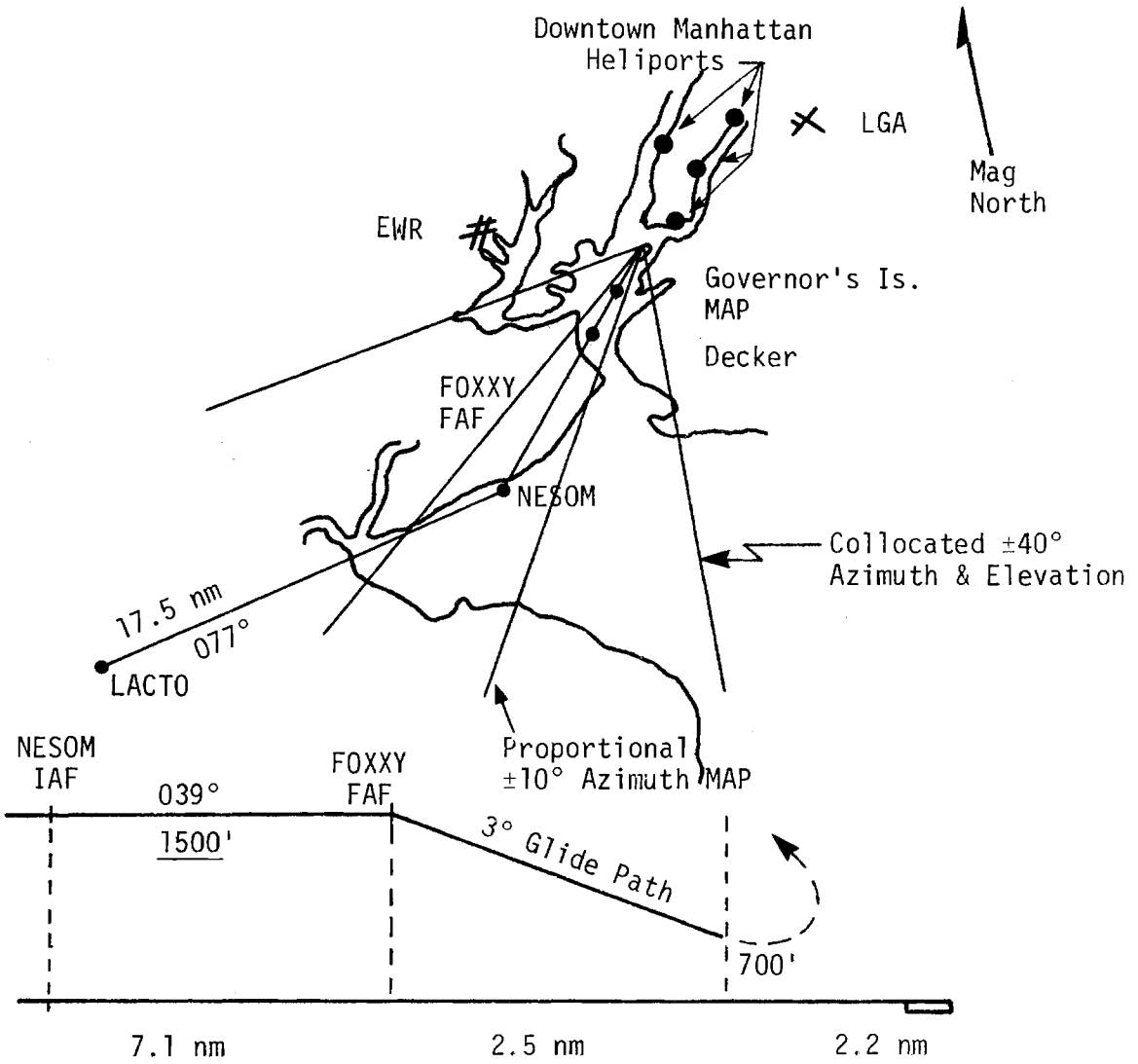
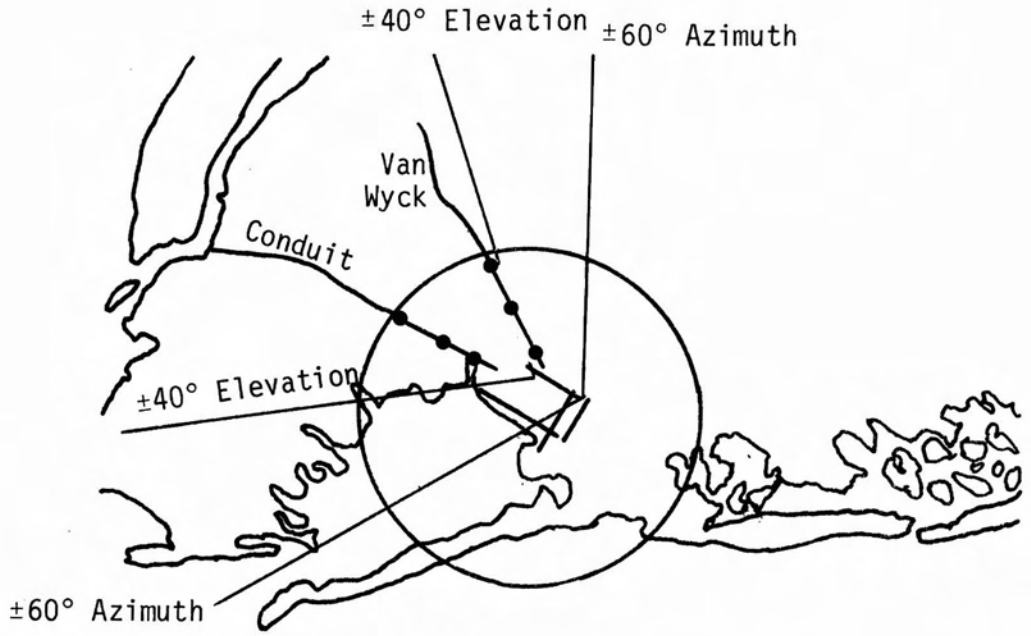
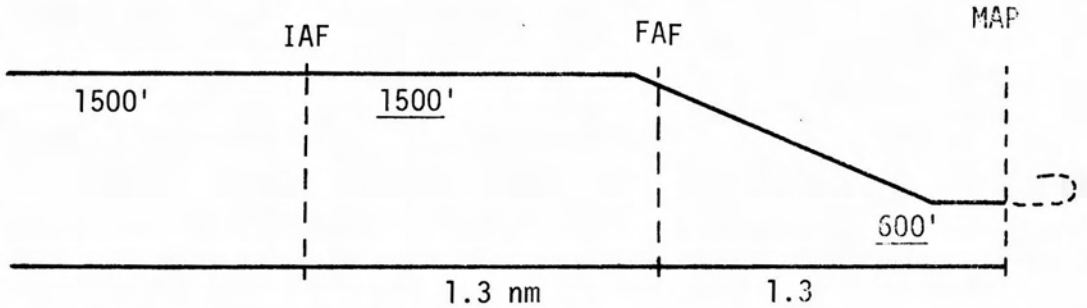


Figure 5.9 Straight in MLS Point In Space Approach to the Downtown Manhattan Heliport



Van Wyck MLS/RNAV Approach



Conduit MLS/RNAV Approach

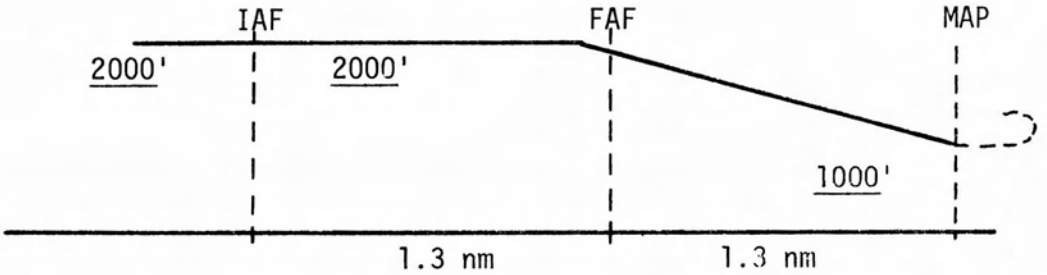


Figure 5.10 MLS/RNAV Copter Approach Procedures

Two MLS/RNAV helicopter approaches are shown. These approaches overlie current VFR routes utilized by a scheduled helicopter service that currently operates VFR routes within the New York terminal area. The Van Wyck MLS/RNAV approach will lose MLS elevation guidance approximately 1.3 nm from the landing point. The missed approach point should probably be located prior to the point where the elevation signal becomes unusable.

The Conduit MLS/RNAV approach will require climbing to intercept the initial approach fix at 2000' in order to assure separation from the Canarsie/Shore Parkway fixed-wing approach. At the FAF, the rotorcraft would be allowed to descend on a glide slope angle of 6° to 8° to MAP. At MAP, if weather conditions permit, the rotorcraft will transition to visual and overfly the airport at a sufficient altitude to clear surface obstacles prior to helipad touchdown.

5.3.3 Non-Hub Airport MLS Approach Procedures

Since the traffic activity is much less at non-hub airports during IMC than for major hubs, the MLS requirements are considerably less. The candidate MLS configuration for non-hub airports is a straight in approach with selectable elevation guidance.

The MLS ground configuration is a system with a proportional azimuth angle range of ±10°. The elevation angle coverage is 1° to 15°. The MLS airborne equipment requires azimuth centerline guidance and selectable elevation control. A DME capability is assumed in the following section. Alternative procedures using marker beacons can be developed without the requirement for DME in many instances.

An example of this candidate MLS procedure is shown in Figure 5.11, configured for Imperial Beach (Ream Field), California. The current approch is a 3.5 nm DME arc to the 084° radial. The MLS approach is transposed over the current approach. The centerline azimuth path is intercepted in the conventional manner using the 3.5 nm DME arc. Since the airborne MLS equipment allows selectable elevation guidance, the initial approach fix can be positioned closer to the airport, and at a higher altitude than required for fixed-wing. This allows ATC to maintain separation more efficiently by either holding the rotorcraft at the initial approach fix while on the centerline azimuth path, or else holding the rotorcraft on a parallel course to the azimuth path until cleared to intercept the final approach fix. Once at the MAP, the rotorcraft could either continue straight in to land on the runway or side-step the approach course to land at the helipad. If the winds require an approach from the opposite direction, the rotorcraft could overfly the runway using MLS and then make a circling approach.

5.3.4 Remote Area MLS Approach Procedures

Remote area operations are largely conducted under VFR due to the requirements of most remote helicopter applications. However, MLS may offer operational benefits to applications which require the transportation of personnel and equipment to temporary, centralized remote areas where

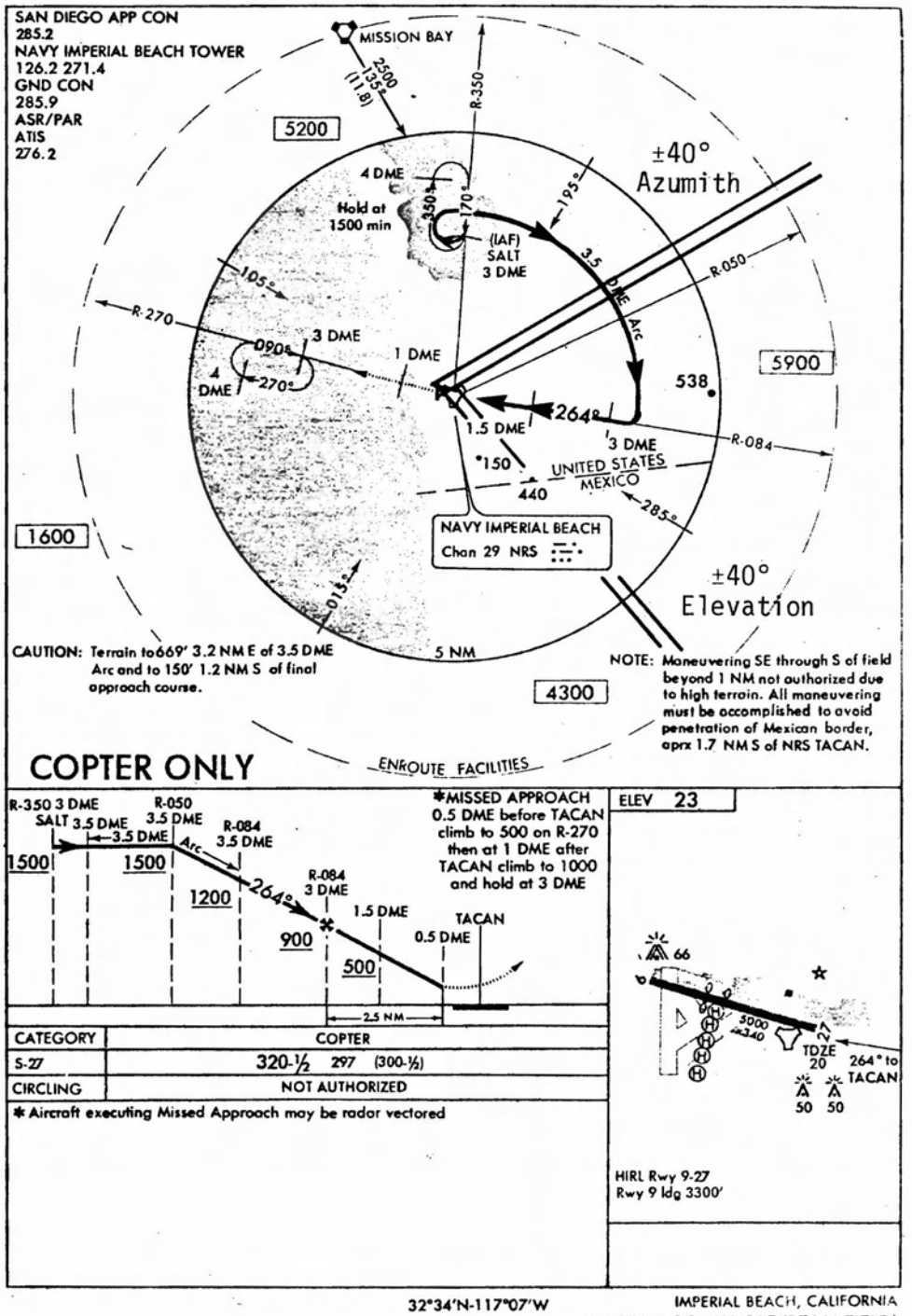


Figure 5.11 Non-Hub Candidate MLS Approach Procedures

instrument meteorolgical conditions prevail. This could also apply to long term disaster relief operations.

The candidate MLS configuration for remote area operations, shown in Figure 5.12, is a straight in MLS approach. Since traffic is normally low density in remote operations, only ±10° of proportional azimuth coverage is necessary. The elevation angle coverage range is 1° to 15°. The airborne requirements include centerline azimuth guidance and selectable elevation angle. DME is required in this application to define initial approach segments and the FAF.

In Figure 5.12 the azimuth and elevation antennas are collocated at the helipad. The monitor equipment would be positioned in line with the MLS signal paths to detect signal abnormalities and shut the system down if necessary.

5.3.5 Offshore Oil Rig MLS Approach Procedures

There are two candidate MLS approach procedures considered for offshore, one for the stable platform and one for the unstable platform. The basic difference is primarily with the MLS rig configuration. The stable platform is compatible for both azimuth and elevation antennas. However, on the unstable platform, the elevation antenna cannot be totally isolated from wave and heave motion to provide acceptable accuracy for elevation guidance. Therefore, the unstable platform will not be required to have an elevation antenna. The MLS rig equipment requirements are azimuth guidance coverage of 10°. Elevation antenna requirements for the stable platform include a 1° to 15° glide path angle coverage. The MLS airborne equipment requirements are centerline guidance only for the unstable platform and centerline guidance with selectable elevation for the stable platform.

Also required for oil rig MLS approaches in this candidate procedure is airborne radar equipment. This requirement is based on the need to see and avoid ships and other rigs at altitudes of 300' and below. It has been repeatedly demonstrated that approach procedures using airborne radar and radar altimeters are capable of providing approaches down to 200'-1½ mile minimums in the offshore environment. The addition of MLS as an approach aid must be weighted on the criticality of the accuracy provided by azimuth and elevation guidance.

An example of an MLS/ARA approach to a stable oil rig platform is illustrated in Figure 5.13. Conventional ARA approach procedures call for an approach course parallel and not less than 500' from the centerline course to the helipad. This is to assure rig clearance on a missed approach. MLS/ARA approach accuracy allows for a centerline 0° azimuth angle approach procedure. Missed approach would be a climbing turn into a clear area. MLS/RNAV could be used to fly an offset path.

To provide for approaches into the wind the MLS antennas could be installed on a swivel or a circular track, to be turned toward the preferred approach direction. This technique is probably technically

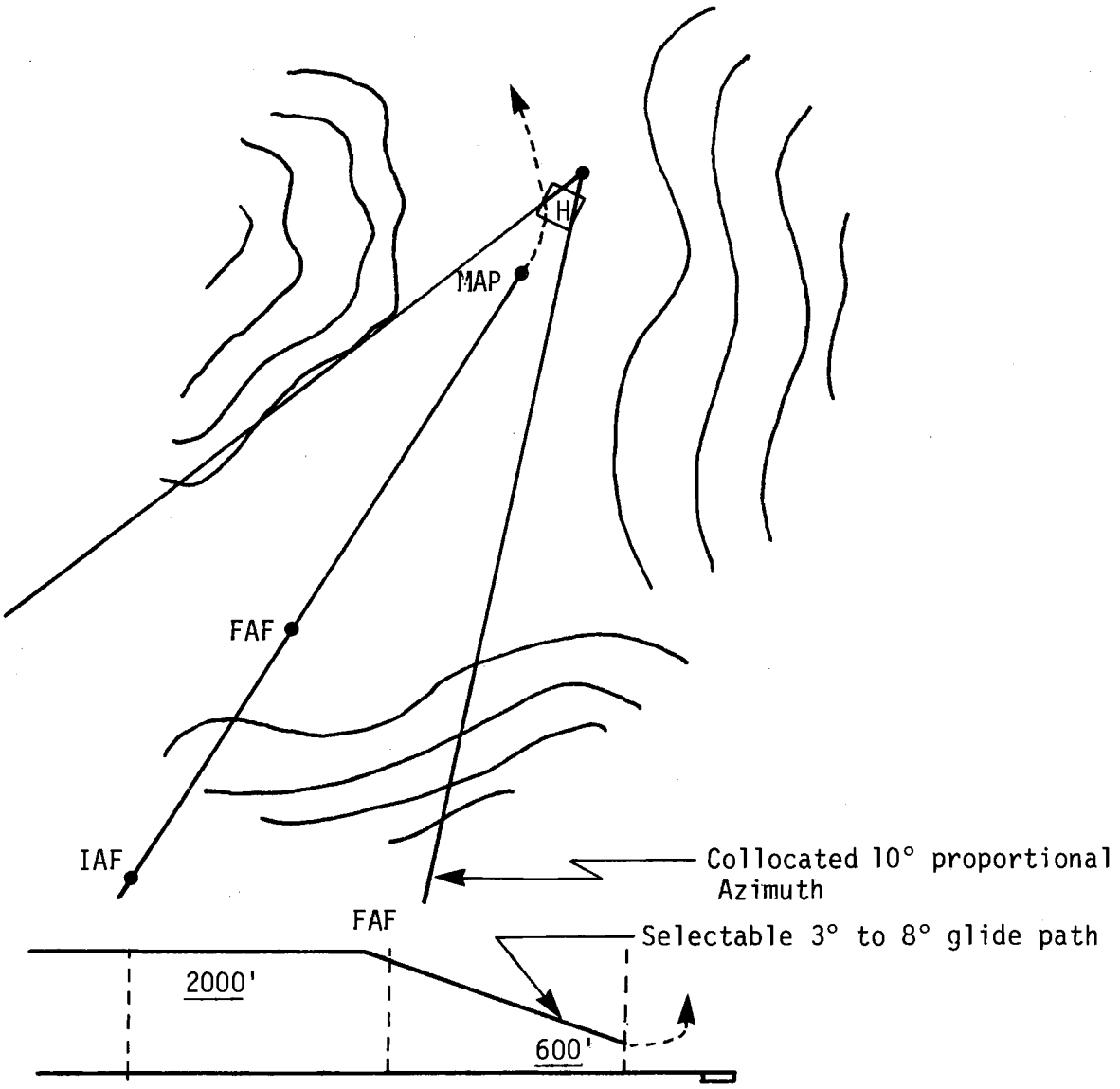


Figure 5.12 Remote Area Candidate MLS Approach Procedure

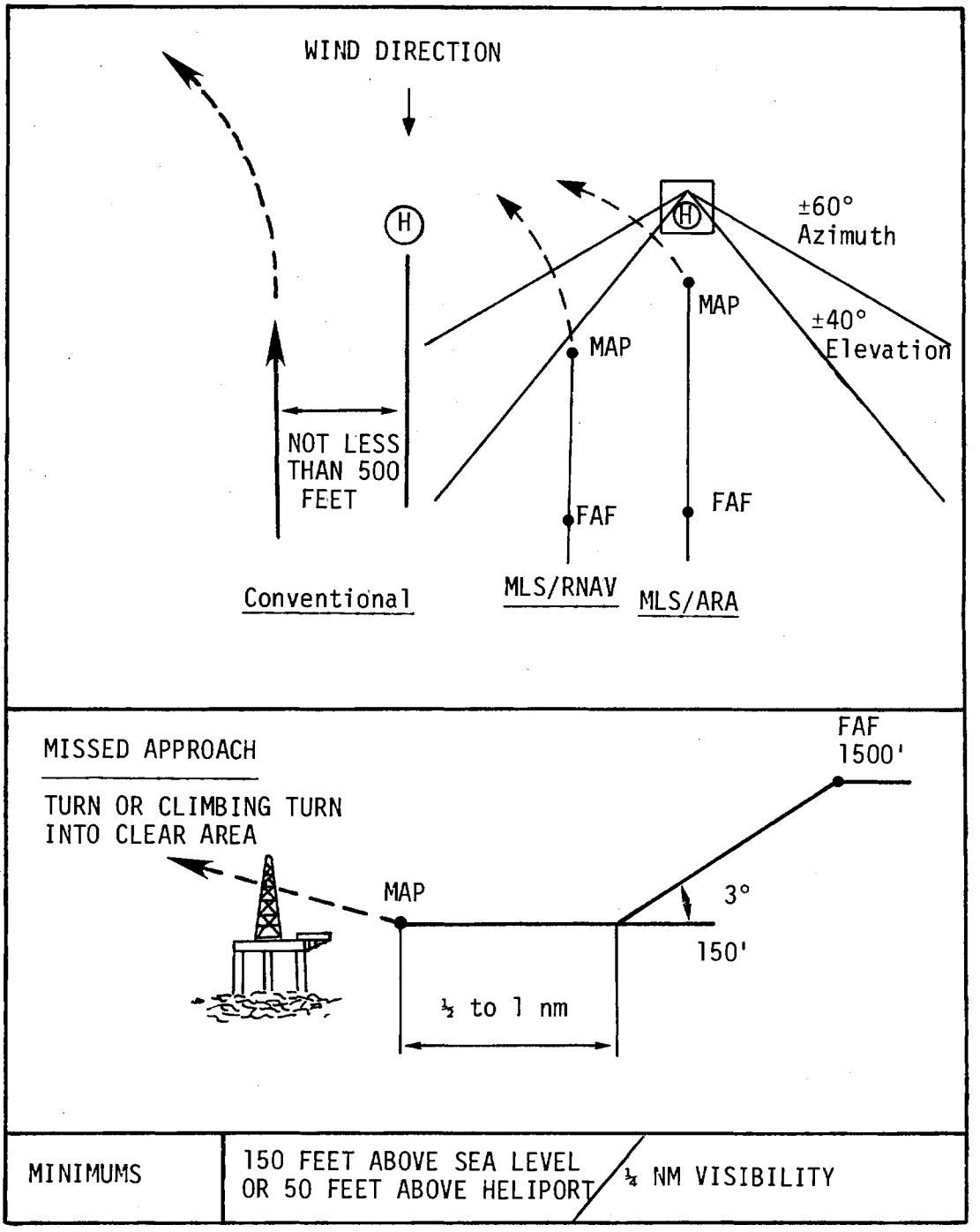


Figure 5.13 Offshore Heliport Candidate MLS/ARA Approach Profile

feasible; however, the practical limitations of flight inspecting every possible approach azimuth is a problem area. It is perhaps more appropriate to flight check two to four azimuth values and restrict approach directions to those that are acceptable and flight checked.

5.4 HELICOPTER PERFORMANCE CONSIDERATIONS

In recent years the Terminal Instrument Procedures Handbook[3] has been modified to recognize the unique capabilities of the helicopter, relative to fixed-wing aircraft, for performing instrument approach procedures. These modifications have been assembled into a separate section of the handbook called Chapter Eleven, Helicopter Procedures. Chapter Eleven is based upon data obtained primarily with military and older models of rotorcraft. Recently, with the development of high performance rotorcraft, questions arose as to the relevance and applicability of the current Chapter Eleven procedures.

The FAA is currently addressing these questions in flight test programs at Layfayette, Louisiana and Atlantic City, New Jersey. These tests are using ILS, VOR, DME and NDB navigation aids. Therefore the results of the tests are not directly applicable to MLS and MLS/RNAV procedures. However, the parameters that are being considered and measured in the tests are those that also need to be quantified in MLS related procedures. These parameters determine airspace and procedural requirements and include the following measurable quantities:

- turn overshoot and undershoot as a function of intercept angle (30°, 60° and 90° angles)
- minimum segment length for stabilizing the aircraft
- height loss at the missed approach point as a function of descent gradient
- minimum decision height or descent altitude

In addition to these quantities, specialized MLS approaches such as offset radial procedures and MLS/RNAV procedures, have additional performance parameters that require test data. Some of these parameters include:

- offset radial procedures
  - side step DME distance and altitude
  - visibility requirements
  - guidance requirements during the sidestep maneuver (visual or instrument)
  - decision height or minimum descent altitude
  - transition to missed approach
- MLS/RNAV procedures
  - minimum waypoint separation distance

- maximum course change at the waypoint
- 2D and 3D MLS/RNAV procedures
- decision heights or minimum descent altitude
- enroute to terminal guidance transition
- transition to missed approach

The current tests are being performed using various sizes of turbine aircraft including a Bell 206L, Sikorsky S-76 and a Sikorsky CH53A. These tests should determine the effect of helicopter size on the airspace criteria. If size proves not to be an important factor in the current series of tests, the MLS tests could conceivably be limited to one or two aircraft sizes.

The current flight tests using ILS should produce data which will allow estimates of many of these parameters to be made. However, until tests are made with actual MLS equipment, final MLS approach procedure criteria can not be established.

5.5 SUMMARY

In summary, the following MLS approach procedures have applications for helicopter operations:

Approach Procedure

MLS straight-in

Operational areas

city center
non hub airport
remote area (for long term-repeatitive operations only)
offshore (stabilized platforms or installation)

Ground equipment

azimuth coverage ±10 from centerline
elevation coverage 1° to 15°
collocated azimuth and elevation at helipads
split site installation at non-hub airports
DME required at most installations
marker beacon, compass locator can be used in lieu of DME required at some non-hub airports
monitor equipment (may require non-standard installation in city center, remote area and offshore locations)

Airborne equipment

MLS receiver with centerline guidance and selectable glide path angle
DME, marker beacon or automatic direction finding equipment depending upon ground installation

Approach Procedure

MLS point in space

Operational areas

city center

Ground equipment

azimuth coverage ±10° from centerline
elevation coverage 1° to 15°
collocated azimuth and elevation
DME required for fix identification
monitor equipment (may require non-standard installation)

Airborne equipment

MLS receiver with centerline guidance and selectable glide path angle
DME receiver

Approach Procedure

MLS offset azimuth

Operational areas

major hub airports

Ground equipment

azimuth coverage ±40° to ±60° from centerline
elevation coverage 1° to 15°
split site azimuth and elevation
DME required for fix identification and arc transitions
monitor equipment at standard locations

Airborne equipment

MLS receiver with selectable azimuth and selectable glidepath angle
DME receiver

Approach Procedure

MLS/RNAV

Operational areas

major hub airports
areas requiring noise abatement procedures

Ground equipment

azimuth coverage ±40° to ±60° from centerline
elevation coverage 1° to 15°
split site azimuth and elevation
DME required for RNAV position determination
monitor equipment at standard locations

6.0 COST/BENEFIT ANALYSIS OF MLS FOR HELICOPTERS

An analysis of the costs and benefits associated with the use of MLS for helicopter operations is presented in this section. The analysis is patterned after ILS establishment criteria described in Reference 4. The reference does not specifically cover either MLS or helicopter operations. However, the methodology and relevant parameters are applicable to the problem under consideration. For these reasons considerable effort was put forth to adapt the establishment criteria methodology to an analysis of cost/benefit relationships for MLS helicopter operations.

The analysis procedure treats costs from the standpoint of the ground system operator and benefits from the system users viewpoint. Costs are broken down into investment cost and operation/maintenance cost. Included in investment cost are the purchase and installation of the equipment for the ground system. These costs include:

Investment Costs

- Equipment
  - transmitters
  - antennas and cabling
  - power supplies (commerical and standby)
  - monitors
  - shelters
- Installation
  - surveys
  - system layout design
  - power lines and cables
  - site preparation
  - construction
  - initial flight inspection and certification

Operations and Maintenance Costs Include:

- spare parts inventory
- power
- maintenance personnel
- maintenance equipment
- routine flight inspection

Investment costs are considered as lump sum values required at the present time. Operations and maintenance are annual costs that are required each year to keep the ground system operational. These annual costs are considered over a twenty-five year period and discounted at a rate of 10% per year. Net discount factors are applied to treat these annual costs on a present value basis. This procedure is consistent with guidelines published by the Office of Management and Budget.

Benefits are divided into two categories, safety benefits and benefits derived from averted flight disruptions. Safety benefits are

derived from reductions in accident rates through the use of precision approach procedures. Accident reduction provides savings in terms of helicopter airframe costs, reduced fatalaties, and reductions in medical cost for survivors of the accidents. Safety benefits accrue for each approach in which the precision approach guidance is used.

Averted flight disruption benefits, or more simply, efficiency benefits, are derived from approaches that can be made with MLS but would have been disrupted in some manner if MLS had not been available. The types of disruptions that occur are:

- delays
- cancellations
- diversions to other airports
- overflight of an intended destination

The analysis treats disruptions in terms of aircraft operating costs and passenger costs in lost time and rescheduling. Cargo costs are not specifically included in the analysis but are assumed to have approximately the same benefit value as passenger operations.

The final set of cost/benefit parameter values required to complete the analysis concerns the evaluation of the number of operations that will receive safety benefits and/or efficiency benefits. The ILS establishment criteria utilizes annual instrument approaches (AIAs) for this purpose. Use of this parameter implies that an airport, or heliport, currently has an existing instrument approach procedures. In the case of heliports or helicopter landing areas at airports, this assumption may not be valid. Therefore, an alternative procedure using annual aircraft operations was developed to be utilized at helicopter landing facilities where there were no current insturment approach capabilities.

6.1 MLS AND HELICOPTER DATA BASE DEVELOPMENT

Since the use of MLS and the use of IFR helicopters are both relatively new compared to fixed-wing ILS operations, a considerable amount of data base development activity was necessary. Where possible, MLS system costs and helicopter operational costs were evaluated by utilizing current studies performed by the FAA and the helicopter industry.

6.1.1 MLS Cost Determination

For MLS ground and airborne system costs the primary source of data was a recent FAA report entitled "Life-Cycle-Cost Analysis of the Microwave Landing System Ground and Airborne Systems", Report No. FAA-RD-81-96, October 1981 (Reference 25). This report analyzes the expected life-cycle-cost through the year 2010 to the government and to users of implementing MLS in the United States. The emphasis in Report 81-96 was on the integrated costs of MLS across the entire country. The emphasis in the present study is to evaluate cost and benefits of establishing MLS at a specific heliport or airport facility. Both studies utilize the same MLS cost data for single systems. However the

accumulation of costs is different for the reasons stated.

6.1.2 Helicopter Cost Determination

IFR helicopter operations have a relatively limited history. Accident statistics were not considered to be sufficiently comprehensive to permit quantification of IFR helicopter safety benefits. Consequently, the accident analyses used for fix-wing aircraft in Reference 4 were applied to ascertain safety benefits.

Helicopter operating costs are required as one element in determining efficiency benefits. IFR helicopters were divided into five categories:

- single engine turbine (3000-5000 lbs gross weight)
- light twin engine turbine (up to 6000 lbs)
- medium twin engine turbine (6000 to 12,500 lbs)
- heavy twin engine turbine (12,500 to 30,000 lbs)
- very heavy turbine (over 30,000 lbs)

Operating costs for these aircraft include:

- crew costs (including benefits)
- fuel and oil
- insurance (hull and liability)
- maintenance

Depreciation and interest costs, overhead and other business operating expenses are not included, per the guidelines in Reference 4.

Data for the helicopter operating costs were derived from References 10, 11 and 12. In addition, insurance companies were contacted to ascertain insurance rates for hull and liability insurance. Rates vary considerably depending upon crew experience and the type of activity for which the helicopter is being used. Averages of high and low rates were utilized in the analysis.

In order to determine efficiency benefits, the flight disruption effects upon helicopter flight time, passenger time lost, passenger handling expenses must be considered. These effects have been divided into four categories:

- delays
- cancellations
- diversions
- overflights

The effect upon helicopter operations varies as the operational area varies. For this reason flight disruption effects were also categorized by operational area:

- city center
- major hub airport
- non-hub airport
- remote area
- offshore

The resulting matrix of operational areas versus flight disruption effects is described in detail in Section 6.3.2 and Appendix A.

6.1.3 Forecast Helicopter IFR Operations

There are currently very little available data concerning the number of helicopter IFR approaches currently flown or forecast to be flown in future years. Widespread use of IFR helicopters is relatively new to the aviation industry. However, they are a rapidly growing segment of the helicopter market and their rapid growth rate makes forecasts and projections subject to considerable error.

In the cost/benefit analysis task, the New York area had documented counts of the number of approaches and types of aircraft currently being used at the Manhattan Heliports and the three major airports, Kennedy, LaGuardia and Newark. These counts did not include IFR approaches as most current helicopter operations are VFR. However, a methodology was developed which permitted estimates of IFR approaches that would be made if MLS approach procedures were available. These methods and the analysis are described in Section 6.4.

For other areas, where helicopter approach counts are not always separated from fixed-wing statistics, a methodology was developed which identified the relationship between helicopter instrument approaches versus annual dollar benefits. These methods and analysis are described in Section 6.5.

6.2 MLS SYSTEM COST DATA

6.2.1 MLS Establishment Costs

MLS ground system costs were derived directly from information contained in References 25 and 4. Reference 25 contains MLS angle and DME cost figures; Reference 4 was used to develop heliport lighting cost estimates.

MLS Equipment Costs

Reference 25 describes four ground station configuration which are referred to as Small Community MLS (SCMLS), Basic I, Basic II, and Expanded. The characteristics of these four systems shown in Table 6.1.

Table 6.1 MLS Ground Station Configurations

	CONFIGURATION			
Characteristic	SCMLS	Basic I	Basic II	Expanded
ICAO Category	I	I	II	III
Azimuth Beamwidth	3°	2°	2°	1°
Proportional Azimuth	±10°	±40°	±40°	±60°
Elevation Beamwidth	2°	1°	1°	1°
Proportional Elevation	1°-15°	1°-15°	1°-15°	1°-15°
Electronics Redundancy	Single	Single	Dual	Dual
System Range	20 nm	20 nm	20 nm	20 nm
DME Type	Conventional	Precision	Precision	Precision
Environmental Protection	Weatherproof Enclosure	Shelters	Shelters	Shelters

Ground station costs include equipment acquisition, installation, non-recurring logistics and recurring logistics. Data for these costs were obtained directly from Table 5.2 of Reference 25. The costs for acquisition, installation and non-recurring logistics were assumed to occur in the first year of operation and are not discounted. The recurring logistics costs in Reference 25 are for a 22 year period. Annual recurring logistics costs were assumed to be constant over the life-cycle of the ground system. Present value recurring logistics costs were computed by multiplying the annual cost by the 25 year, 10% discount rate factor which is 9.077. All costs are quoted in terms of constant 1980 dollars. Both cumulative system costs for all systems planned for the United States through the year 2005 and system unit costs are presented in Table 6.2.

Heliport Lighting Costs

At the current time heliport lighting standards have not yet been finalized by the FAA. It is anticipated that heliports will have fewer lights than conventional runways due to the limited size of the landing area. In order to compensate for the smaller number of lights, high intensity lights will be utilized. Therefore, while a Medium Intensity Approach Light System (MALSR) can be used for a conventional MLS runway installation, a heliport installation will likely use high intensity lights.

As a first order estimate, it was assumed that the trade of fewer lights for high intensity lights would provide offsetting costs. Therefore, MALSR costs from Reference 4 were used to develop heliport lighting cost estimates.

Table 6.2 MLS Ground System Costs (Reference 25)
(Constant 1980 dollars)

M - millons of dollars K - thousands of dollars	Configuration			
	SCMLS	Basic I	Basic II	Expanded
Acquisition (Cumulative)	$88.149M	$172.930M	$103.754M	$37.911M
Installation (Cumulative)	89.498M	120.826M	48.956M	20.311M
Nonrecurring Logistics (Cumulative)	24.704M	22.977M	20.908M	18.726M
Recurring Logistics	84.020M	148.263M	75.336M	43.720M
Number of Systems	463	464	188	62
Acquisition (Unit)	$190K	$373K	$552K	$611K
Installation (Unit)	193K	260K	260K	328K
Nonrecurring Logistics (Unit)	53K	50K	111K	302K
Recurring Logistics (Unit)	181K	320K	401K	705K
Annual Recurring Logistics	8.25K	14.52K	18.22K	32.05K
25 Year Discounted Recurring Logistics (Unit)	75K	132K	165K	291K

The 1975 acuisition and installation cost of a MALSR system is about $80,000 annual operation and maintenance cost is 10% of the establishment cost. Corrected for inflation, the 1980 cost is approximately $112,000. Annual costs are $11,200. Twenty five year operating costs, discounted at a 10% annual rate are approximately $102,000.

MLS Establishment Costs

MLS establishment costs for the twenty five year period beginning with installation of the system were obtained by adding the MLS equipment and heliport lighting costs. The results are contained in Table 6.3.

6.2.2 MLS Airborne Equipment

MLS airborne equipment costs are derived from data contained in Reference 25. The costs attributed to MLS are those necessary to receive, process and display MLS angle data and precision DME (DME/P). The costs of the MLS angle equipment is entirely attributed to the use of MLS, but the cost of DME/P is only partially assigned to MLS. Most serious IFR operators would have conventional DME receivers as a part of their avionics suite. Therefore, the differential between a DME/P receiver and a conventional DME receiver is a cost attributable to MLS for those users that choose to equip their aircraft with the higher performance receiver.

Table 6.3 MLS Establishment Costs
(In 1980 dollars with recurring costs discounted at a 10% rate for a 25 year period.)

	System Type			
Cost Category	SCMLS	Basic I	Basic II	Expanded
MLS Acquisition	$190K	$373K	$552K	$611K
MLS Installation	193K	260K	260K	328K
MLS Nonrecurring Logistics	53K	50K	111K	302K
MLS Recurring Logistics	75K	132K	165K	291K
Lighting Acquisition and Installation	112K	112K	112K	112K
Lighting Recurring Logistics	102K	102K	102K	102K
Total System Cost	$725K	$1029K	$1302K	$1746K

K-Thousands of dollars

Four levels of user equipment are considered. These levels are:

System	Performance Level
1.	low-performance general aviation
2.	intermediate-performance general aviation
3.	high-performance general aviation
4.	integrated MLS/RNAV systems

The costs for Systems 1, 3 and 4 are derived directly from Reference 25. System 2 is an upgraded version of System 1 that is capable of providing guidance on selectable MLS azimuth radials.

Costs are broken down into three categories; acquisiton, installation and recurring logistics.

Acquisition Costs

Acquisition costs for System 1 are obtained directly from Table 7.13 of Reference 25. Only the cost of the receiver-processor and C-band antenna are included. The information is assumed to be displayed on a conventional course deviation indicator (CDI) or horizontal situation indicator (HSI) that is available in the aircraft. A 20% discount is included for dealer installation. This figure is consistent with current general aviation pricing practices in low cost avionics. System 1 costs are as follows:

Unit	Quantity	Cost
MLS Receiver-Processor	1	$1,648
C-Band Antenna	1	$ 346
Total		$1,994
Less 20% Discount		- 399
Net Acquisition Cost - System 1		$1,595

System 2 is similar to System 1 with additional capabilities to allow users to select offset radials. The unit is assumed to have the capability of displaying MLS azimuth and elevation angles as well as determining deviations from selected azimuth radials and glide path angles.

It is estimated that these capabilities would add approximately 25% to the cost of the receiver-processor. System 2 acquisition costs are as follows:

Unit	Quantity	Cost
MLS Receiver-Processor	1	$2,060
C-Band Antenna	1	346
Total		$2,406
Less 20% Discount		- 481
Net Acquisition Cost-System 2		$1,925

Costs for System 3 are taken directly from Table 7-10 of Reference 25. The units that directly affect the MLS system cost are the receiver-processor, antenna and MLS control panel. The DME and CDI components are assumed to be available on the aircraft in its standard configuration. System 3 acquisition costs are as follows:

Unit	Quantity	Cost
MLS Receiver-Processor	1	$7,219
MLS Control Panel	1	923
C-Band Antenna	1	195
Total Acquisition Cost-System 3		$8,337

System 4 consists of System 3 components plus equipment that permits an interface to an RNAV system to provide a segmented approach capability. The additional equipment was assumed to include an MLS Auxiliary Data Display, a precision DME and a RNAV computer interface. Costs for these units were obtained from Table 7-6 of Reference 25. System 4 acquisition costs are as follows:

Unit	Quantity	Cost
MLS Receiver-Processor	1	$7,219
MLS Control Panel	1	923
MLS Auxiliary Data Display	1	2,539
C-Band Antenna	1	195
DME Differential (Precision Cost-Conventional Cost)	1	5,535
Computer Interface	1	1500
Total Acquisition Cost - System 4		$17,911

Installation Costs

Detailed estimates of MLS installation costs are contained in Reference 25. These estimates are based on retrofit installations. New aircraft installations, performed at the aircraft manufacturer's facility as the aircraft is being constructed, are assumed to cost about 60% of the retrofit installation cost. These costs, based on fixed-wing aircraft, are assumed to apply to helicopters also.

Installation costs for System 1 and System 2 types of equipment are estimated to be $195 for new aircraft and $325 for retrofit installations (Table 9.3, Reference 25). Furthermore, over the MLS implementation period, approximately 92% of the installations are assumed to be on new aircraft and 8% are retrofit installations in the low-cost general aviation category. Weighting the installation costs by these factors produces an average installation cost of $205 per aircraft for Systems 1 and 2.

Installation costs for System 3 types of MLS equipment on medium and large size helicopters is assumed to equivalent to installations in turboprop fixed-wing aircraft. For retrofit installations, this cost was estimated to be $4,672 (Table 8-2, Reference 25). New installations are estimated to cost $2,857, or 60% of the retrofit cost.

Over the implementation period approximately 68% of the installations are anticipated to occur on new aircraft and 32% are retrofit installations (Table 8-16, Reference 25). For medium and large helicopters, new installations will exceed the 68% value derived from fixed-wing aircraft due to the limited numbers of these aircraft current found in civil operations. A new installation versus retrofit installation ratio of 80% to 20% for these aircraft seems more appropriate. Weighting the installation costs by these factors produces an average System 3 installation cost of $3,238.

Installation costs for System 4 level equipment is considerably more costly than System 3 because the MLS signals must be integrated with other aircraft navigation systems such as DME and RNAV. Estimates of these costs were based upon turboprop installations in fixed-wing aircraft. These costs are $11,067 for retrofit installations and $6,640 for new aircraft installations. Weighting these costs by the expected percentage of each type of installation (80% new, 20% retrofit) produces an average installation cost of $7,633 for System 4 types of MLS avionics.

Recurring Logistics Costs

The MLS equipment will likely be constructed from highly reliable, integrated circuit technology. Recurring logistics costs in terms of maintenance and overhaul are expected to be very small. Estimates of annual costs in Reference 25 reflect this fact. Annual costs for low-cost equipment, typical of System 1 and System 2 type equipment, is $10 (Table 9-3, Reference 25). Estimates for higher cost equipment, typical of System 3 and System 4 levels of MLS equipment, are $135 per year. These values were assumed to apply to helicopter aircraft as well as fixed-wing aircraft.

Life-cycle-costs for the recurring logistics cost were computed by multiplying the annual cost by 9.077, which is the 25 year, 10% discount rate factor. This produced the following cumulative recurring logistics cost values:

System	Recurring Logistics Costs
1	$91
2	$91
3	$1,225
4	$1,225

Airborne Equipment Costs

The acquisition, installation and recurring costs together define the total cost per aircraft of providing an MLS capability in the aircraft. These costs are presented in Table 6.4.

Table 6.4 MLS Airborne Equipment Costs
(In 1980 dollars-25years costs discounted at 10% per year)

	System			
Identifier	1	2	3	4
DESCRIPTION	Low-Performance GA	Intermediate-Performance GA	High-Performance GA	Integrated MLS/RNAV Systems
Cost Category				
Acquisition	$1,595	$1,925	$8,337	$17,911
Installation	$ 205	$ 205	$3,238	$ 7,633
Recurring Logistics	$ 91	$ 91	$1,225	$ 1,225
Total Cost Per Aircraft	$1,891	$2,221	$12,800	$26,769

6.3 MLS BENEFITS

The benefits derived from having MLS available for approach and landing procedures are broadly divided into two areas, safety and efficiency.

6.3.1 Safety Benefits

The basic concept underlying safety benefits is that the use of MLS approach and landing procedures can reduce accidents in the final phase

of flight. The reduction in accident rates can be translated into benefits in terms of:

- aircraft damage reduction
- lives saved
- serious injury averted

A schematic representation of the derivation of safety benefits is shown in Figure 6.1. The development of this benefit relies on having available, comprehensive data on accident histories so that the number of approach accidents that can be averted through the use of MLS can be evaluated. For rotorcraft, a comprehensive set of IFR accident statistics, representative of current and forecasted numbers of operations, was not available. Consequently, the methodology and statistics utilized in the ILS establishment criteria, Appendix B of Reference 4, was used for this study with certain modifications.

Reference 4, utilizing accident records from 1964-1972, determines the ratio of averted accidents to the number of non-precision approaches to be:

User Group	Avertable Accident: Approaches
• air carrier	1 : 355,000
• air taxi	1 : 16,000
• general aviation	1 : 19,000

These ratios were applied to rotorcraft through the following rationale:

1. Single pilot IFR (single engine turbine aircraft) was assumed to be similar to general aviation - 1 : 20,000
2. Two pilot IFR was assumed to be much better than general aviation but less than air carrier. Light twin operations were assumed to have an accident ratio of 1 : 80,000; medium and heavy twin turbine rotorcraft were assumed to have an accident to approach ratio of 1 : 160,000.

Reference 4 uses the figure of 90 percent of replacement cost for aircraft damage. An analysis of helicopter costs for new and used aircraft (Reference 10) indicated that for three to four year old aircraft, the estimated age of IFR helicopters in service, the replacement cost was 80 percent of the current list price of the helicopter. Combining these factors produces the following accident damage benefit per IFR approach:

Type of Aircraft	Avertable Accidents/ Approach	Average Purchase Cost	Damage Benefit Per IFR Approach
Single engine turbine	1/20,000	$456,000*	$16.42
Light Twin Turbine	1/80,000	$920,000	$ 8.30
Medium Twin Turbine	1/160,000	$1,535,000	$ 6.91
Heavy Turbine	1/160,000	$4,217,000	$18.98
Very Heavy Turnine	1/160,000	$9,850,000	$44.33

*Includes $100,000 for IFR capability

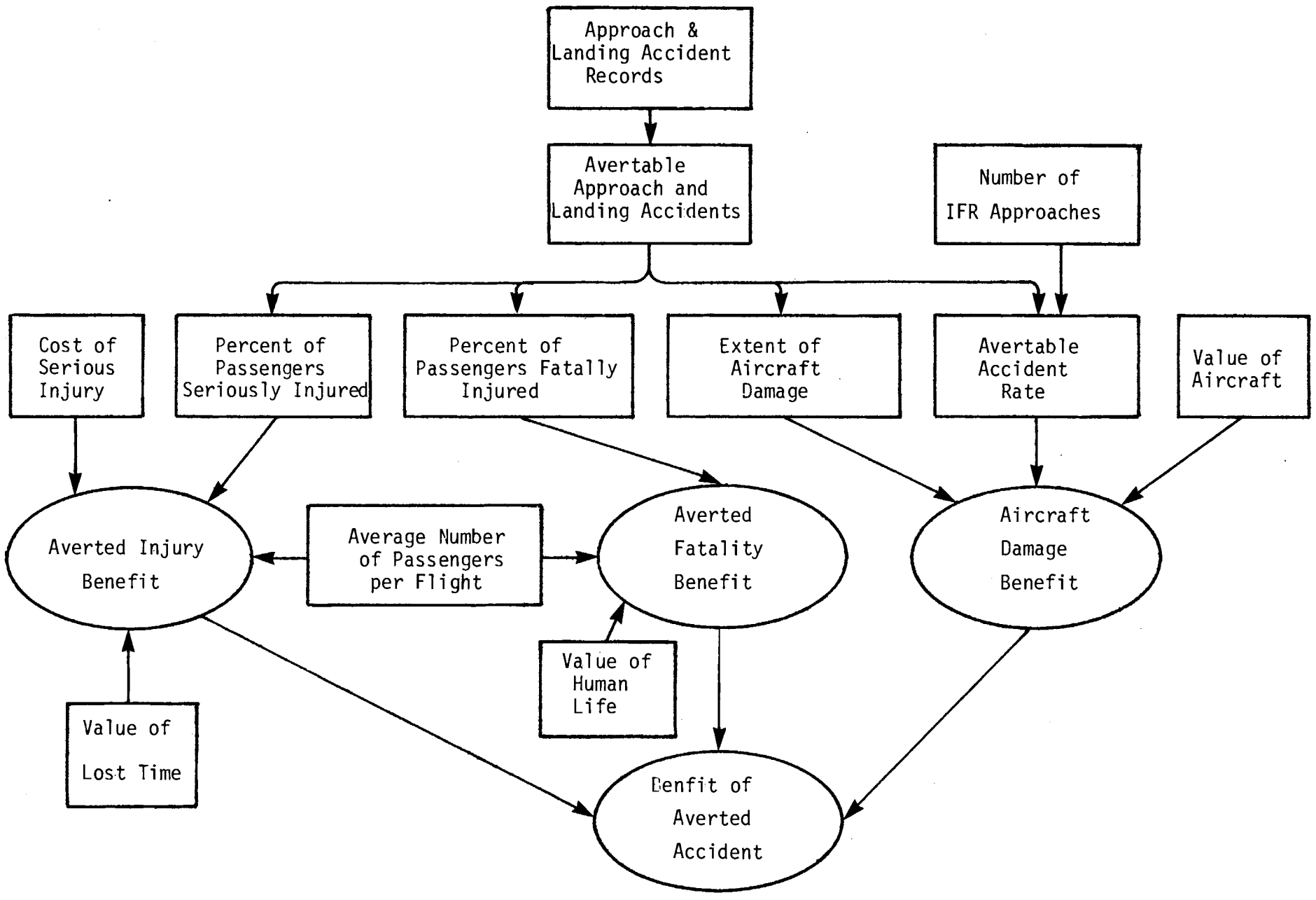


Figure 6.1 Safety Benefit Parameters

Data on the average number of fatalities and serious injuries in IFR helicopter accidents is not readily available. Reference 17 states that on the average 0.4 fatalities occur per accident (IFR and VFR combined). Many of these accidents occured with one or two occupants in the aircraft. This suggests that a 25 percent fatality rate is approximately correct. A serious injury rate of 25 percent was also assumed. This value applies to all occupants of the helicopter, passengers plus crew.

Reference 4 assumes a value of human life $300,000. This value appears low for rotorcraft passengers. Typical helicopter passengers are undoubtedly higher paid than is the average fixed-wing passenger. A typical professional person, aged 40-45 earning $30,000 to $50,000 per year would make approximately $800,000 over the remainder of his or her career. Therefore the value of life used in Reference 4 was doubled to $600,000 as a conservative figure for this analysis.

The cost of serious injury includes medical costs, cost of time lost on the job, and liability claims. This value has been estimated at $200,000 per individual for this analysis.

The following table summarizes averted fatality and serious injury benefits:

Type of Aircraft	Passengers + Crew	Fatality Benefit Per Approach	Injury Benefit Per Approach
Single engine turbine	2.3+1	$24.75	$8.25
Light twin turbine	2.6+2	$ 8.63	$2.88
Medium twin turbine	5.5+2	$ 7.03	$2.34
Heavy turbine	10.8+2	$12.00	$4.00
Very heavy turbine	26.4+3	$27.56	$9.19

Combining damage benefits, fatality benefits, and injury benefits the following safety benefits are obtained:

Type of Aircraft	Safety Benefit per IFR Approach
Single engine turbine	$49
Light twin turbine	$20
Medium twin turbine	$16
Heavy turbine	$36
Very heavy turbine	$81

A forecast of rotorcraft for the next 20 years suggests that a reasonable breakdown by aircraft type is:

Type of Aircraft	Percent of Turbine Aircraft
Single engine turbine	70%
Light twin turbine	17%
Medium twin turbine	9%
Heavy turbine	3.5%
Very heavy turbine	.5%

Applying these weighting factors, and assuming each aircraft type flies the same number of approaches, the following safety benefit value is obtained:

Overall safety benefit per approach - $41

6.3.2 Efficiency Benefits

Efficiency benefits are derived from the ability to operate to lower approach minimums through the use of MLS procedures. Because the aircraft can operate to lower minimums, some flight disruptions such as delays, cancellations, overflights, and diversions are averted. These disruptions affect passengers, aircraft operating time and passenger handling costs.

A detailed explanation of the accumulation of disruption costs is contained in Appendix A. The data from the four disruption categories was combined in a weighted average utilizing the following disruption schedule:

delay	70%
cancellation	20%
diversion	5%
overflight	5%

In summary the following costs per flight disruption were obtained

Operational Area	Cost Per Disruption
City center	$290
Major hub airport	$350
Non hub airport	$240
Remote area	$190
Offshore	$210

6.4 HELICOPTER OPERATIONS FORECAST

The purpose of the helicopter operations forecast is to determine the number of approaches that receive the safety and efficiency benefits. A schematic represenation of the procedure followed in ILS establishment criteria (Reference 4) is shown in Figure 6.2. Generally, runways that are candidates for ILS equipment have existing non-precision approach procedures, or the airport has other existing ILS facilities. In both cases the airport has a history of instrument approach procedure demand. As a result, the statistic that describes this demand, annual instrument approaches (AIA), is a major input to the establishment of new ILS facilities.

In this section the procedure that is applied to ILS establishment criteria is discussed. Most of the parameters that apply to the ILS criteria can be utilized in the MLS criteria for helicopters. The one parameter that causes some concern in the helicopter analysis is the count of annual instrument approaches flown to a helicopter landing area.

At many helicopter landing areas that could be considered candidates for MLS establishment there is no history, or only limited history, of

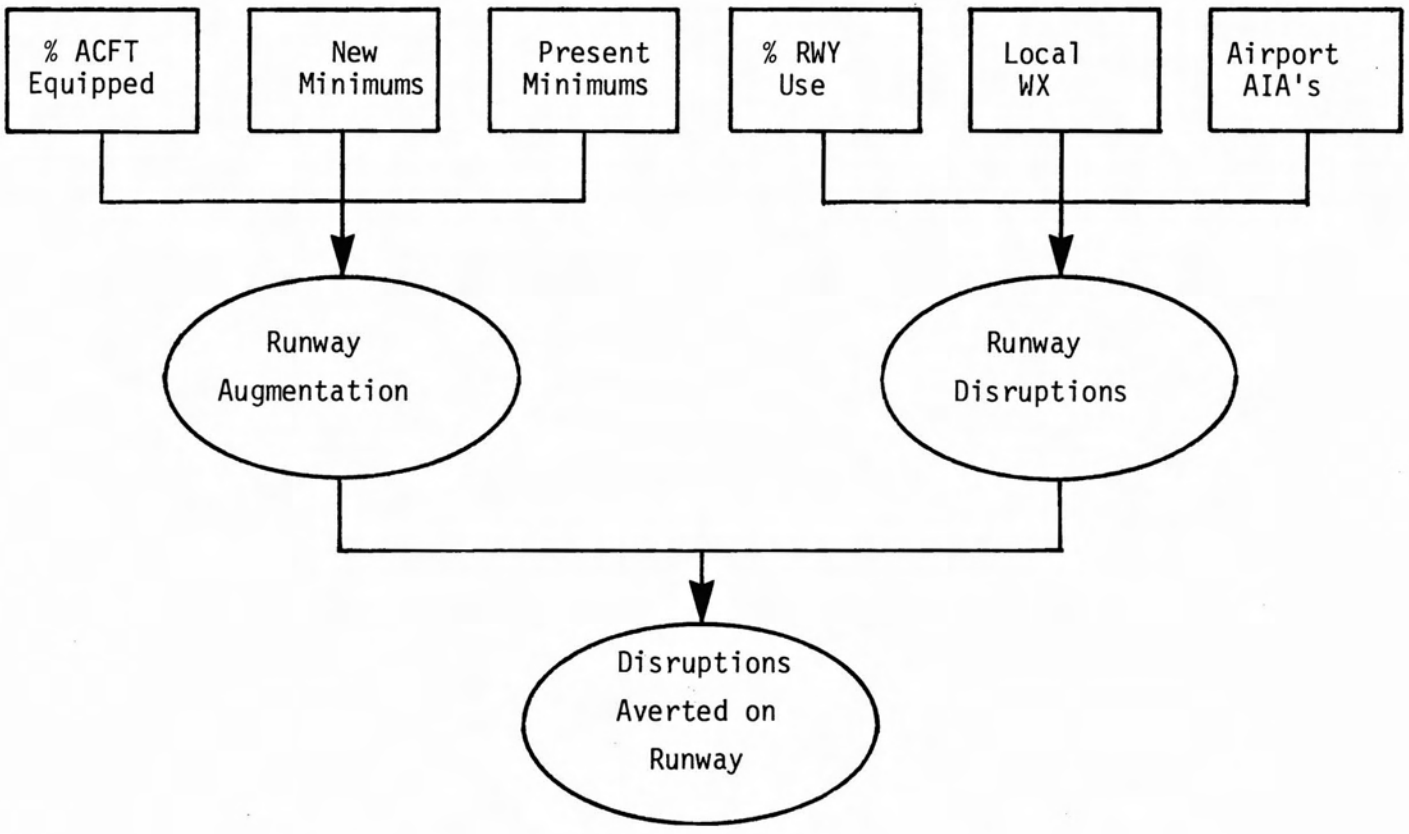


Figure 6.2 Parameters to Forecast Averted Disruptions

AIA activity. Therefore an alternative statistic or approach had to be developed. Two alternative methods were developed. The first method utilizes annual itinerant operations as a substitute statistic for the AIA. The second method produces, as an output, the required AIA demand to achieve a specified benefit or benefit/cost ratio. Both methods are developed in this section. The first method was applied to the case of the New York Manhattan heliports. The second method was used to produce two curves for general application. The first curve presents benefits versus AIA demand; the second curve presents benefit/cost ratio versus AIA demand.

6.4.1 ILS Establishment Criteria Benefits

The following parameters are used in developing forecasts of IFR approaches that will benefit from ILS establishment:

AIA	- The count of current annual instrument appraoches for the airport under study
INC	- The percentage increase in IFR approaches that will occur with ILS in place and operating
RWUSE	- Runway use factor; a percentage that the runway will be used if an ILS is established
EQPT	- Percent of aircraft using the airport having ILS receiving equipment
SAFBEN	- Safety benefit per IFR approach developed in Section 6.2
DISBEN	- Averted disruption benefits per IFR approach developed in Section 6.3.
DISCNT	- Annual discount factor for benefits and costs incurred in future years
GROWTH	- Percent growth factor to account for increases (or decreases) in operations in future years.

These eight parameters form the basis for computing annual benefits for the establishment of ILS facilities at airports. The following paragraphs describe how these parameters are combined to produce benefit values.

Safety benefits are assumed to apply to all IFR approaches to the runway under consideration. This includes current AIAs as well as these resulting from averted disruptions. The total 25 year safety benefit is BNFTS, and is computed from the following summation formula:

$$BNFTS = \sum_{N-1}^{25\ Years} AIA \cdot RWUSE \cdot EQPT \cdot GROWTH \cdot DISCNT \cdot (1+INC) \cdot SAFBEN$$

Efficiency benefits apply only to flights that were able to be completed because the ILS is in place. This is also called an averted

flight disruption benefit. The total 25 years efficiency benefit is computed from the following summation formula:

$$BNFTE = \sum_{N=1}^{25\ Years} AIA \cdot RWUSE \cdot EQUPT \cdot GROWTH \cdot DISCNT \cdot INC \cdot DISBEN$$

These benefits can be combined to produce the overall 25 year benefit for establishing an ILS facility. This formula is:

$$BENFIT = \sum_{N=1}^{25\ Years} AIA \cdot RWUSE \cdot EQPT \cdot GROWTH \cdot DISCNT \cdot \left[(1+INC) \cdot SAFBEN + INC \cdot DISBEN\right]$$

(Equation 6.1)

6.4.2 Helicopter MLS Benefits

In this section the parameters described for the ILS establishment criteria are discussed in terms of their application to helicopter MLS operations. As a first step, the dependence upon the AIA statistic and the IFR increase factor, INC, was modified through the following considerations.

6.4.2.1 Helicopter MLS Instrument Approaches

First, it is assumed that current helicopter IFR operations are sufficiently small that current helicopter AIA statistics are not valid indications of future helicopter IFR demand. The AIA term will be deleted and in its place will be used the expression

AITO - Annual itinerant operations

In general AITO will be an independent variable which is used to plot curves of benefit/cost ratio versus AITO and benefit versus AITO. In specific cases where helicopter operations statistics are available, such as the New York Mahattan Heliports, the value of ATIO is used to calulate benefit values and benefit/cost ratios. In other areas, AITO is used parametrically.

Current itinerant helicopter operations are assumed to occur in visual meterological conditions (VMC). For helicopters this is assumed to occur when ceilings exceed 1000 ft and visibilities exceed 1.5 miles. From Table 6.5, which is an average of observations at 32 airports for the years 1949-1958, these conditions occur for all but 8.05% of the year. The demand for approaches, assuming weather is no factor, is therefore

$$AITAD = \frac{AITO}{2} \quad \frac{1}{(1-.0805)} = .5438 \cdot AITO$$

where

AITAD = Annual itinerant approach demand
AITO = Annual itinerant operations

Table 6.5 Percentage Distributions of Weather Observations Equal to or Less Than Selected Ceilings and/or Visibilities

Ceiling (Feet)	Visibility (Miles) 1/2 %	3/4 %	1 %	1-1/2 %	3 %
200	1.12	1.52	2.01	3.13	7.10
300	1.48	1.79	2.21	3.25	7.13
400	2.14	2.37	2.73	3.64	7.29
500	2.88	3.08	3.38	4.20	7.60
600	3.67	3.84	4.09	4.81	7.99
700	4.57	4.72	4.95	5.60	8.57
800	5.47	5.61	5.81	6.40	9.15
1,000	7.24	7.36	7.54	8.05	10.48
1,500	10.80	10.91	11.05	11.45	13.48

Of this demand 91.95% is satisfied during VMC leaving 8.05% to be satisfied by MLS approaches or not satisfied at all.

MLS Straight In Approach

Assuming MLS straight in minimums of 200 ft and 1/2 mile the following percentage of approaches can be aided by MLS:

Percent of time weather less than VMC	→	8.05%
Percent of time weather less than MLS	→	1.12%
Percent of time MLS is effective	→	6.93%

Applying this factor to the approach demand yields

HMIAD = .0377 x AITO

where HMIAD - helicopter MLS approach demand

MLS Point in Space Approach

Assuming MLS point in space minimums of 300 ft and 3/4 mile the following percentage of approaches can be aided by MLS:

Percent of time weather less than VMC	8.05%
Percent of time weather less than MLS	1.79%
Percent of time MLS is effective	6.26%

Applying this factor to the approach demand yields

HMIAD = .0340·AITO

The parameter HMIAD, the helicopter MLS instrument approach demand, must be further modified by three other parameters to obtain the actual count of aircraft utilizing the approach procedure under consideration. These parameters are called

HADUSE - helicopter approach direction use
EQPT - the rate of equippage of MLS receiving equipment
GROWTH - growth in the number of operations at a helicopter landing area

These parameters are further discussed and quantified in the adjoining section.

6.4.2.2 Helicopter Approach Parameters

Several of the parameters discussed in Section 6.4.1 have application to helicopter MLS benefit computation. These parameters will be discussed in a helicopter MLS context in this section.

RWUSE/HADUSE

In ILS establishment criteria, this factor is the percent for use that the runway under consideration receives. Typically, for the first ILS runway at an airport, this factor is 60%; for the second runway, 30%; and for the third, 10%. These factors can be adjusted for local wind and weather conditions and runway directions as deemed appropriate.

For helicopter MLS approaches a similar factor named

HADUSE - helicopter approach direction use

is used. It would appear that a reasonable breakdown for approach directions is similar to the ILS criteria. Therefore a 60% value was assigned to HADUSE for these studies.

EQPT

EQPT is the equipage rate for airborne equipment, which in this case is MLS receivers and corresponding guidance equipment. Obviously, for MLS these figures can only be estimates. These figures were broken down by helicopter category and the following values applied:

single engine turbine	-	15% initially with 5% per year growth rate to 50% and constant thereafter
light twin turbine	-	25% initially with 5% per year growth rate to 80% and constant thereafter
Medium, heavy and very heavy turbine	-	50% initially with 5% per year growth rate to 100% and constant thereafter

These equippage rates are shown in Figure 6.3 for the 15 year period considered.

DISCNT

DISCNT is the discount factor applied to each future years benefits. Consistent with current federal policy a 10% discount rate was utilized. The discount factor for year N is

$$\text{DISCNT} = \frac{1}{(1+10\%)^N} = (1.1)^{-N}$$

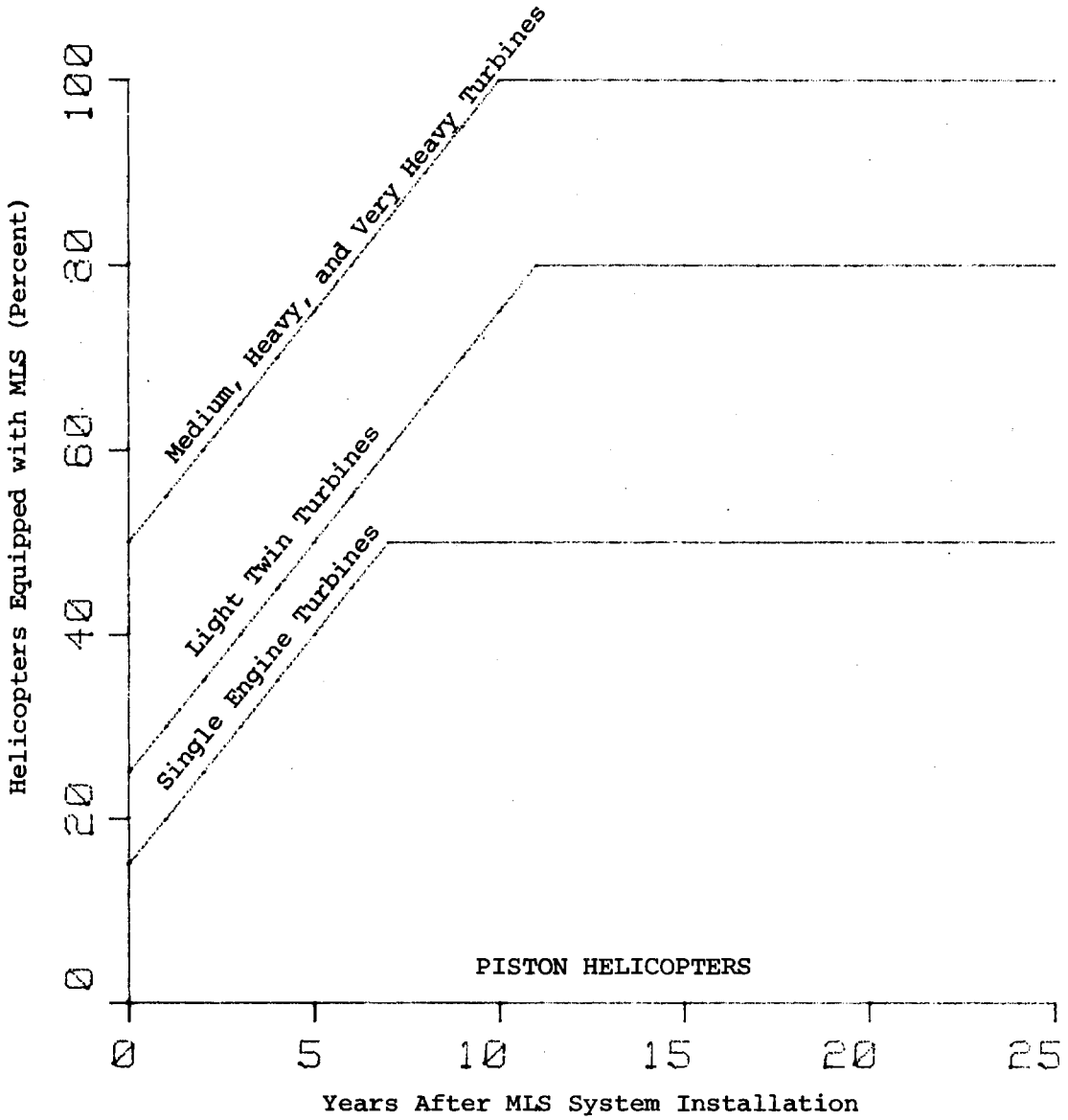


Figure 6.3 Estimated MLS Equippage Rates

GROWTH

GROWTH is the growth factor applied to future years' operations. Reference 18 presents a linear growth rate for turbine helicopters of about 300 helicopters per year beginning with approximately 2,900 helicopters in 1981. Operations are assumed to grow in the same proportion. The growth factor for year N is therefore

$$GROWTH = 1 + .1034 \cdot N$$

SAFBEN

SAFBEN is the safety benefit which applies to each IFR approach. Under the assumptions described at the beginning of this section the demand for MLS helicopter approaches is called HMIAD. In order to determine the number of MLS approaches this parameter must be augmented by the equippage rate, EQPT, the approach direction use factor, HADUSE, and the growth factor, GROWTH. Therefore, the number of MLS approaches by helicopters at a helicopter landing area is:

$$HMIA = HMIAD \cdot HADUSE \cdot EQPT \cdot GROWTH$$

Discounted safety benefits BNFTS for the 25 year period are

$$BNFTS = \sum_{N=1}^{25\ Years} HMIA \cdot DISCNT \cdot SAFBEN$$

or

$$BNFTS = \sum_{N=1}^{25\ Years} HMIAD \cdot HADUSE \cdot EQPT \cdot GROWTH \cdot DISCNT \cdot SAFBEN$$

DISBEN

DISBEN is the efficiency benefit obtained per averted flight disruption. Therefore, it also must be multiplied by HMIA to obtain an annual benefit and discounted for present value purposes. Therefore, the discounted efficiency benefit BNFTE is

$$BNFTE = \sum_{N=1}^{25\ Years} HMIAD \cdot HADUSE \cdot EQPT \cdot GROWTH \cdot DISCNT \cdot DISBEN$$

In the analyses the terms HMIAD, HADUSE, DISBEN and SAFBEN are considered constant. Therefore the total MLS benefit for helicopters BENFIT can be written

$$BENFIT = HMIAD \cdot HADUSE \cdot (DISBEN+SAFBEN) \cdot \sum_{N-1}^{25\ Years} EQPT \cdot GROWTH \cdot DISCNT \qquad \text{(Equation 6.2)}$$

The summation terms were evaluated for each of the helicopter categories as a multiplier value. The results of this evaluation is

Helicopter type	Multiplier
Single engine turbine	7.14
Light twin turbine	10.50
Medium twin turbine	14.40
Heavy turbine	14.40
Very heavy turbine	14.40

6.5 MLS HELICOPTER BENEFITS

The benefit formula, Equation 6.2, was evaluated using the parameter values contained in Section 6.4.2.2.

Utilizing the following weighting factors for the various types of aircraft the ratio of BENFIT/HMIAD, benefit to helicopter MLS instrument approach demand ratio, was calculated for each of the five helicopter operational areas. The results are shown in Table 6.6.

Aircraft Type	Present
Single engine turbine	70%
Light twin turbine	17%
Medium twin turbine	9%
Heavy turbine	3.5%
Very heavy turbine	0.5%

Table 6.6 Benefit to Helicopter MLS Instrument Approach Demand Ratio

OPERATIONAL AREA	BENFIT / HMIAD
City center	$1921
Major hub airport	$2326
Non-hub airport	$1621
Remote area	$1338
Offshore	$1423

These ratio values were related to AITO, annual itinerant operations, through the relationships developed in Section 6.4.2.1. These relationships are

MLS straight in approach

$$HMIAD = .0377 \cdot AITO$$

MLS point in space approach

$$HMIAD - .0340 \cdot AITO$$

The resulting benefit to itinerant operation ratio values, BENFIT/AITO, are shown in Table 6.7.

Table 6.7 Benefit to Annual Helicopter Itinerant Operations Ratios

Operational Area	BENFIT/AITO	
	MLS Straight In	MLS Point in Space
City center	$72	$65
Major hub airport	$88	$79
Non-hub airport	$61	$55
Remote area	$50	$45
Offshore	$54	$48

6.6 SENSITIVITY OF MLS HELICOPTER BENEFITS

A brief analysis of the sensitivity of benefits to certain parameters used in the analysis was performed to evaluate the effect of changing parameter values. From the analysis the following effects were noted:

Parameter	Change in Parameter	Change in Benefit
Direct Operating Cost	10%	1% to 4%*
Safety Benefits	10%	1% to 4%*
Passenger Time Value	10%	3% to 7%*
VFR/HSVFR Minimums	1000-1½ to 700-1½	-38% to -42%**
	1000-1½ to 500-1	-69% to -76%**

*Variation depands upon the operational area
**Variation depends upon straight in or point in space approach procedures

Obviously the greatest impact concerns the minimums to which VFR or HSVFR operations can be flown. These minimums have a very strong influence on the demand for MLS services.

Table 6.8 was prepared to demonstrate this dramatic reduction in benefits as VFR/HSVER minimums are reduced. This same effect occurs if alternative non-precision approach (NPA) procedures to the stated HSVFR minimums are available.

Table 6.8 Helicopter MLS Benefit per Annual Itinerant Operation versus HSVFR or Non-Precision Approach Minimums

OPERATIONAL AREA	Straight In Approach (200-½)			Point in Space Approach (300-3/4)		
	HSVFR or NPA Minimums			HSVFR or NPA Minimums		
	1000-1½	700-1½	500-1	1000-1½	700-1½	500-1
City center	$72	$46	$22	$65	$39	$16
Major hub airport	$88	$55	$27	$79	$47	$19
Non-hub airport	$61	$38	$19	$55	$33	$13
Remote area	$50	$31	$16	$45	$27	$11
Offshore	$54	$34	$17	$48	$29	$12

NOTE: Minimums are interpreted as ceiling (ft) - visibility (miles)

6.7 BENEFIT/COST ANALYSIS FOR NEW YORK MANHATTAN HELIPORTS

One approach procedure that could be applied to the heliports around Manhattan Island is the MLS point in space procedure described in Section 5.3.1. In this section an analysis of the costs and benefits of providing such a service is considered.

In the year 1980 there were approximately 100,000 operations to the three Manhattan heliports. Applying this value to the city center operations data from Table 6.7 produces the following benefit estimates:

Assumed HSVFR Minimums	Benefit Estimate	Benefit/Cost Ratio*
1000 ft - 1½ mile	$6,500,000	9.0
700 ft - 1½ mile	$3,900,000	5.4
500 ft - 1 mile	$1,600,000	2.2

*Based on the use of a Small Community MLS

The installation of a small community MLS system at a location, such as Governor's Island, where it can be used for a point in space approach to all Manhattan heliports, produces a benefit/cost ratio greater than one in all cases. Therefore such an installation should return greater benefits than the system costs to purchase and install. The effect of assumed HSVFR minimums strongly affects the ratio however. At least one operator in the area is known to operate to the 500 ft - 1 mile minimum using HFVFR procedures. Other operators undoubtedly utilize different minimums by regulation or by choice.

6.8 HELICOPTER MLS BENEFIT AND BENEFIT/COST CURVES

Curves of helicopter MLS benefit and benefit/cost ratios have been prepared for application to airports, heliports and helicopter landing areas in general. The independent variable in each case is average daily itinerant operations. Separate curves have been prepared for each

operational area. The benefit curves are presented in Figures 6.4, 6.6, 6.8, 6.10 and 6.12. The benefit/cost ratio curves are presented in Figures 6.5, 6.7, 6.9, 6.11 and 6.13. For purposes of the benefit/cost ratio curves the following MLS ground systems are assumed:

Operational Area	MLS Ground System
City center	Small Community MLS
Major hub center	Basic I* MLS
Non-hub airport	Small Community MLS
Remote area	Small Community MLS
Offshore	Small Community MLS

*Note: At major hub airports it is anticipated that the first Basic I systems accommodate GA and Air Taxi operations. Later these systems will be upgraded to Basic II or expanded systems.

6.9 ALTERNATIVE APPROACH PROCEDURES

6.9.1 Onshore Approaches

In some locations it may be possible to achieve approach minimums that come near MLS minimums with alternative navaids. A recent study (Reference 5) considered several approach procedures that were designed specifically for helicopters. The results of that study showed non-precision approach minimums for onshore locations in the following range:

Ceilings

Approach Type	Sample Size	Average HAT	Minimum HAT	Maximum HAT
NDB/DME	1	348	-	-
VOR/DME	10	352	290	520
RNAV (Point in Space)	10	502	300	620
VOR/DME ARC	1	515	-	-
RNAV	9	560	411	768

Note: HAT is height above threshold

Visibility

1/2 mile - 14 approaches
3/4 mile - 17 approaches

With non-precision approach minimums on the order of 400 ft and 3/4 mile approximately 97.63% of the approaches can be successfully flown with properly equipped aircraft. For MLS straight in approaches an additional 1.25% approaches can be successfully completed. These figures produce the following MLS benefits per annual itinerant operation ratio:

Operational Area	Benefit per Annual Itinerant Operation Ratio
City center	$12.30
Major hub airport	$14.89
Non-hub airport	$10.38
Remote area	$ 8.57
Offshore	$ 9.11

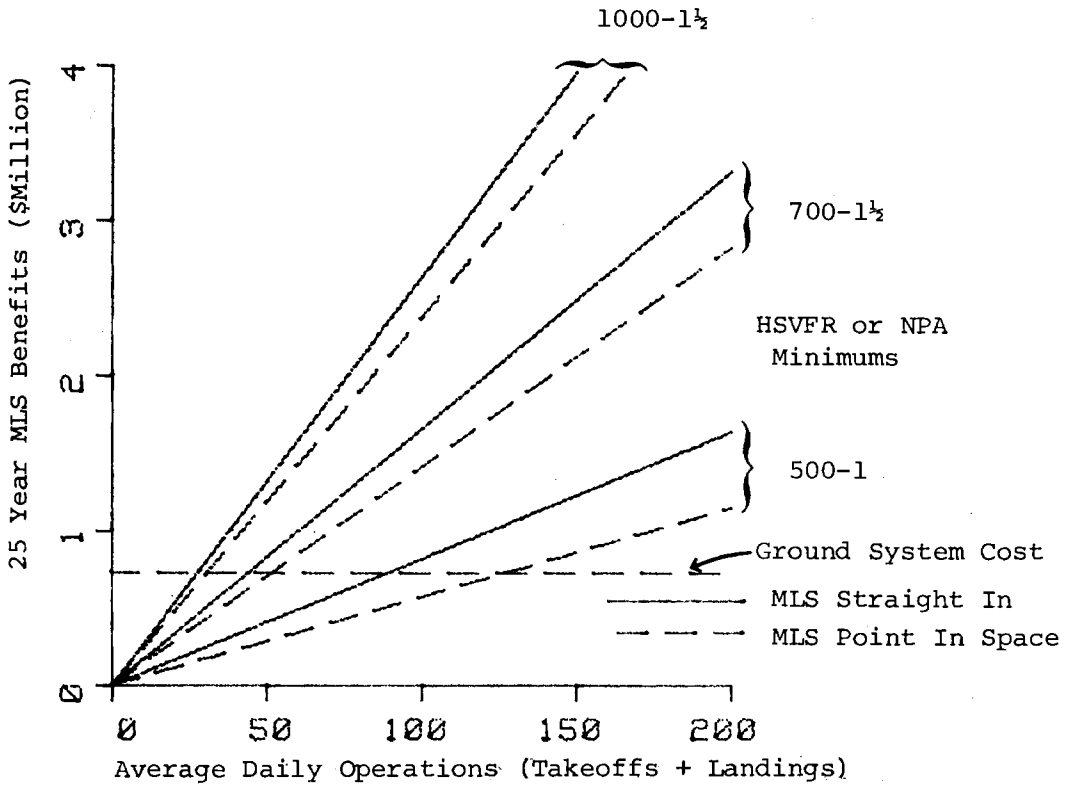


Figure 6.4 MLS Benefit for City Center Operations

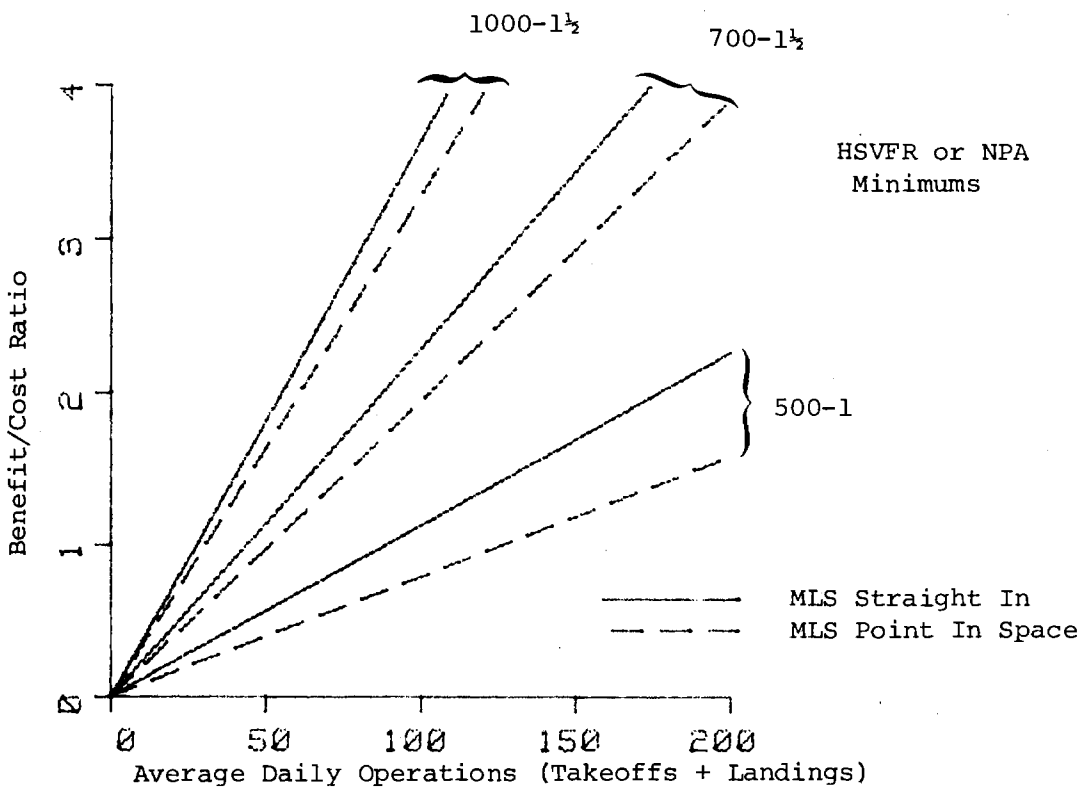


Figure 6.5 MLS Benefit/Cost Ratio for City Center Operations

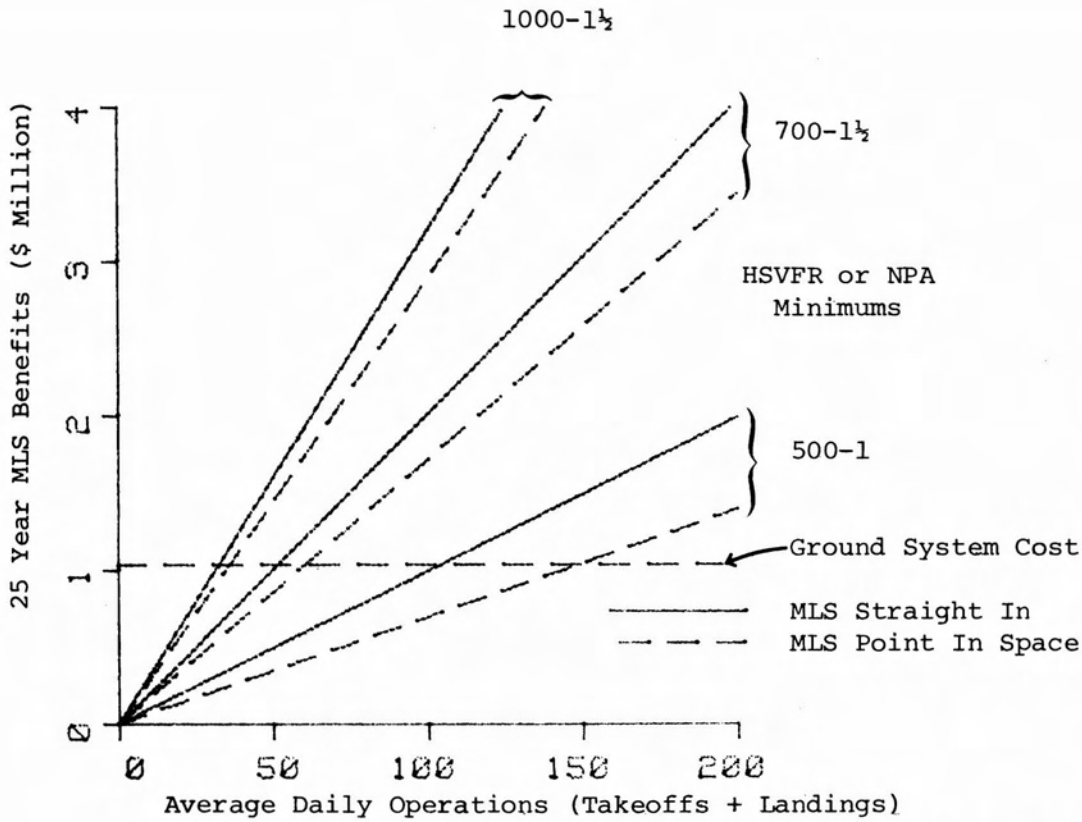


Figure 6.6 MLS Benefits for Major Hub Airport Operations

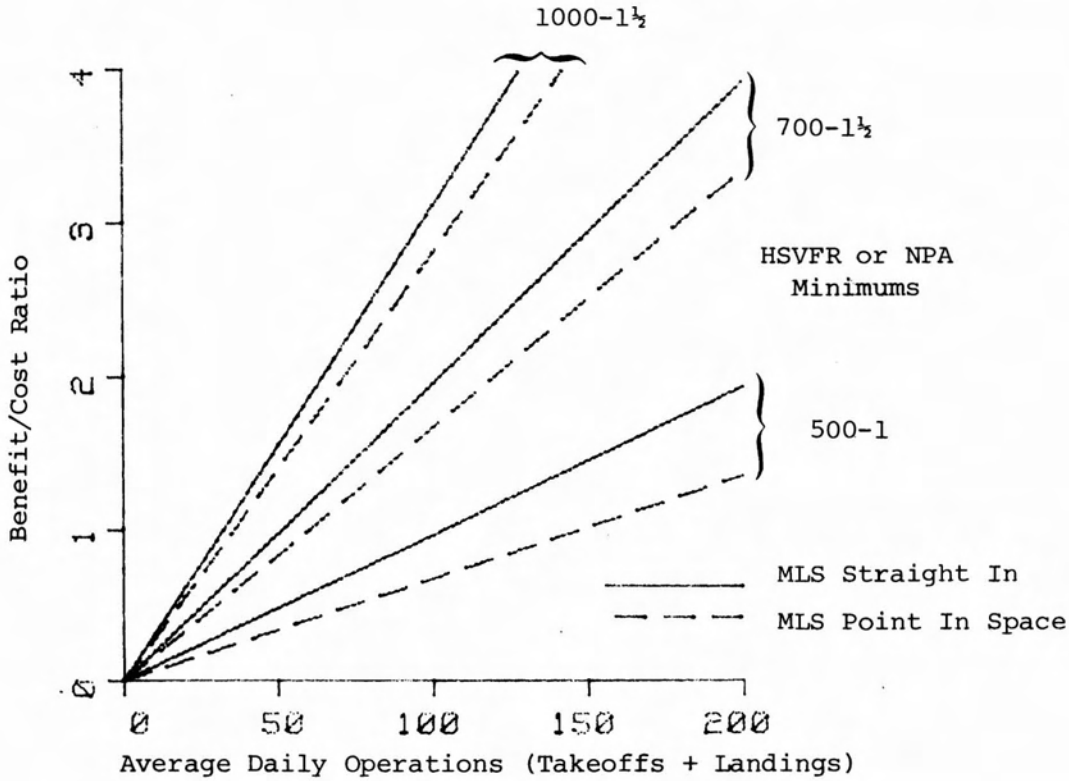


Figure 6.7 MLS Benefit/Cost Ratio for Major Hub Airport Operations

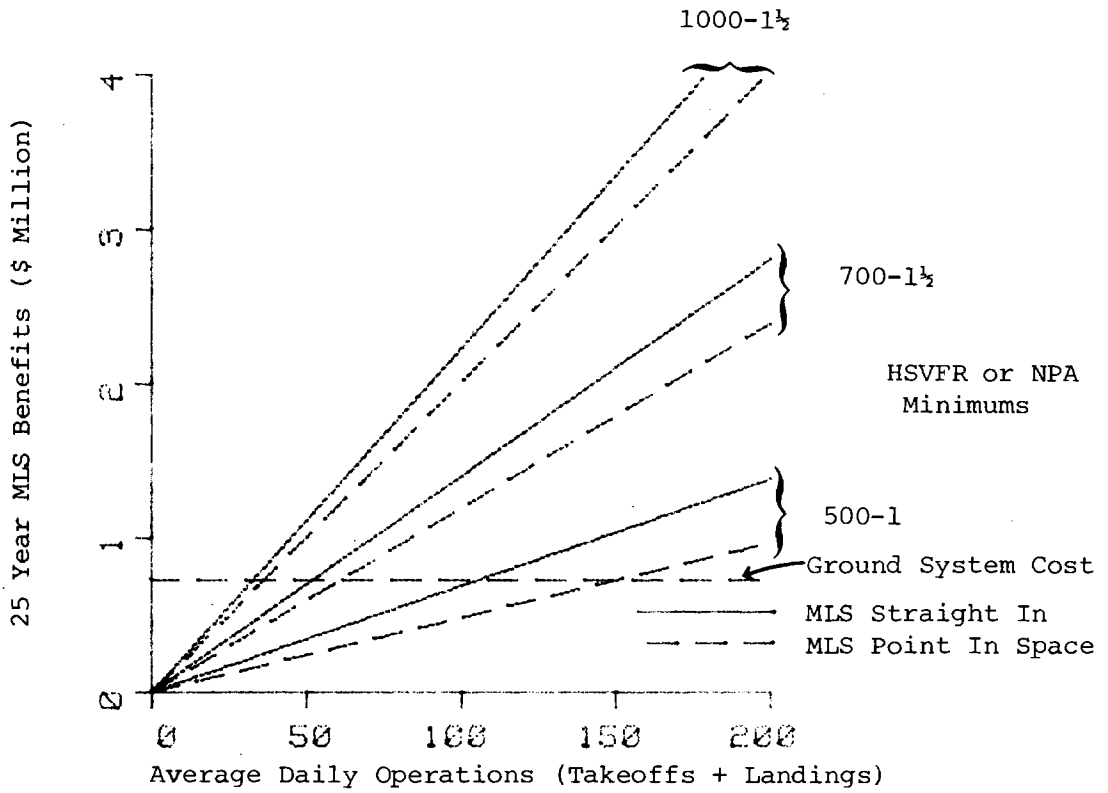


Figure 6.8 MLS Benefits for Non-Hub Airport Operations

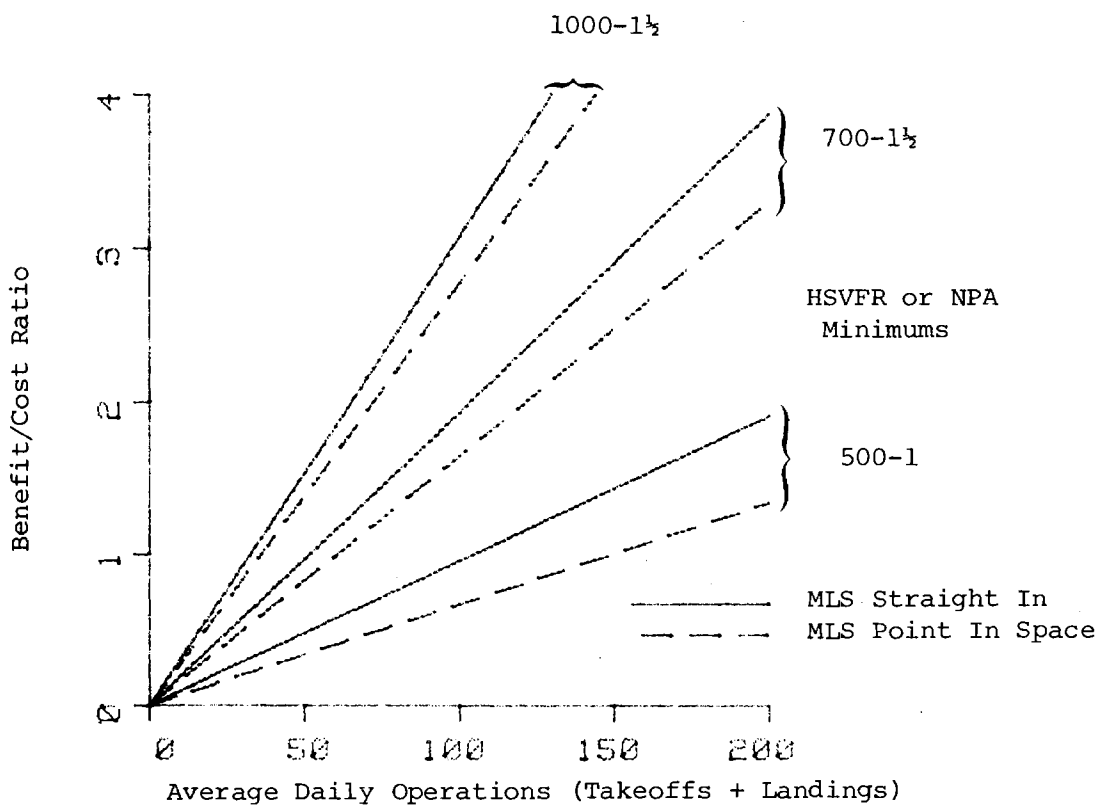


Figure 6.9 MLS Benefit/Cost Ratio for Non-Hub Airport Operations

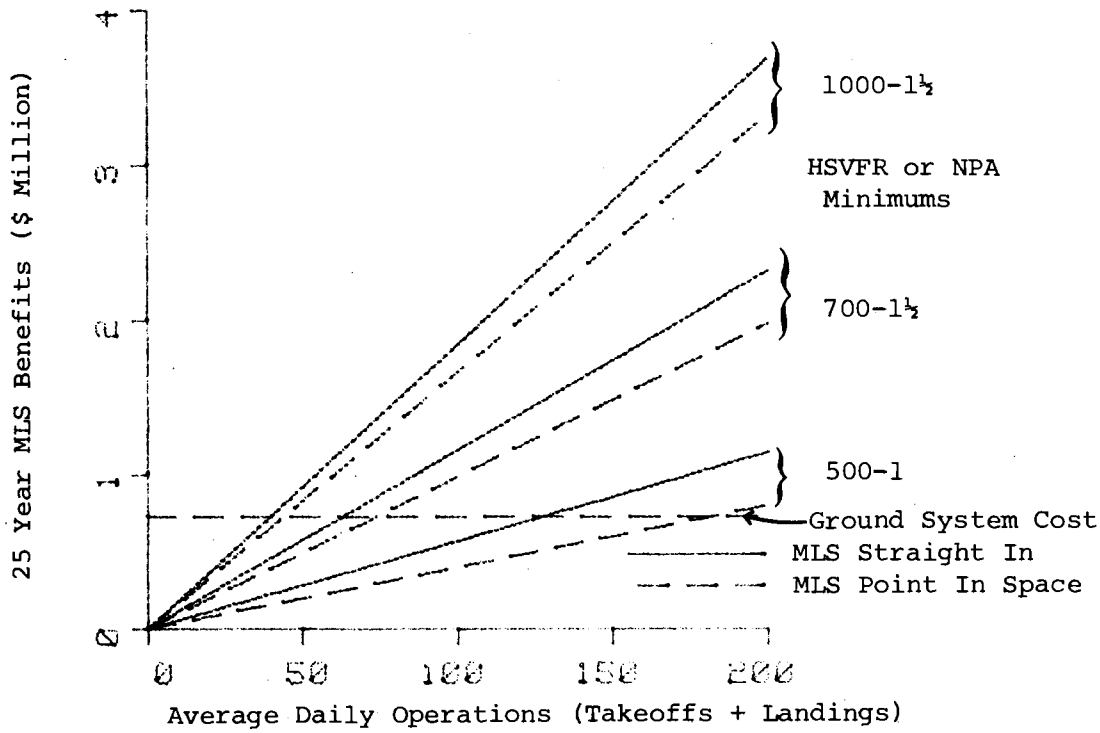


Figure 6.10 MLS Benefits for Remote Area Operations

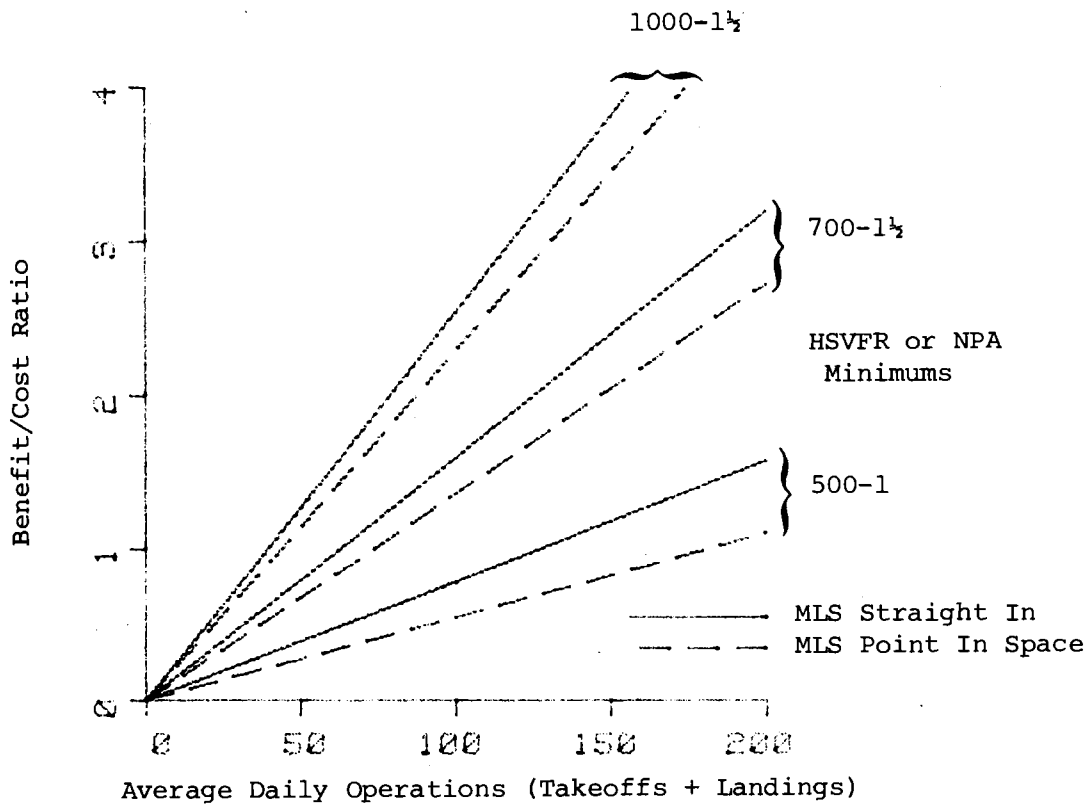


Figure 6.11 MLS Benefit/Cost Ratio for Remote Area Operations

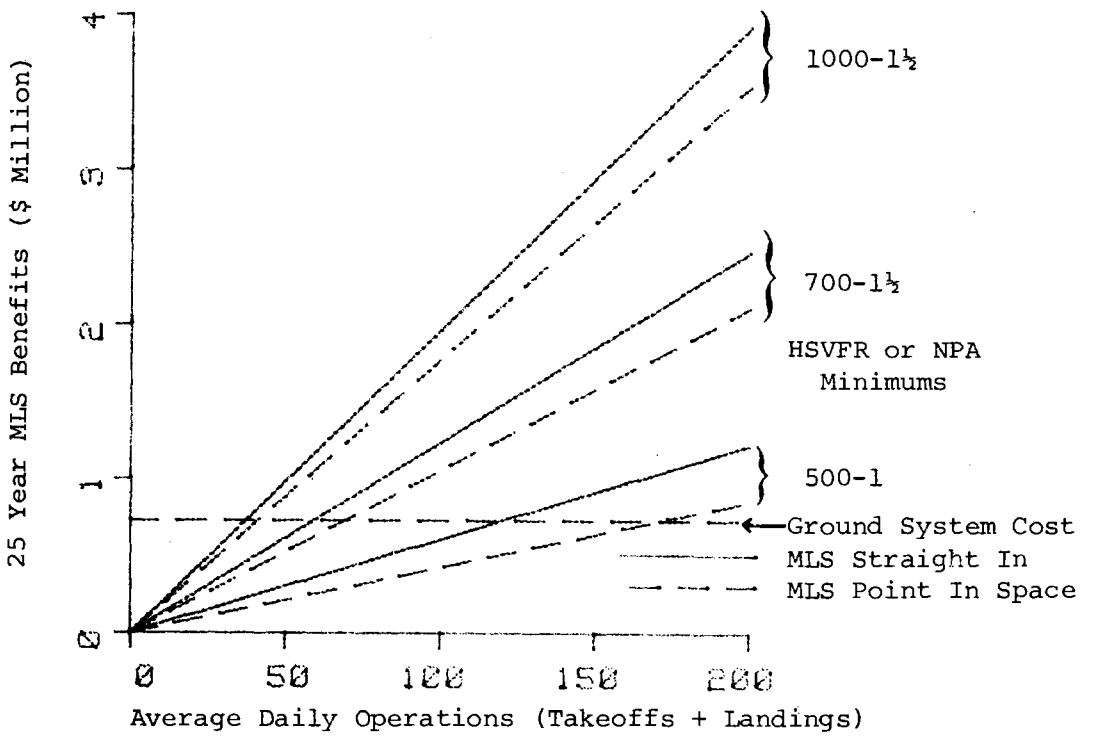


Figure 6.12 MLS Benefits for Offshore Operations

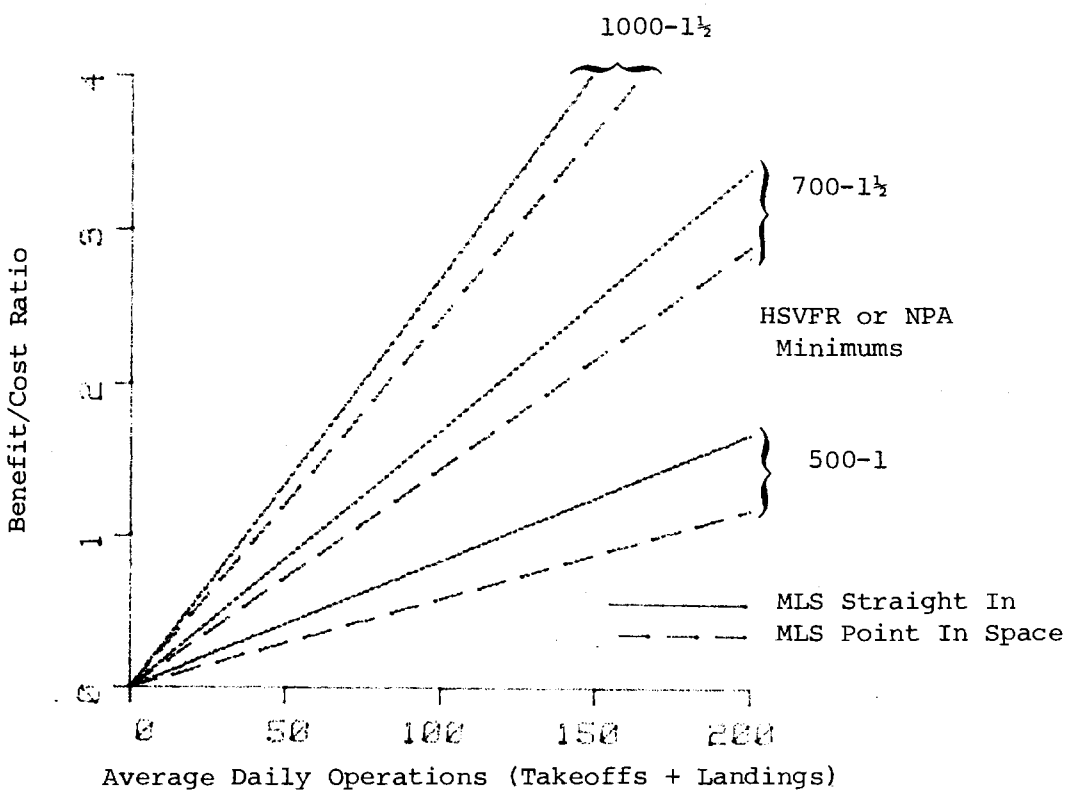


Figure 6.13 MLS Benefit/Cost Ratio for Offshore Operations

With this information it is possible to estimate the number of average daily approaches necessary to obtain a benefit/cost ratio of unity. These values are:

Operational Area	MLS Ground System	Annual Itinerant Operations	Average Daily Operations
City center	Small Community MLS	58,900	161
Major hub airport	Basic I MLS	69,100	189
Non hub airport	Small Community MLS	69,800	191
Remote area	Small Community MLS	84,600	232
Offshore	Small Community MLS	79,600	218

Under these conditions where alternative non-precision approach procedures are available it is unlikely, based on helicopter traffic alone, that MLS will have a benefit/cost ratio greater than unity in most locations.

In areas where no alternative approach procedures with reasonable minimums are available, or in areas where precision guidance is required, MLS can be supported by helicopter operations. For example Table 6.9 presents operations required to achieve a unity benefit cost ratio with alternate system minimums of 700-½ and 1000-1½. It can be observed that these operations counts are well within the achievable range at many heliports. Typically areas which would fit this category of approach are:

- mountainous areas
- city center areas with tall buildings and narrow corridors
- major hub airport areas where airspace is very limited
- remote heliports supporting active helicopter operations

Table 6.9 Operations Required to Produce Unity Benefit/Cost Ratio for Areas with High Alternative Approach Minimums

Operational Area	MLS Ground System	Annual Itinerant Operations		Average Daily Operations	
		1000-1½	700-1½	1000-1½	700-1½
City center	Small Community MLS	10,000	15,900	27	44
Major hub airport	Basic I MLS	11,700	18,700	32	51
Non-hub airport	Small Community MLS	11,900	18,900	33	52
Remote area	Small Community MLS	14,400	22,900	39	63
Offshore	Small Community MLS	13,500	21,500	37	59

6.9.2 Offshore Approaches

Reference 5 contains data on twenty-seven offshore approach procedures. Of these, twelve procedures used airborne radar and radar altimetry. These twelve approaches had the lowest minimum descent altitudes of all the procedures. The airborne radar permits identification of rigs and ships in the approach airspace, including the destination rig, and permits obstacle avoidance. The radar altimeter provides positive height-above-the-water indications rather than having to rely on barometric altimetry and corrections for local conditions.

Data from these offshore approaches are as follows:

Ceilings

Approach Type	No.	Average HAT	HAT MIN	HAT MAX
ARA-R-ALT	7	141 ft	107 ft	200 ft
TACAN/ARA	1	287	-	-
NDB/DME/ARA	4	344	327	369
TACAN	1	427	-	-
VOR/DME	5	463	406	485
NDB/DME	4	494	487	509
NDB	5	534	506	569

Visibilities

All 27 offshore procedures had visibility minimums of 0.5 mile.

Use of MLS without airborne radar would likely produce decision heights on the order of 400 to 500 ft above sea level to account for rig height, ship heights, and a buffer airspace of about 200 feet above these obstacles. As seen in Reference 5, use of airborne radar and radar altimetry can produce minimum heights above threshold levels of 100 to 200 ft and visibility minimums on the order of 0.5 mile.

Use of MLS for helicopter offshore approaches was discussed extensively in Reference 19. This report concluded, as did Reference 5, that MLS is of little economic benefit in the offshore environment.

There are potential technical problems in stabilizing an elevation antenna on a rolling, pitching, heaving platform. For this reason, even the potential operational advantage of having vertical guidance information available to the pilot may not be technically feasible. The one operational advantage to using MLS or MLS/RNAV is the availability of lateral course guidance throughout the approach. This benefit can only be measured in terms of pilot confidence in performing the procedure. This would not appear to have any substantial economic benefit. Therefore the use of MLS in the offshore environment for helicopter approaches is not recommended at this time.

6.10 USER RELATED COSTS

Up to this point in the helicopter MLS benefits analysis only user related benefits and ground system related costs have been considered.

Since implementation of MLS will require users to purchase airborne equipment, there are user costs to be considered. Initially, these costs will have to be offset by benefits attained by operating at one or more heliports or airports with MLS capability.

To consider user costs requires detailed knowledge of the number of MLS equipped aircraft operating to the heliport or airport under study and the average number of approaches flown by these aircraft. Since this information is not now available, an analysis was performed utilizing many of the assumptions used in the benefits analysis. Many of these assumptions can only be considered reasonable estimates of situations that will develop over the next several years. The results of the analysis should be considered in this context and not treated as definitive data concerning user related costs.

In the efficiency benefits analysis the average flight time was estimated for each operational area. These values can be used to estimate the number of annual landings made by these helicopters. Many of these landings will be made at landing areas that have MLS capability. For this analysis one approach in three is assumed to occur at the heliport under study. These assumptions are used to develop the number of MLS equipped aircraft that operate at the facility. The analysis proceeds as follows:

Operational Area	Assumed Flight Time	Landings per Hour	Landings per Hour at MLS Field	Assumed Flight Hours per Year	Annual Landings at MLS Field
City center	10 min	6	2	500	1000
Major hub airport	20 min	3	1	500	500
Non-hub airport	20 min	3	1	500	500
Remote area	20 min	3	1	500	500
Offshore	30 min	2	7	500	350

The number of landings per year at any airport can be calculated by dividing annual itinerant operations, AITO, by two. The number of aircraft operating at the field is then estimated by dividing by the annual landings at the MLS field per one aircraft. This produces the following aircraft estimates:

Operational Area	MLS Aircraft
City center	.0005·AITO
Major hub airport	.0010·AITO
Non-hub airport	.0010·AITO
Remote area	.0010·AITO
Offshore	.0015·AITO

Aircraft equipment costs can be calculated by applying the MLS airborne equipment costs developed in Section 6.2.2. The assignment of avionics systems to helicopter categories is shown in Table 6.10.

Table 6.10 MLS Avionics Systems Assignments in User Cost Analysis

Operational Area	Type of Aircraft				
	Single Engine Turbine	Light Twin Turbine	Medium Twin Turbine	Heavy Turbine	Very Heavy Turbine
City center	1	1	1	3	3
Major hub airport	2	2	2	4	4
Non-hub airport	1	1	1	3	3
Remote area	1	1	1	3	3
Offshore	1	1	1	3	3
Percentage of Aircraft	70.0%	17.0%	9.0%	3.5%	0.5%

System 1 - Low-performance GA MLS avionics
System 2 - Intermediate-performance GA MLS Avionics
System 3 - High-performance GA MLS avionics
System 4 - Integrated MLS/RNAV Avionics

The following user costs are obtained, both in terms of annual intinerant operations, AITO, and average daily operations, ADO.

Operational Area	Number of Aircraft	Weighted Cost per Aircraft	Total User Cost	Total User Cost
City center	.0005·AITO	$2327	1.16 AITO	425 ADO
Major hub airport	.0010·AITO	$3203	3.20 AITO	1170 ADO
Non-hub airport	.0010·AITO	$2327	2.33 AITO	850 ADO
Remote area	.0010·AITO	$2327	2.33 AITO	850 ADO
Offshore	.0015·AITO	$2327	3.49 AITO	1275 ADO

Note: AITO is annual itinerant operations, ADO is average daily operations

These costs are added to the ground station costs and benefit-cost curves and benefit/cost ratio curves are presented in Figure 6.14 through 6.23 for MLS straight in approach procedures.

6.11 SUMMARY OF BENEFIT AND COST ANALYSIS

In the onshore areas where alternative non-precision approach procedures can be flown to minimums of 500-1 and less, the cost of the MLS ground system will usually mean that costs will outweigh benefits except in areas with very high operations counts. For areas where non-precision approach minimums are on the order of 700-1½, benefits will begin to exceed costs with moderate operations counts (16,000 to 23,000 annual itinerant operations). Typically, areas which would be initial candidates for MLS installations would be:

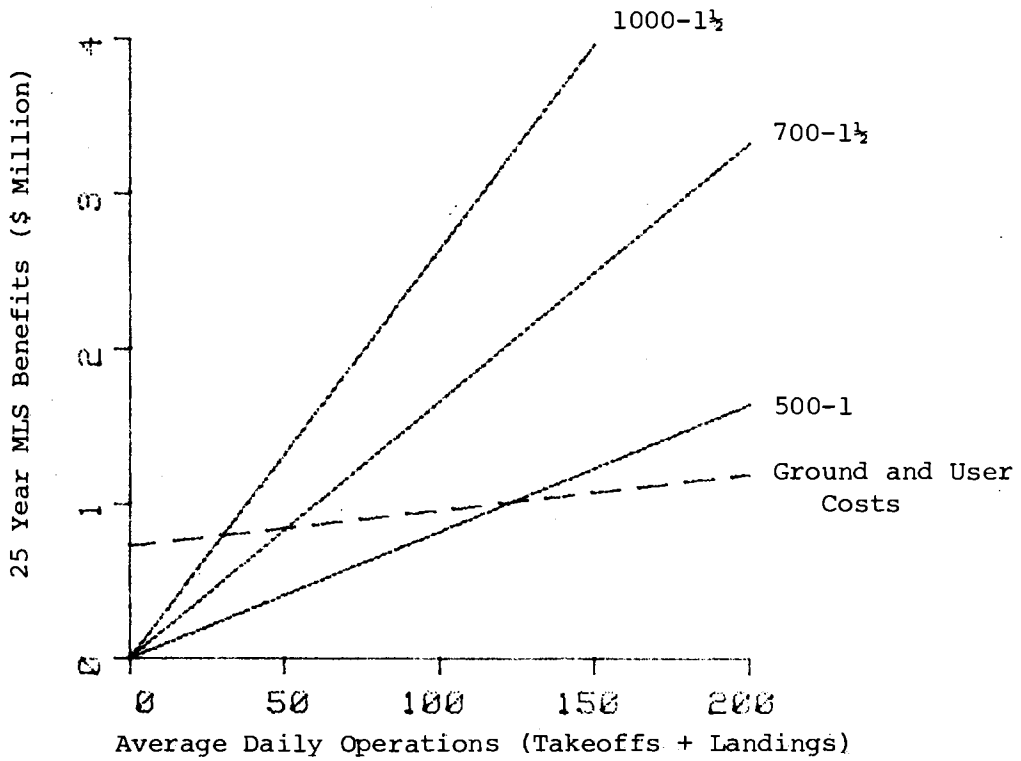


Figure 6.14 MLS Benefits and Costs for City Center Operations

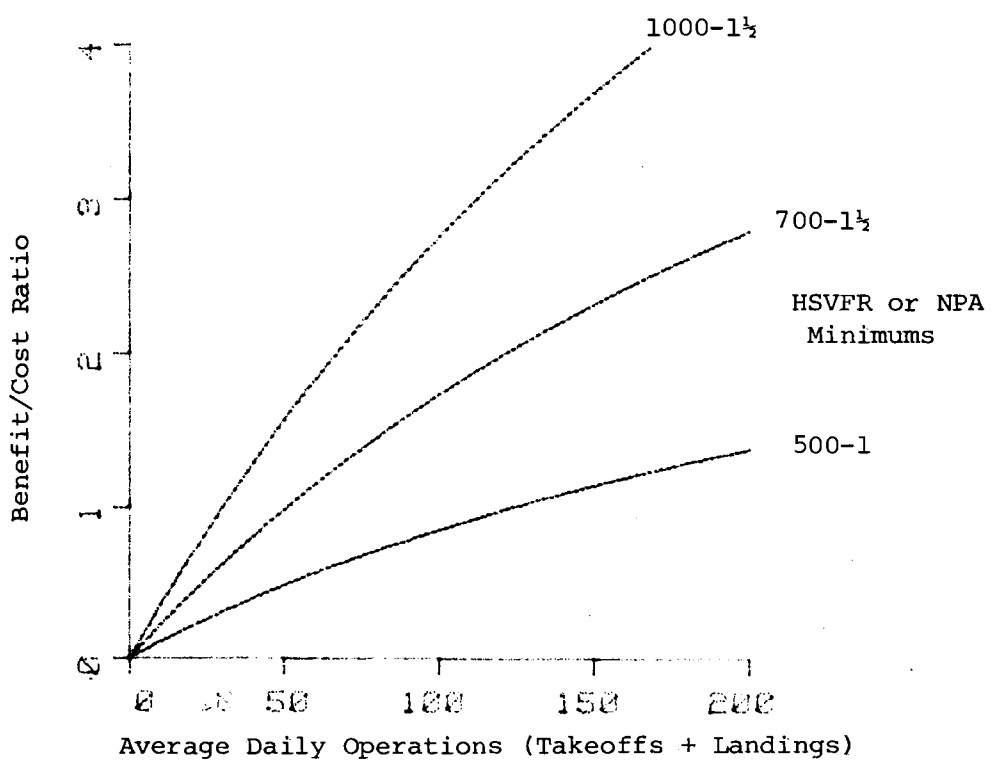


Figure 6.15 MLS Benefit/Total Cost Ratio for City Center Operations

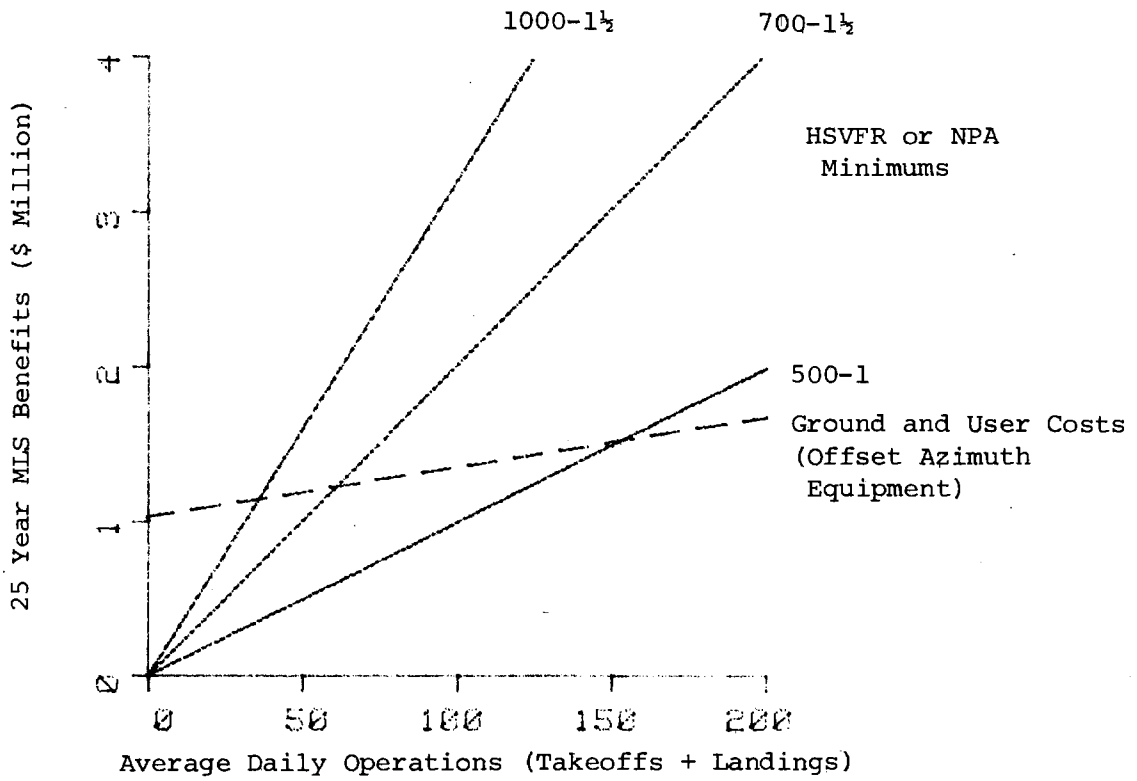


Figure 6.16 MLS Benefits and Costs for Major Hub Airport Operations

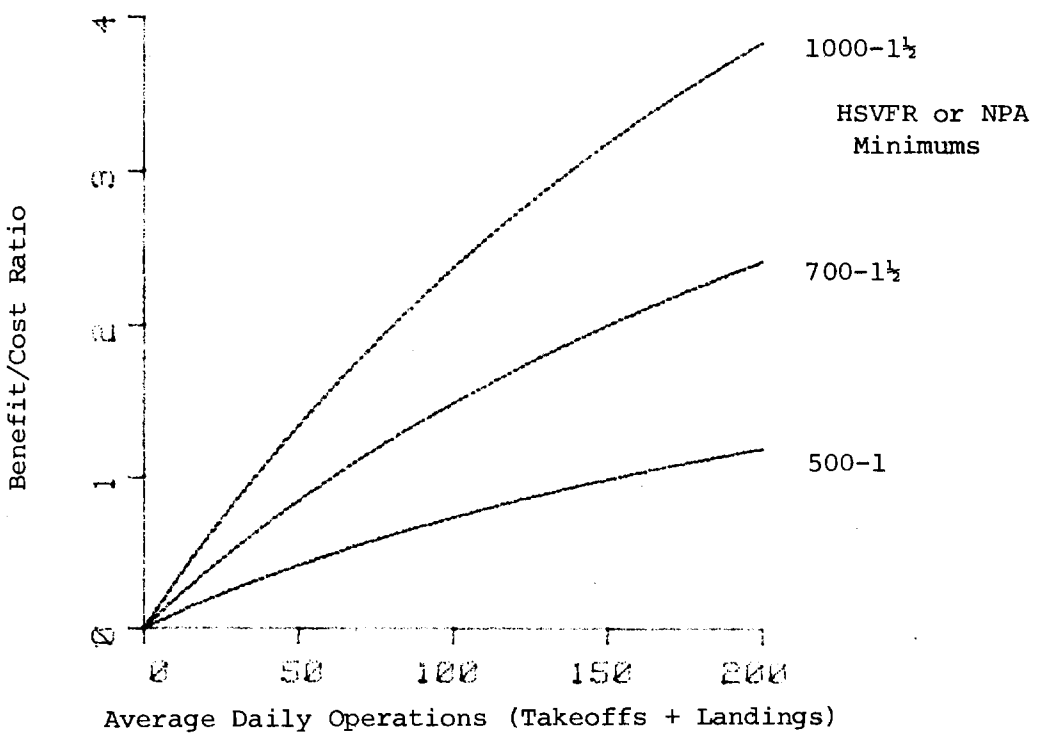


Figure 6.17 MLS Benefits/Total Cost Ratio for Major Hub Airport Operations

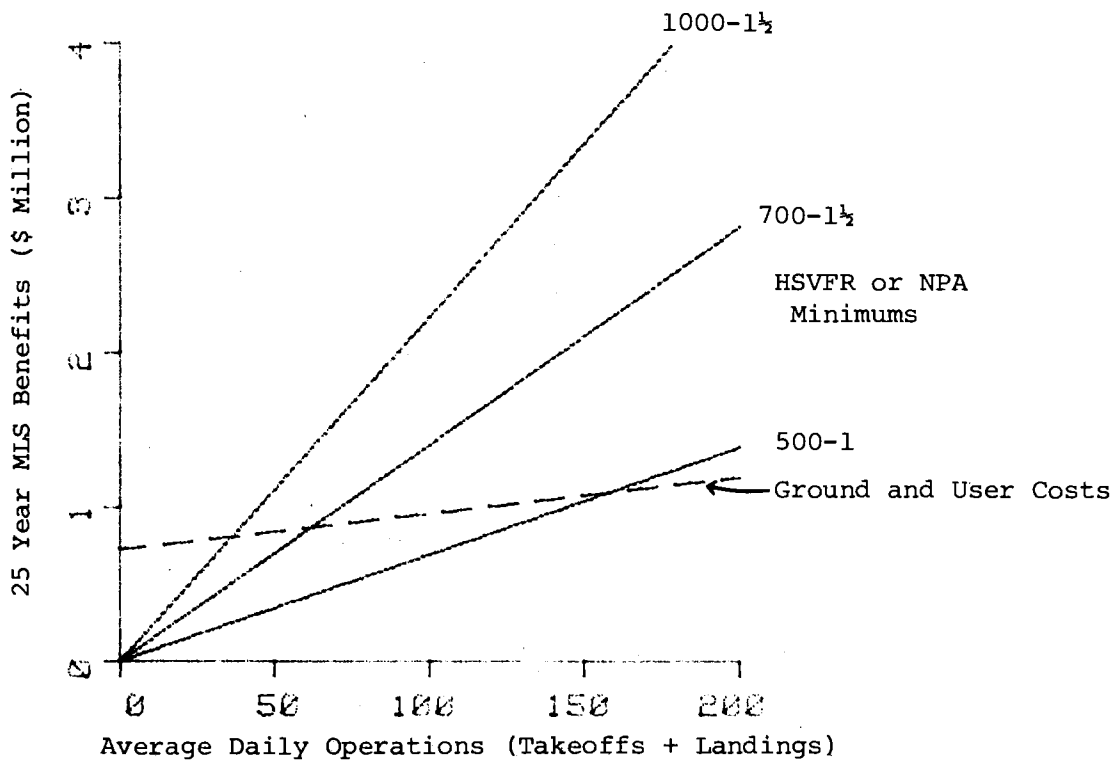


Figure 6.18 MLS Benefits and Costs for Non Hub Airport Operations

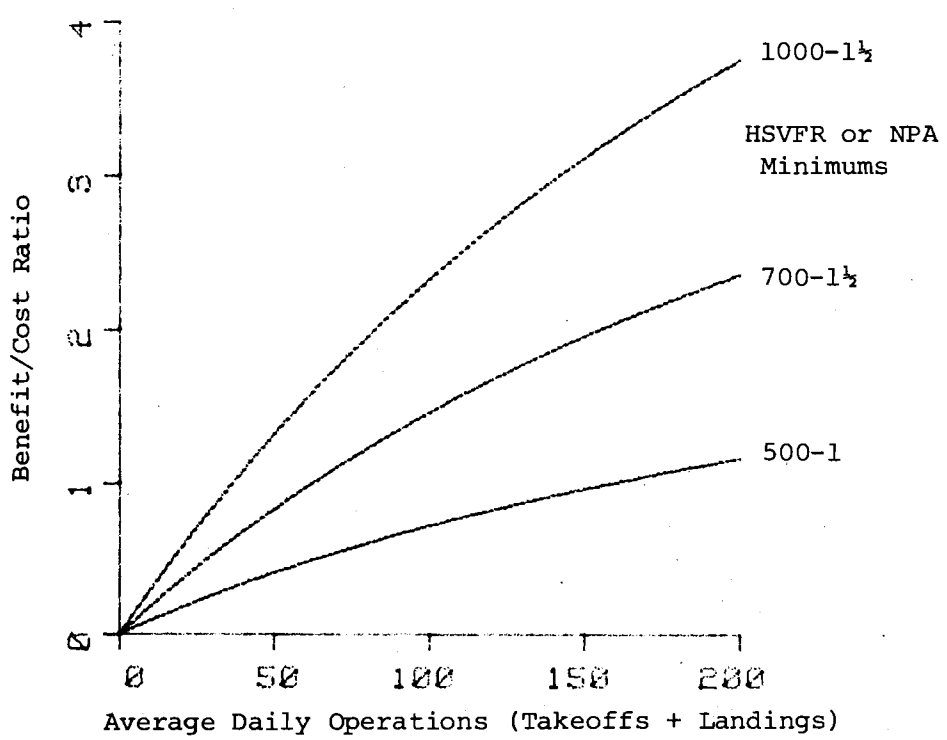


Figure 6.19 MLS Benefit/Total Cost Ratio for Non Hub Airport Operations

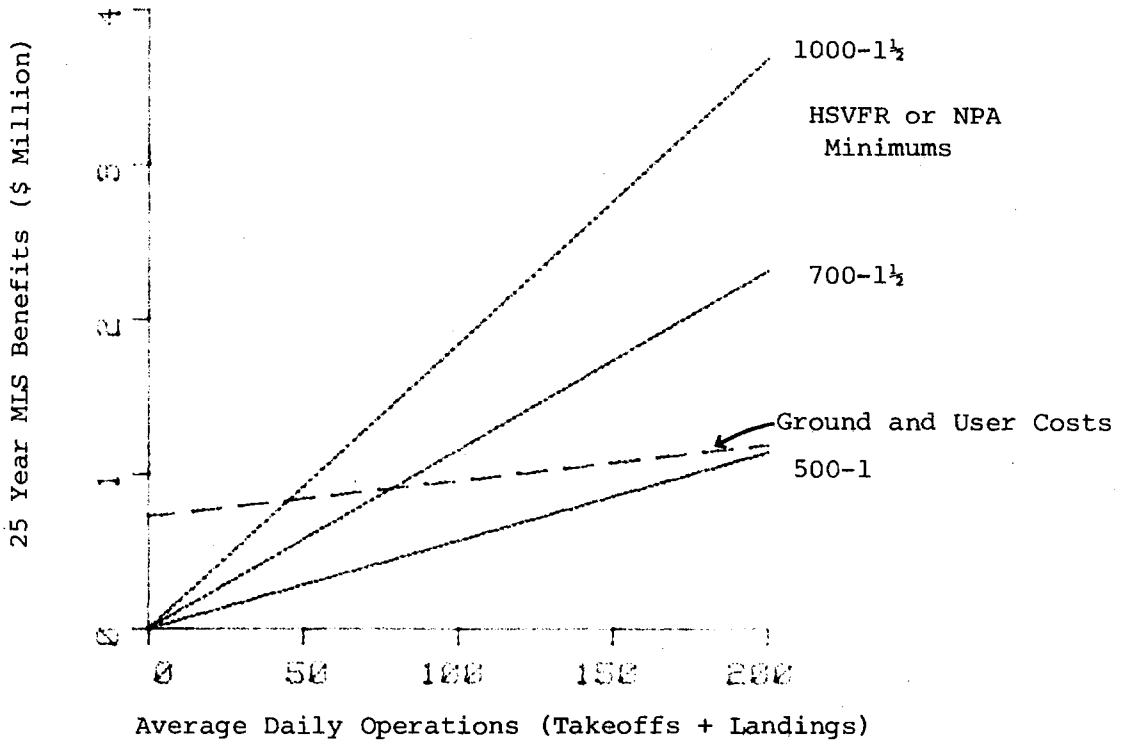


Figure 6.20 MLS Benefits and Costs for Remote Area Operations

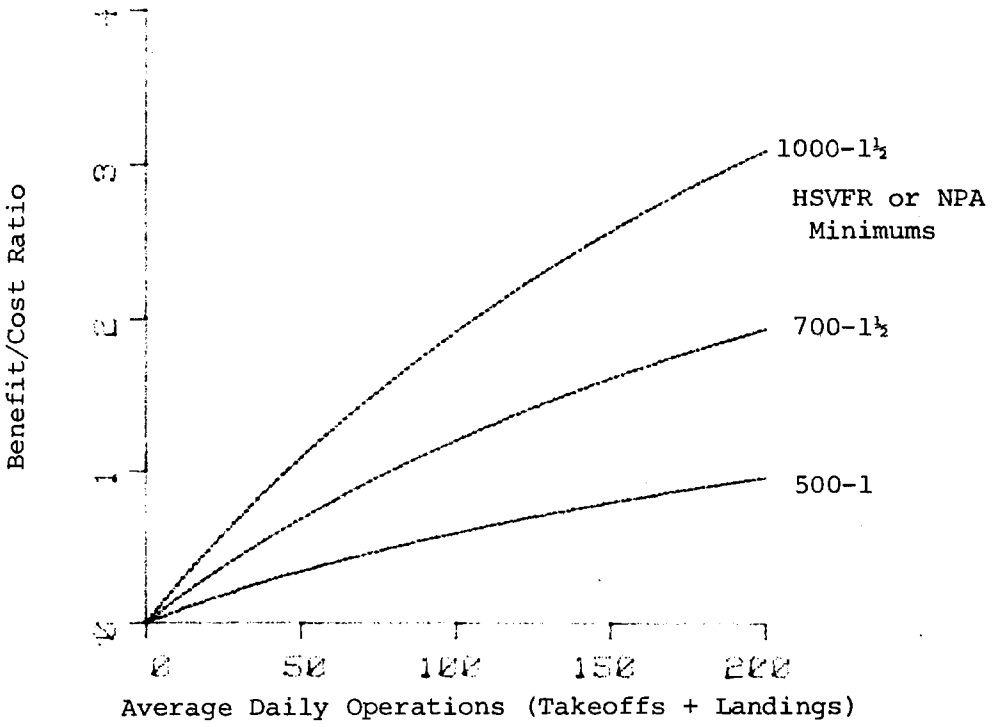


Figure 6.21 MLS Benefit/Total Cost Ratio for Remote Area Operations

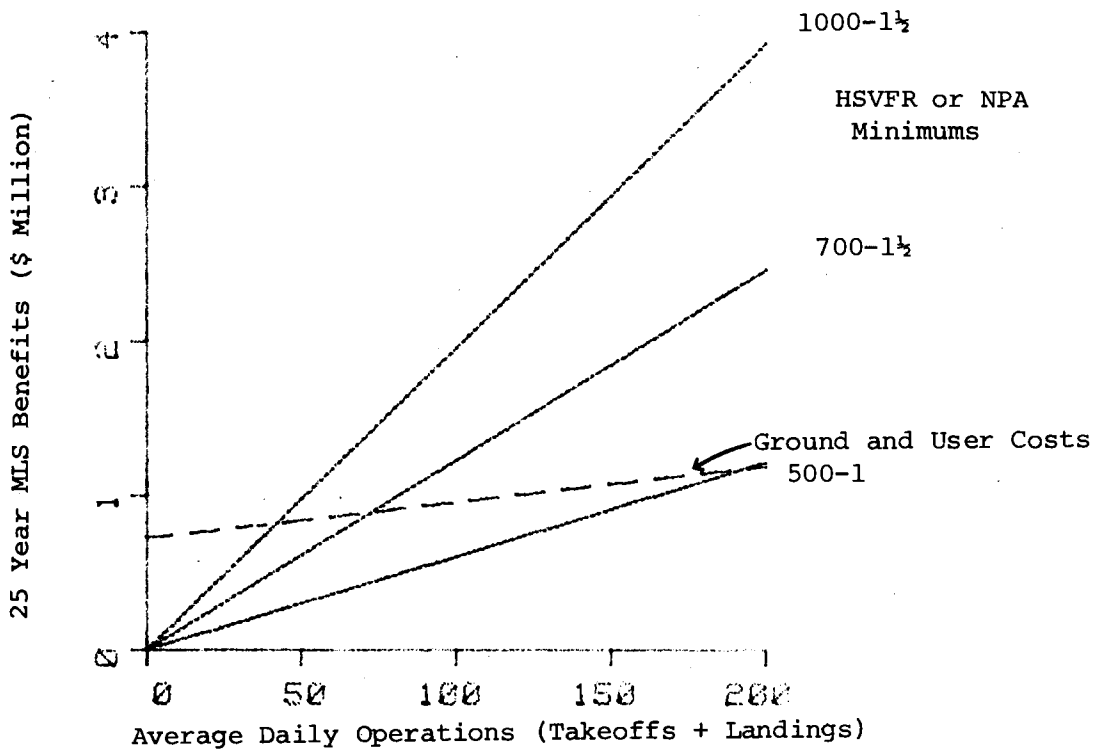


Figure 6.22 MLS Benefits and Costs for Offshore Operations

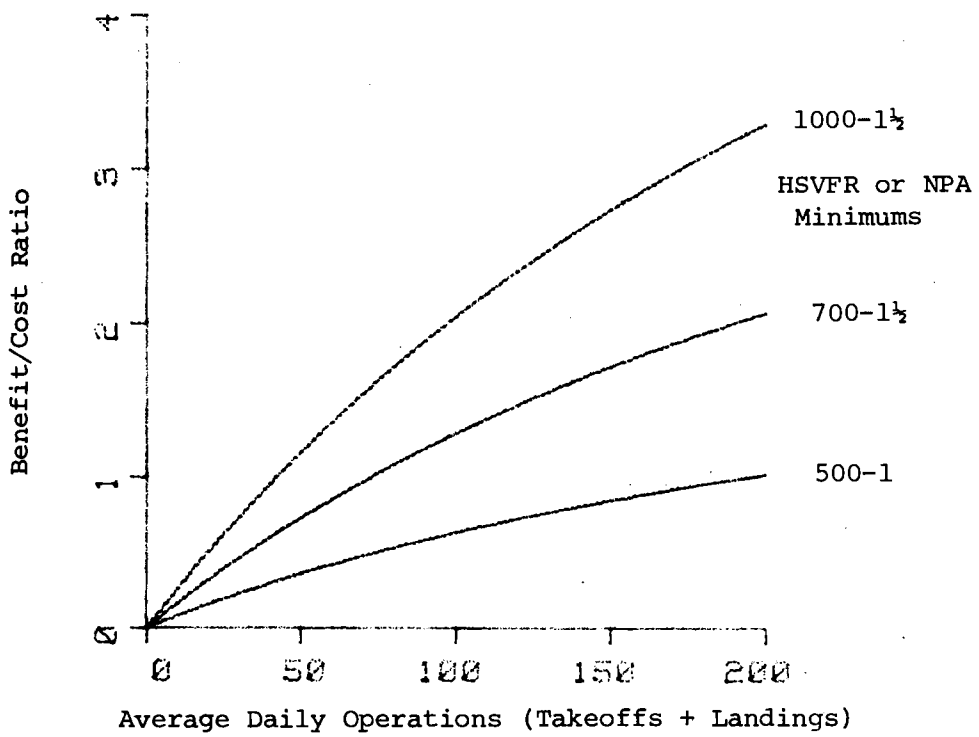


Figure 6.23 MLS Benefit/Total Cost Ratio for Offshore Operations

- Airports/heliports in mountainous areas
- City center areas with tall buildings and narrow corridors
- Major hub airport areas where airspace is limited
- Remote heliports supporting active helicopter operations

In the offshore areas the presence of the rig and possible presence of ships in the area require the use of airborne radar for obstacle avoidance. Without radar, MLS minimums will necessarily be high. With radar and no MLS, the ARA procedure can be flown to minimums that are as low as most anticipated MLS minimums. Therefore in the offshore environment MLS procedures are not considered to be economically feasible.

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APPENDIX A

EFFICIENCY BENEFITS

A.1 FLIGHT DISRUPTION PARAMETERS

A schematic representation of the factors pertaining to efficiency benefits, taken from Reference 4, is shown in Figure A.1. A flight disruption has an effect upon passengers, aircraft flying time, and passenger handling costs. These effects are categorized into the five helicopter operational areas. The time lost and handling cost of flight disruptions are summarized in Table A.1. The following paragraphs briefly describe the parameters. These quantities are described in greater detail in Appendix A of Reference 4.

Delays

For helicopters, an average delay of 30 minutes (0.50 hours) waiting for weather to improve was assumed. This value appears as passenger time lost due to delays in the table. Since many helicopter operations are flights of short duration, the pilot is often aware of delays in landing prior to takeoff. Therefore 75% of the delay is absorbed waiting at the origination helipad. The remaining 25% (0.13 hours) is increased flight time shown in the table as a primary delay in all categories.

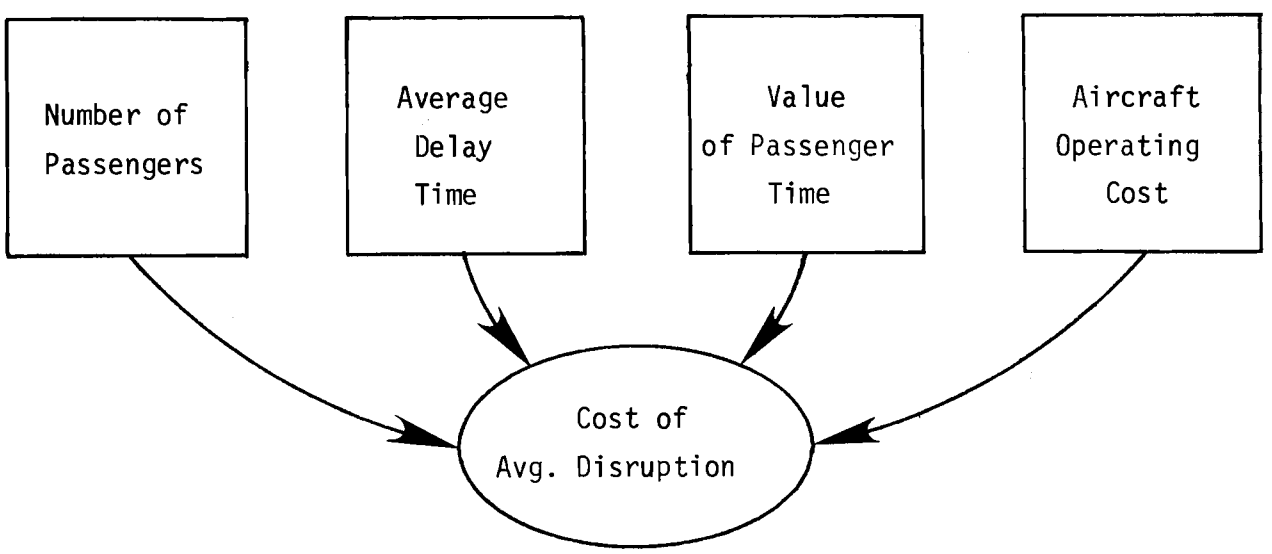

Figure A.1 Flight Disruption Cost Factors

Table A.1 Summary of Flight Disruption Effects

Flight Disruption Effect	City Center	Major-Hub Airport	Non-Hub Airport	Remote Area	Offshore Oil Rig
Extra Aircraft Flight Time (Hours)					
Delays					
Primary*	.13	.13	.13	.13	.13
Queue Reduction	.13	.25	-	-	-
TOTAL	.25	.38	.13	.13	.13
Diversions					
Primary	.50	.50	.50	.50	.50
Repositioning Aircraft	.25	.25	.25	-	.25
TOTAL	.75	.75	.75	.50	.75
Cancellations					
Repositioning Aircraft	.15	.15	.15	-	-
Average Flight Duration	.17	.33	.33	.33	.50
Passenger Time Lost (Hours)					
Delays					
Primary	.50	.50	.50	.50	.50
Queue Reduction	.13	.25	-	-	-
Secondary	.25	.25	.25	.25	.25
TOTAL	.88	1.00	.75	.75	.75
Diversions					
Primary	1.25	1.25	1.25	1.25	1.25
Secondary	.50	.50	.50	.50	.50
TOTAL	1.75	1.75	1.75	1.75	1.75
Cancellations					
Primary	1.00	1.00	1.00	1.00	1.00
Secondary	.50	.50	.50	.50	.50
TOTAL	1.50	1.50	1.50	1.50	1.50
Overflights					
Diverted Passengers	1.25	1.25	1.25	1.25	1.25
Cancelled Passengers	1.00	1.00	1.00	1.00	1.00
Passenger Handling Expense ($)					
Delays	-	-	-	-	-
Diversions	$50	$50	$25	$25	$50
Cancellations	$15	$15	$8	$8	$15
Revenue Lost Due to Cancellations (%)	80%	80%	80%	40%	40%

*75% taken on the helipad - 25% in the air

Delays cause queues to build at the destination airport in congested traffic areas. Fifteen minutes (0.25 hours) was the delay associated with queue build up at major hub airports. This value applies to both the passengers and the aircraft. Half of this value was assumed in city center operations and no queue build up delay was applied to the remaining three operational areas due to lower traffic activity in these areas.

Passengers waiting for subsequent flights experience almost the same delay as those on the delayed flight. This effect is noted in the row entitled secondary delay. A value of half the original delay was applied to all operational areas.

Delays cause little additional expense for the operator in terms of passenger handling. No amount of expense was applied to this parameter.

Aircraft Diversions

An aircraft that is diverted to another heliport produces substantial extra flight time and passenger time lost. It is assumed that the aircraft arrives at the destination field, circles, waiting for the weather to improve, and finally flies to an alternate landing area. One half hour of flight time is assumed for the diversion. An additional three-fourths of an hour is required for passengers to get to their initial destination via alternate transportation modes. One-quarter hour is required to reposition the aircraft to return it to normal service except in remote areas. In remote areas the aircraft is usually returned to the origin airfield so that no repositioning is required.

Passengers waiting for subsequent flights from the destination airport will also be delayed or forced to seek alternate transportation. One half hour is attributed to this secondary delay.

The helicopter operator must provide the passenger with a means to return to the original destination. Also meals and overnight lodging may be involved in a few cases. Diversion values used in Reference 4, adjusted to 1980 dollars, were applied. City center and offshore operations were considered to be similar to major hub operations. Remote area operations were categorized with non-hub costs.

Cancellations

Cancellations cause passengers to wait for later flights or arrange for alternate transportation. Substantial time lost by the passenger is incurred. One hour was used as an average loss for all operational categories. Passengers on subsequent flights at the destination heliport also encounter time lost. One-half hour was attributed to secondary time lost.

Cancellations have little effect upon additional aircraft flight time except when the aircraft must be repositioned to resume normal service. A small amount of time (9 minutes) has been alloted for this purpose in city center, hub, and non-hub airports. No repositioning was provided for remote area and offshore operators.

The helicopter operator may incur some passenger handling expense when a flight is cancelled. These expenses can include meals, overnight lodging, arranging for alternate transportation and so forth. A value of 30% of the diversion cost was assumed.

Cancellations may mean a loss of operator revenue for each passenger who choses an alternate form of transportation or who decides to cancel his trip altogether. Sometimes the trip may be rescheduled in which case the revenue is only deferred, not lost. At city center heliports, major hub airports, and non-hub airports it was assumed that 80% of the passengers are lost to other transportation modes. In remote areas and offshore operations this loss was assumed to be 40%.

These passengers who use other modes of transportation represent lost revenue to commercial operators and lost helicopter utilization to private operators. To account for this value an hourly revenue rate per passenger was utilized. An analysis of current helicopter commercial operations in New York and Houston provided the following data:

Average ticket cost = $3 to $4 per minute of flight

These flights are made currently on VFR aircraft. It was assumed that passengers would pay slightly more for reliable all weather service. Therefore a revenue figure of $4.50/minute of flight per passenger ($270/hour) was utilized in the study.

Overflights

Overflights, where the aircraft skips an intermediate stop, do not generally create any excess aircraft flight time. Overflights do cause passengers to lose time however. For passengers an overflight is similar to a diversion for passengers who intend to stop at the overflown field plus a cancellation to passengers waiting to board at that same field. Thus, for the passenger, an overflight is equivalent to a diversion plus a cancellation.

Average Flight Duration

In order to ascertain the number of approaches per flight hour an estimate of the average flight duration is necessary. For city center operations a 10 minute flight is assumed. For hub airport, non-hub airport and remote area operations a 20 minutes flight is assumed. For offshore work a 30 minute flight is used.

A.2 VALUE OF PASSENGER TIME

Reference 4 uses a $12.50/hr value for passenger time. Corrected for inflation this is approximately $20.00 per hour in 1980 dollars. As mentioned in Section 6.3.1, the yearly salary for many helicopter passengers is considerably higher than average: $30,000 to $50,000 per year and higher. In terms of value to a person's company, this figure is often three to four times this amount when items such as overhead and administrative expenses are considered. In deriving a figure for this analysis, $80,000 per year is used, based on a salary of $40,000 per

year and a conservative factor of two to account for a persons industrial worth. Dividing by 2000 working hours per year produces an hourly value of passenger time of $40.00 per hour.

A.4 AIRCRAFT OPERATING COST

To derive aircraft operating cost, helicopters were divided into five categories. Only turbine powered aircraft were considered to have IFR capability. The categories are:

- single engine turbine (all weights)
- light twin turbine (up to 6,000 lbs)
- medium twin turbine (6,000 to 12,499 lbs)
- Heavy turbine (12,500 to 30,000 lbs)
- very heavy turbine (greater than 30,000 lbs)

Data on aircraft operting cost are averages for each category.

Guidelines for the aircraft operating cost analysis in Reference 4 consider only the following cost categories:

- crew costs (labor and burden)
- fuel and oil
- insurance (hull and liability)
- maintenance (labor and replacement parts)

No consideration of depreciation and interest costs or business expenses is provided according to the guidelines.

Crew Costs

Professional crews were considered in all aircraft categories. Single pilot operation was assumed for the single engine helicopter. Two pilots were assumed for all twin engine and multiengine aircraft. Crew salaries were taken from Reference 20 for the year 1980. A range of $30,000 to $40,000 per year was used for pilot salary based on IFR license and medium to high time experience. A copilot's salary of 70% of the pilot's salary was assumed. To the salary figures was added a 35% figure for benefits.

Fuel and Oil

Fuel flow data were obtained from Reference 11 for all aircraft. Fuel costs for the first three categories were taken from a recent fuel survey in Reference 21. This value for Jet A fuel is $1.72 per gallon is representative of prices paid at fixed base operator facilities. For the two heavy helicopter categories a price figure based upon an average of FBO prices and prices paid by the air carriers (Reference 22). This average figure is $1.37 per gallon. An additional 7% was applied to the fuel cost for engine and lubrication oil.

Insurance

Insurance cost vary widely according to the use of the helicopter and the experience of the crew. Several references [12, 23] use 10%

of the aricraft value for hull insurance and 2% for liability insurance. A check of insurance companies indicate that 10% is probably high for turbine helicopters. A figure of 8% was assumed for hull insurance and 2% for liability.

The aircraft value was determined by applying a factor of 80% to the price of new helicopters (from Reference 10). The price of single engine helicopters was increased by $100,000 to account for IFR autopilot and avionics equipment. An analysis of used helicopters from data in Reference 10 indicated that three to four year old helicopters cost about 80% of a new helicopter.

Maintenance

Estimated hourly maintenance costs were derived from the value of the aircraft by multiplying by a factor of 2.5×10^{-4}. This figure was derived from examples of helicopter operating costs derived in Reference 12.

Average helicopter direct operating costs are summarized for each of the five categories in Table. A.2.

A.4 NUMBER OF PASSENGERS

The number of passengers was developed from the aircraft capacity figure in Reference 11. The single engine and light twin aircraft categories were assumed to be in an executive configuration. Medium twin aircraft were assumed to be 50% executive and 50% transport configuration. The heavy helicopter categories were assumed to be in transport configuration. A 60% load factor was assumed for all categories. The results are presented in Table A.2.

Table A.2 Aircraft Direct Operating Costs and Passenger Capacity

Category	Direct Operating Cost (IFR)	Passenger Capacity + Crew
Single engine turbine	$280/hour	2.3 + 1
Light twin turbine	$560/hour	2.6 + 2
Medium twin turbine	$850/hour	5.5 + 2
Heavy turbine	$1775/hour	10.8 + 2
Very heavy turbine	$4025/hour	26.4 + 3

A.5 AIRCRAFT DISTRIBUTION

Projections of the number and type of aircraft to be produced during the upcoming decade are developed in Reference 18. These projections do not directly correspond to the categories used in this

analysis but a reasonable correspondence can be obtained by suitably grouping the five categories. From this analysis the following distribution projections were obtained:

- Single engine turbine 70%
- Light twin turbine 17%
- Medium twin turbine 9%
- Heavy turbine 3.5%
- Very heavy turbine 0.5%

Applying these weighting factors to the direct operating cost and the passenger capacity figures produces the following:

Average hourly direct operating cost	-	$450/hour
Average passenger capacity	-	3.1 passengers

For more detailed analyses of specific heliport locations, it would undoubtedly be desirable to utilized specific percentages of helicopter types that use that facility. In the general analysis developed in this report these weighted average figures will be applied.

A.6 DISRUPTION COSTS

Flight disruption costs are computed by combining the aircraft related costs and passenger related costs. Since these cost parameters differ for the various operational areas and types of aircraft, the analysis was performed using parametric terms for direct operating cost (DOC) and the number of passengers per aircraft on each flight (PASS). The following expressions were obtained from Table A.1 and the cost data developed in Sections A.2 and A.3:

Delays Costs

Operational Area	Aircraft flight time lost	+	Passenger Time Lost
City center	.25 hours x DOC	+	0.88 hours x $40/hr x PASS
Major hub airport	.38 hours x DOC	+	1.00 hours x $40/hr x PASS
Non-hub airport	.13 hours x DOC	+	0.75 hours x $40/hr x PASS
Remote area	.13 hours x DOC	+	0.75 hours x $40/hr x PASS
Offshore	.13 hours x DOC	+	0.75 hours x $40/hr x PASS

Cancellation Costs

Applying the procedures from Reference 4, cancellation costs are computed as follows:

Aircraft flight time cost = repositioning time x DOC
Aircraft flight time saved = average flight duration x DOC
Passenger handling costs = (From Table A.1) x PASS
Revenue lost = average flight duration x revenue/hour per passenger ($270/hour) x percent revenue lost x PASS
Passenger time lost = lost passenger time x $40/hr x PASS

The following expressions were obtained:

Operational area	Cancellation costs
City center	-.067 hours x DOC + $111 x PASS
Major hub airport	-.183 hours x DOC + $147 x PASS
Non-hub airport	-.183 hours x DOC + $140 x PASS
Remote area	-.333 hours x DOC + $104 x PASS
Offshore	-.500 hours x DOC + $129 x PASS

Diversion Costs

Diversion costs are the sum of the cost due to extra aircraft flight time, passenger time lost, and passenger handling. The following expressions are obtained:

Operational area	Diversion costs
City center	0.75 hours x DOC + $120 x PASS
Major hub airport	0.75 hours x DOC + $120 x PASS
Non-hug airport	0.75 hours x DOC + $95 x PASS
Remote area	0.50 hours x DOC + $95 x PASS
Offshore	0.75 hours x DOC + $120 x PASS

Overflight Costs

No aircraft costs are attributed to overflights. Passenger costs include diversion costs for those passengers who did not land at their destination and cancellation costs for those passengers who were to board the aircraft at the intended destination.

Overflight diverstion costs	Overflight cancellation costs
Passenger handling	Passenger handling
Passenger time lost	Passenger time lost
	Revenue passengers lost

The total overflight cost is the sum of these two categories. The following expressions were obtained:

Operational area	Overflight costs
City center	$191 x PASS
Major hub airport	$227 x PASS
Non-hub airport	$195 x PASS
Remote area	$159 x PASS
Offshore	$209 x PASS

Disruption Costs

Disruption costs were computed by assuming a percentage of the time that each type disruption occurs. The following schedule of disruptions was assumed.

Delays	70%
Cancellations	20%
Diversions	5%
Overflights	5%

The cost expressions were weighted by these disruptions percentages and the following expressions were obtained:

Operational area	Disruption costs
City center	0.2091 x DOC + 62.39 x PASS
Major hub airport	0.2669 x DOC + 74.75 x PASS
Non hub airport	0.0919 x DOC + 63.50 x PASS
Remote area	0.0490 x DOC + 54.40 x PASS
Offshore	0.0285 x DOC + 63.25 x PASS

A.7 EFFICIENCY BENEFITS

When the use of MLS permits an approach and landing that would have otherwise been disrupted, the averted disruption cost becomes the MLS benefit. The disruption cost expressions were evaluated for each aircraft type. The following efficiency benefit matrix was obtained:

Efficiency Benefits

Aircraft Type	Operational Area: City Center	Major Hub Airport	Non-Hub Airport	Remote Area	Offshore
Single engine turbine	$200	$250	$170	$140	$150
Light twin turbine	$280	$340	$220	$170	$180
Medium twin turbine	$520	$640	$430	$340	$370
Heavy turbine	$1040	$1280	$850	$680	$730
Very heavy turbine	$2490	$3050	$2050	$1640	$1780

In order to produce an overall efficiency benefit value for each operational area, the following aircraft distribution was assumed (see Section 6.3.1).

Single engine turbine	70%
Light twin turbine	17%
Medium twin turbine	9%
Heavy turbine	3.5%
Very heavy turbine	0.5%

Applying these weighting values to the efficiency benefits matrix produces the following efficiency benefits for each operational area:

Operational area	Efficiency benefit (per averted disruption)
City center	$290
Major hub airport	$350
Non-hub airport	$240
Remote area	$190
Offshore	$210

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