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Investigation of Advanced Navigation and Guidance System Concepts for All-Weather Rotorcraft Operations

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PREFACE

This investigation of Advanced Navigation and Guidance System Concepts for All-Weather Rotorcraft Operations has been conducted under National Aeronautics and Space Administration Contract No. NAS2-10743. Gratitude is expressed for the guidance and assistance of Messrs. William Snyder, John Foster, and John Bull, NASA-Ames, and also to the BHT employees who aided in the investigation and preparation of this report.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Concluded)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Concluded)

LIST OF TABLES

SUMMARY

This study of Advanced Navigation and Guidance Systems for Rotary Wing Aircraft investigates the requirement for all-weather operations for rotary wing aircraft and the technical and cost feasibility of several advanced systems.

A survey of commercial operators was conducted in which it was found that there is strong interest in improved Instrument Flight Rule (IFR) operations with the average desiring 30.5m (100 foot) minimum ceiling and 0.4 Km (1/4 mile) visibility.

Both IFR and non-IFR operators indicated that present regulatory weather minimums for sites which they operate into average 91m (300 foot) ceilings and 0.8 km (1/2 mile) visibility.

It was also indicated that the operators would pay an average of 7 percent of aircraft cost to achieve lower IFR limits.

An analysis of the problems of operating in 30.5m (100 foot) ceiling and 0.4km (1/4 mile) visibility was made. The inability of obtaining accurate data on very low visibility conditions, especially at remote sites, led to a recommendation for designing a system for zero-visibility operation. A mission model was then constructed to represent the modes of flight normally encountered in a mission representative of operation in these visibility limits.

Candidate systems were then examined for capability to meet the requirements of the mission model. It was then determined that in addition to the requirement for area navigation, terminal area navigation, and approach that it was critical to the mission to have good low-speed handling qualities on approach.

The most promising terminal navigation systems were found to be LORAN-C and Differential C/A code GPS with neither system having capability of precision approach in zero-visibility. The most promising terminal navigation system and the only system that shows good promise for precision approach to a remote, restricted site in zero-visibility is high resolution X-band radar, probably using a rotor-mounted antenna.

Two principal systems are recommended. The first is for approaches to a hover in zero-visibility based on LORAN-C, high-resolution radar and a dual-redundant fail-safe control system with good low-speed handling qualities. The system also contains advanced pictorial-type displays.

The second recommended system for 30.5m (100 feet) minimum ceiling operation is based on using the Differential C/A Code GPS with a navigation computer, advanced displays, and a dual redundant fail-safe control system.

A third system, recommended for 30.5m (100 feet) minimum ceiling and 0.4 km (1/4 mile) visibility, uses a monopulse beam-sharpening technique to improve tracking accuracy of the weather radar. The system would be aided by strong lights on the landing site.

Recommendations are made for development of the high resolution radar, simulation of the control display system for steep approach and landing, and for development of an obstacle sensing system for detecting wires. A cost feasibility analysis is included.

1. INTRODUCTION

This study of Advanced Navigation and Guidance System Concepts for All-Weather Rotorcraft Operation has the objective of determining the requirements for and improved methods of operating rotorcraft in Instrument Meteorological Conditions (IMC).

The helicopter is one of the fastest growing segments of the aircraft industry. It is widely used for transportation, ambulance and rescue work, petroleum exploration and production, agriculture, forestry, police work, and many other tasks. All forecasts predict continued rapid growth of the helicopter industry in the next two decades.

The helicopter can rise and descend vertically to operate from restricted and unprepared sites; it is through this unique capability that it delivers patients to hospital roofs, lands on oil rigs at sea, and performs hundreds of other tasks from unprepared sites. Without this vertical lift capability, it cannot compete with fixed wing aircraft.

Unfortunately, when visibility is restricted by fog, rain, or other conditions, many helicopters are grounded. Most of the ones that can fly IFR can operate only to and from airports; this is a serious limitation for the helicopter operator. This program was initiated to study ways to remove this limitation.

The study method included the survey of active helicopter operators to determine the extent to which they wished to operate in IMC conditions. They were asked the visibility limits in which they wished to operate, the revenue benefits they would gain from such operations, and the percent of aircraft cost that they would pay for such increased capability. The survey included the operators of small, medium, and large helicopters who performed a wide variety of missions; it also ranged from single helicopter operators up to operators with large fleets. The results of the operators survey were analyzed and used to formulate a mission model for future rotary wing all-weather operations.

Navigation and Guidance systems were investigated to determine their capability for meeting the requirements of the mission model. The area and terminal navigation requirements were considered.

The most critical segment of the mission is the approach and landing phase. The handling qualities of the helicopter must enable a slow speed decelerating approach with little pitch change at the terminal end. The control-display design must enable performance of the mission with low pilot workload throughout the mission.

There are many other related issues that must be addressed to implement an all-weather system including Air Traffic Control (ATC), Federal Aviation Agency (FAA) Certification and regulations, heliport design and location, and pilot proficiency and training. These issues were not addressed in this study.

2. SURVEY

A survey of operators was conducted to determine interest in operating helicopters in Instrument Meteorological Conditions (IMC). The results of the survey are given below.

Specific goals of this analysis were to ascertain the extent of rotorcraft operations in IMC, the desire of rotorcraft operators to operate to lower IFR limits, and to establish a range for aircraft cost increases that could be justified for this improved operational capability.

To achieve these goals, a comprehensive questionnaire was developed and distributed to approximately two hundred helicopter operators in the U. S., Canada, and around the North Sea. The results of this questionnaire form the basis for these analyses. A computer software package, Statistical Analysis System (SAS), provided the statistical tools necessary for the extensive data manipulation and analyses required in this study. A copy of the questionnaire is included in the Appendix.

2.1 MAJOR FINDINGS

1. Slightly less than half of all respondents presently operate IFR.

2. Respondents operating IFR helicopters employ nearly six times the pilots as Visual Flight Rules (VFR) operators.

3. All respondents indicated a willingness to pay up to 7 percent more for aircraft that could achieve lower minimums; moreover, they anticipate a correspondingly increased return in revenues.

4. LORAN-C is the preferred navigational system because of its accuracy, reliability, and system flexibility.

5. For companies that operate helicopters in IFR roles, approximately 25 percent of all missions involve some IMC flight.

6. The missions normally performed by IFR-equipped helicopters are petroleum offshore and corporate VIP.

7. Both IFR and VFR operators feel present weather predictive capabilities are only adequate to poor.

8. Four weather conditions appear to cause virtually all Instrument Meteorological Conditions (IMC); they are fog, low clouds, snow, and rain. Icing conditions are present in about 7 percent of all IMC missions.

9. IFR operators experience an average of nearly 900 hours per year of IMC flight time, or over 25 times the amount of experience by VFR operators.

10. All operators considered air traffic control generally weak while landing but acceptable while flying.

11. Weather minimums preferred by all response categories were 30.5m (100-foot) ceilings and one-fourth mile visibility.

12. Both IFR and non-IFR operators indicated that present regulatory weather minimums for sites into which they operate average 91m (300-foot) ceilings and 0.8km (1/2 mile) visibility.

2.2 IFR QUESTIONNAIRE ANALYSIS

The objectives of this survey were to obtain response data from an evenly distributed sample of operators in support of the investigation of advanced navigation and guidance system concepts for all-weather rotorcraft operations. Specifically, the extent of operations in instrument meteorological conditions, the desire to operate to lower IFR minimums, and a justifiable increase in cost for improved operations were solicited.

Comprehensive analyses of all responses were made using a general computer software system providing capabilities of information storage and retrieval, data modification and programming, report writing, statistical analysis, and file handling.

2.2.1 Company Related

Respondents could be classified into two general categories of operators, those who presently operate helicopters in IFR roles and those with primarily a VFR orientation. Slightly less than half of all respondents (46 percent) presently operate IFR.

Respondents operating IFR helicopters employ nearly six times the pilots as VFR operators, and tend to operate larger gross weight machines (greater than 8000 pounds). Both respondent types employ approximately 40 percent instrument pilots.

These larger aircraft are primarily used for petroleum offshore and corporate VIP missions. Past experience with these types of medium to large helicopter operators shows them to be larger, better organized businesses than the average fixed-base operator. They also tend to perform more of their own maintenance and provide higher levels of maintenance and pilot proficiency.

All respondents indicated a willingness to pay more for aircraft that could achieve lower minimums, and they anticipate a corresponding increased return in revenues although non-IFR operators are less optimistic about potential returns.

2.2.2 Aircraft and Equipment Related

Companies that now operate IFR helicopters perceive relatively high benefit from improvements in rotary wing IFR systems that would permit flights into high density and remote sites under conditions lower than currently used minimums. Non-IFR operating companies hold the opposite perception.

	Perceived Benefit from IFR Systems Improvements							
	High Benefit					Low Benefit		
IFR Operators	1	2	X	3	4		5	6
Non-IFR Operators	1	2		3	4	X	5	6

All companies also appear willing to incur approximately 7 percent additional cost for helicopters that can operate to lower minimums and feel that these aircraft will achieve higher revenues and will be generally safer.

VFR operators appear more willing to incur higher additional aircraft costs (percent) for improved helicopter abilities to operate to lower minimums than do IFR operators. Generally, the lower the aircraft will operate, the greater cost increase can be justified by both IFR and VFR operators. Sample sizes were statistically unacceptable to verify the data below; however, general trends can be ascertained.

Distribution by Operating Minimums of Weighted Acceptable Percent Cost Increase for Helicopter Sizes and Operator Classes

Operating Minimum Height		Visibility		Large Helicopter IFR	Large Helicopter VFR	Medium Helicopter IFR	Medium Helicopter VFR	Small Helicopter IFR	Small Helicopter VFR
152.4m	500 ft.	1600m	1 mi.	1.6	10.0	3.2	8.5	4.0	5.5
61.1m	200	800m	1/2	3.0	-	5.6	0	5.0	3
30.5m	100	400m	1/4	4.1	3.8	6.2	10.5	10.5	7.8
15.2m	50	200m	1/8	6.2	4.4	5.7	10.0	10.0	11.4
	0		0	18.0	5.0	8.3	8.75	-	10.7
Overall Average				7.0	4.0	7.0	9.0	8.0	7.0

En route navigation systems are presently used in the order of frequency shown below with VFR operators showing strong preference for VOR/DME and IFR operators preferring LORAN-C.

VOR/DME	OTHER
RNAV	OMEGA
LORAN-C	

Overall, LORAN-C is the preferred system because of its accuracy, reliability, and system flexibility allowing lower altitude approaches.

2.2.3 Mission Related

Weather

For companies that operate helicopters in IFR roles, approximately 25 percent of missions involve some Instrument Meteorological Conditions (IMC) flight. These missions are presently performed almost exclusively by medium and heavy helicopters, although the trend toward IFR-equipped light, single and twin-turbine helicopters should cause a shift to light helicopter IMC experiences in the 1981-1985 time frame.

Helicopter Size	Percent IMC Missions
Large	27
Medium	25
Small	-

Helicopter sizes were defined as follows:

Large:	Above 12,500 pounds gross weight
Medium:	8,000-12,500 pounds gross weight
Small:	Below 8,000 pounds gross weight

Missions normally performed by helicopters not equipped for IFR are listed below in priority order.

Corporate VIP	Rescue Ambulance
Survey Mapping	Logging, Forestry Management
Petroleum Offshore	Police, Federal or Local
Media	Agriculture Spraying
Scheduled Air Taxi	

Rescue ambulance, and logging, forestry management missions are not scheduled or are cancelled because of weather about twice as often as the other missions shown.

Missions normally performed by IFR-equipped helicopters are petroleum offshore and corporate VIP, with each not scheduled or cancelled less than 10 percent of the time. Interestingly, IFR operators fail to schedule and cancel missions nearly 60 percent more often than VFR operators. This is felt to be a result of the more stringent regulator agency controls over IFR flight regimes as compared to VFR and special VFR flight. Eleven percent of all IFR missions scheduled to be flown are ultimately scrapped.

	Cancellations Percent of All Missions Flown
IFR Operators	11
Non-IFR Operators	7
Overall	9

All operators perceive the missions that would most benefit from lowered minimums are petroleum offshore and corporate VIP.

Both IFR and VFR operators feel present weather predictive capabilities are adequate to poor, with IFR operators being much more critical than VFR operators of present weather predictions. Weather prediction adequacy does impact the number of flights that are cancelled for all operators.

For all respondents, four weather conditions seemed to be responsible for virtually all Inclement Meteorological Conditions. Operators also experience icing conditions in about 7 percent of all missions and 11 percent of IMC missions.

Weather Condition	Percent IMC Caused
Fog	38
Low Clouds	25
Snow	16
Rain	15

Companies that operate IFR experience an average of nearly 900 hours per year of IMC flight time versus 32 hours per year for non-IFR operators.

2.2.4 Agency

IFR operators are much more satisfied than VFR operators with air traffic control methods, equipment, and procedures, especially during en route and terminal control area operations. All operators felt air traffic control is generally weak while landing but generally acceptable while flying.

Both IFR and non-IFR operators indicated present regulatory weather minimums for sites into which they operate average 300-foot ceilings and one-half mile visibility. Both types of operators tend to favor lower minimums.

Weather minimums preferred by all operators were 100-foot ceilings and one-fourth mile visibility with IFR operators tending to favor still lower limits as alternative choices.

The majority of respondents (71 percent) felt these lower operating minimums would result in improved helicopter life-saving capabilities and benefits.

Ceiling		Visibility		IFR* Operator	Non-IFR Operator
152.4m	500 ft	1600m	1 mi	5	4
61.0m	200 ft	800m	1/2 mi	4	2
30.5m	100 ft	400m	1/2 mi	1	1
15.2m	50 ft	200m	1/8 mi	2	3
	0 ft		0 mi	3	5

*1-Most preferred 5-Least preferred

A number of comments relating to regulatory agency inactivity or flexibility with regard to rotary-wing operations were received and can be found in Attachment C.3 in the Appendix.

2.2.5 Facilities

IFR operators showed a higher propensity to use airports while VFR operators appeared more likely to use heliports in congested areas to begin and end missions. Both operator types seemed to fly to remote area heliports 40 percent of the time. Perhaps as a result of this airport use by IFR operators, 20 percent more of their destinations have approved weather reporting stations than those of VFR operators.

While most respondents (82 percent) felt their current terminal area landing aids were adequate for their requirements, a number of comments were received relating to remote or mobile remote landing aids and are included in Appendix A.

A copy of the questionnaire, statistical analysis of the results, response survey and list of respondents is contained in Appendix A.

2.3 INTERVIEW COMMENTS

Approximately one-fourth of the respondents to the questionnaire were interviewed either directly or by telephone in order to explore their thinking about IFR in greater depth. The following were the most common comments:

- It is costly and time consuming to mix VTOL and CTOL traffic. The extended routes necessary to intermingle with fixed-wing traffic causes a waste of fuel and time, adding greatly to the cost of VTOL operations.

- Several operators expressed the need for IFR systems for VTOLs that could operate from heliports. In many cases, helicopters now are forced to operate IFR from expensive airports only because they are presently tied to the ILS for IFR approaches.

- Special traffic procedures are needed for helicopters.

- Several operators expressed the opinion that modern helicopters and equipment are becoming more reliable and require less down time for maintenance and that weather is becoming more and more the factor that delays operations. They feel that, in the future, customers will expect flights to be started and completed as scheduled.

- The opinion was expressed (especially by oil company officials who contract helicopters for offshore use) that they run operations worth many millions of dollars and that they need reliable schedules. Above all, they demand safety and expressed the opinion that ability to operate in lower visibility could improve safety.

- Operators and organizations that operate ambulance and rescue helicopters were among the strongest supporters of very low minimums, including zero-zero. One example is the New York police who operate a rescue helicopter that takes accident victims to a local hospital. The hospital specializes in reattaching severed limbs. Speed is very important in getting the patient to the hospital, but there is often ground fog at the take-off site, at the rescue site (e.g., highway, beach, industrial site, or any other remote areas), or at the hospital heliport. These operators expressed the need not only for low-visibility landing capability in remote areas, but also for some beacon system so that the helicopter could be directed to the accident site by a beacon on a local police car.

Two hospital administrators also discussed the increasing use of ambulance helicopters and the need for all-weather operation at the rescue site and the need to fly a very precise urban route to mid-city hospitals.

3. MISSION MODEL

3.1. VISIBILITY MINIMUMS

The survey indicates that operators who want improved IFR will pay a significant amount to achieve lower minimums. The preferred visibility limit was centered about a 30.5m (100-foot) ceiling and a 1/4-mile visibility but several operators would like lower minimums including zero ceiling and visibility range. This raises the question of the minimum visibility goal for an advanced rotary wing all-weather system. The percentage of time that visibility minimums are below 30.5m (100 feet) in most parts of the world is small (Reference 1). Taking the number of operators who wish to operate below this range and the times these conditions exist results in a very small percentage of total missions that would be eliminated if a 30.5m (100-foot) capability exists. The tendency then is to decide that it is not worth the effort to design a system for near-zero visibility. Detailed examination of the problem, however (including in-depth discussions with operators), indicates that a statistical analysis does not give the true picture.

Weather conditions of fog, rain, snow, or low clouds that limit visibility to 30.5m (100 feet) are often quite variable; the lower the ceiling, the greater effect weather variability has on operations. If the ceiling limit is 152.4m (500 feet), a ceiling decrease of 15.2m (50 feet) may not be noted; at 30.5m (100-foot) ceiling limit, the 15.2m (50-feet) decrease will abort the mission.

Weather reporting capability is unlikely to exist at remote sites and there may be considerable variation in visibility from one local area to another. There is danger of inadvertently attempting a landing when the visibility is below limits because of inadequate detection and reporting.

Ground fog that limits ceiling to 30.5m (100 feet) often results in horizontal visibility to about the same distance.

Downtown urban heliports will frequently be on tall buildings that will raise the ceiling limit to building height plus 30.5m (100 feet). Not only will this increase the time the heliport is weathered in, but it will also require equipment on each heliport to measure whether the ceiling is at least 30.5m (100 feet) above the heliport.

There are safety factors involved in IFR capability and the minimum visibility level. Reference 2 shows that 5.6 percent of the 54 fatal or serious injuries from civil helicopter accidents in the U.S. in 1975 were caused by continued VFR flight in adverse weather conditions. The same report points out that in the same year there were 43 collisions with objects such as trees, poles, buildings, and crops, and 28 collisions with wires. It states that, "Approximately 50 percent of the wire strike accidents occurred below 15.2m (50 feet). Many of these accidents occurred because pilots are forced down to the deck by bad weather through lack of IFR capability."

When making steep approaches, such as are often necessary for obstacle clearance, breakout at 30.5m (100 feet) is much too low to decelerate from 50 or 60 knots, which is a typical present day approach speed, to a hover.

The above facts indicate that there are measurement, operational, and safety problems in a 30.5m (100-foot) ceiling limit: most of these problems can be solved by designing a system that can operate irrespective of visibility. Recognizing that visibility is rarely completely zero (rotor wash disperses fog, for instance), and that airborne or ground lights can be used at commercial sites, the visibility limits set for this model are a 7.6m (25-foot) ceiling and a 7.6m (25-foot) visual range.

3.2 MODEL

The technical requirements for the Advanced Navigation and Guidance System (ANGS) will be determined primarily by the operational requirements of the many missions the helicopter performs. Civil helicopter missions vary greatly in detail but all have common segments. These common segments are described below to formulate a common mission model for use in the system analysis.

3.2.1 Landing and Takeoff Sites

The landing and takeoff site is a restricted area. The size selected for the helicopter is 30.5m (100 feet) diameter or 30.5m (100 feet) square. It can be at ground level or elevated to several hundred feet such as on a tall building or oil rig platform. It can also be a pinnacle site in the mountains. It is assumed that obstacles exist in the area but that there are clear zones for approach and takeoff. The landing site may be surrounded by parked helicopters, buildings, trees, or ground installations of various types. The site location may be in a remote or urban area and may be a dedicated area on an airport. Any of the sites may have limited directions from which takeoff and landings can be made.

3.2.2 Mission Segments

The model contains the following segments:

- Position for takeoff
- Takeoff
- Climb out
- Cruise
- Autorotation
- Approach and takeoff navigation
- Holding pattern
- Approach
- Missed Approach
- Hover
- Land
- Taxi

3.2.3 Mission Segment Description

3.2.3.1 Position for Takeoff. If helicopters are to operate in visibility limits of 7.6m (25 feet), then a sensor must be provided to show whether taxi ways and parking spots are clear. The sensor must also show the outline of ramps, building locations, and other ground obstacles so the pilot can safely ground or air taxi from park to takeoff spot.

3.2.3.2 Takeoff. Takeoff in low visibility requires the capability to come to a hover on instruments and be able to transition and initiate climb-out on instruments. Onboard obstacle detection and clearance capability is required.

3.2.3.3 Climbout. Climbout must be performed on instruments. Obstacle detection and clearance is necessary. Navigational accuracy must be sufficient to enter a 1-n.mi-wide corridor designated as an IFR helicopter route. The width of these corridors must be evaluated; however, they should be as narrow as is feasible within the capabilities of advanced navigation systems. Precise altitude control will also be necessary.

3.2.3.4 Cruise. The cruise segment will be conducted over a designated corridor that has been established for helicopter use or possibly an en route corridor that is established by filing a flight plan with the regulatory agency.

Route control must be maintained with precision. Two-n.mi. wide corridors may be established, but it should be possible with modern navigation systems to navigate near the center of this corridor.

Terrain clearance and obstacle avoidance capability must be available en route. In some special cases, clearance may be obtained along routes at altitudes known to be above all obstacles.

Hazardous weather avoidance must be provided. Capability should be available to change course or altitude within the route to pick the safest path. Since all-weather operation implies operation in many conditions of moderate to high moisture, icing will be a much increased threat. Ice protection should exist for areas where freezing temperatures will be encountered.

3.2.3.5 En route Emergencies. Accessible forced landing areas will be identifiable from an expanded scale of the pictoral display. This capability will increase the safety of autorotation and emergency descents in instrument conditions.

3.2.3.6 Approach and Takeoff Navigation. The flight corridor will narrow as it nears the Initial Approach Fix (IAF) in the terminal area. One nautical mile width is selected as a goal. The path from the IAF to the Final Approach Fix (FAF) may be curved, and obstacle detection and avoidance must be provided. Precise ground track and time control is necessary to intercept the approach path and to comply with secondary considerations such as specific ground tracks for best noise control and fuel.

Redundant navigation inputs should be available with designated or preprogrammed abort routes.

The precise path and time regulation, using the rotary wing variable speed capability, should make holding patterns unnecessary. For special situations, however, sufficient navigation inputs and display should be available to take up a designated holding pattern as required by air traffic control.

3.2.3.7 Approach. The system must permit precision approaches from the FAF to hover into restricted sites without contact visibility.

Approach angles should be selectable from shallow to steep angle as desired. Approach angles of at least 15 degrees should be possible.

- Approach profile will be a complex, curvilinear trajectory to best use limited airspace.
- Approach will involve a near constant-attitude deceleration along a selectable glidepath angle (up to 15 degrees).
- Deceleration values will not exceed 0.1g.
- Approach will achieve zero crab angle.
- Approach will terminate at a hover, followed by translation in hover, then landing.
- Approach profile blends from constant attitude in the approach to linear descent in landing from hover.
- Approach will be flown with stability and control augmented helicopters with low-speed capability. (No other differentiation by helicopter type.)
- Smooth transition from airspeed to ground speed sensing will be provided.
- Approach will be most readily accomplished with primary pictorial displays, rather than symbolic displays. Analog status indicators will be required to augment pictorial displays.
- Obstacle clearance information will be provided pictorially.

The approach should be automated to the point that it is acceptable to the pilot. Couplers will be desirable but should allow pilot control and fly-through to the extent he feels most comfortable.

A Critical Decision Point (CDP) will be computed and displayed. Abort procedures should be preprogrammed for all parts of the approach down to hover and should be capable of automation to the extent the pilot desires.

3.2.3.8 Missed Approach. Missed approach procedures are based on the concept of redundant capability sufficient to make a safe landing in the event of any single failure.

In addition to the onboard system for low-visibility flight, the system will include complete capability for present day IFR, e.g., using fixed point navigation aids to land at airports. This capability could be used as a redundant backup system to divert from the restricted site landing when necessary. It will, of course, require fuel with reserves to reach airport alternates.

Abort should automatically be communicated to air traffic control, and some degraded mode of navigation may be necessary depending on reason for abort.

3.2.3.9 Hover. Hover on instruments requires an aircraft with good 4-axis (pitch, roll, heading, and altitude) electronic stabilization with adequate displays. A good low-airspeed sensor, ground speed sensor, and radio altimeter will be required. Precision location with respect to landing pad edges and nearby obstacles must be shown.

The hover should be capable of automation with pilot fly-through control to the extent he requires.

Obstacle detection should be available so the pilot can see obstacles from near the rotor tip out to several hundred feet through 360 degrees. The obstacle information should be displayed on a horizontal format display, and in heads-up format if possible.

3.2.3.10 Landing. The landing should be accomplished from a hover by the pilot using fly-through control. Transition from instruments to visual environment, including landing light patterns, should be accomplished via heads-up display.

4. SYSTEM DEFINITION

The advanced navigation and guidance system under consideration should have general applicability to all sizes and models of civil helicopters. A medium-sized helicopter is selected as the aircraft for study of the candidate systems; variations of the system will be considered for large and for small helicopters.

4.1 BASELINE AIRCRAFT

The baseline aircraft will be considered to be a modern commercial helicopter in the seven- to twelve-thousand pound class similar to the Bell 222, Sikorsky S76, and Aerospatiale SA365N. The aircraft will have a control system that includes 3-axis SCAS and 4-axis hold features.

The aircraft will have twin engines with single-engine flight capability. The electrical and basic instrument system will have redundancy and reliability suitable for obtaining FAA IFR certification. The basic aircraft will be assumed to have flight instruments and associated sensors including a coupled flight director.

The above-described system will be considered the basic system for cost comparison purposes; changes to the system such as will likely be necessary for sensors and instruments will be added or deleted from the baseline system.

4.2 SYSTEM REQUIREMENTS

The requirements for an Advanced Navigation and Guidance System (ANGS) are determined by the vehicle, types of sensors, facilities, regulations, technology considerations, and cost. These factors are discussed below.

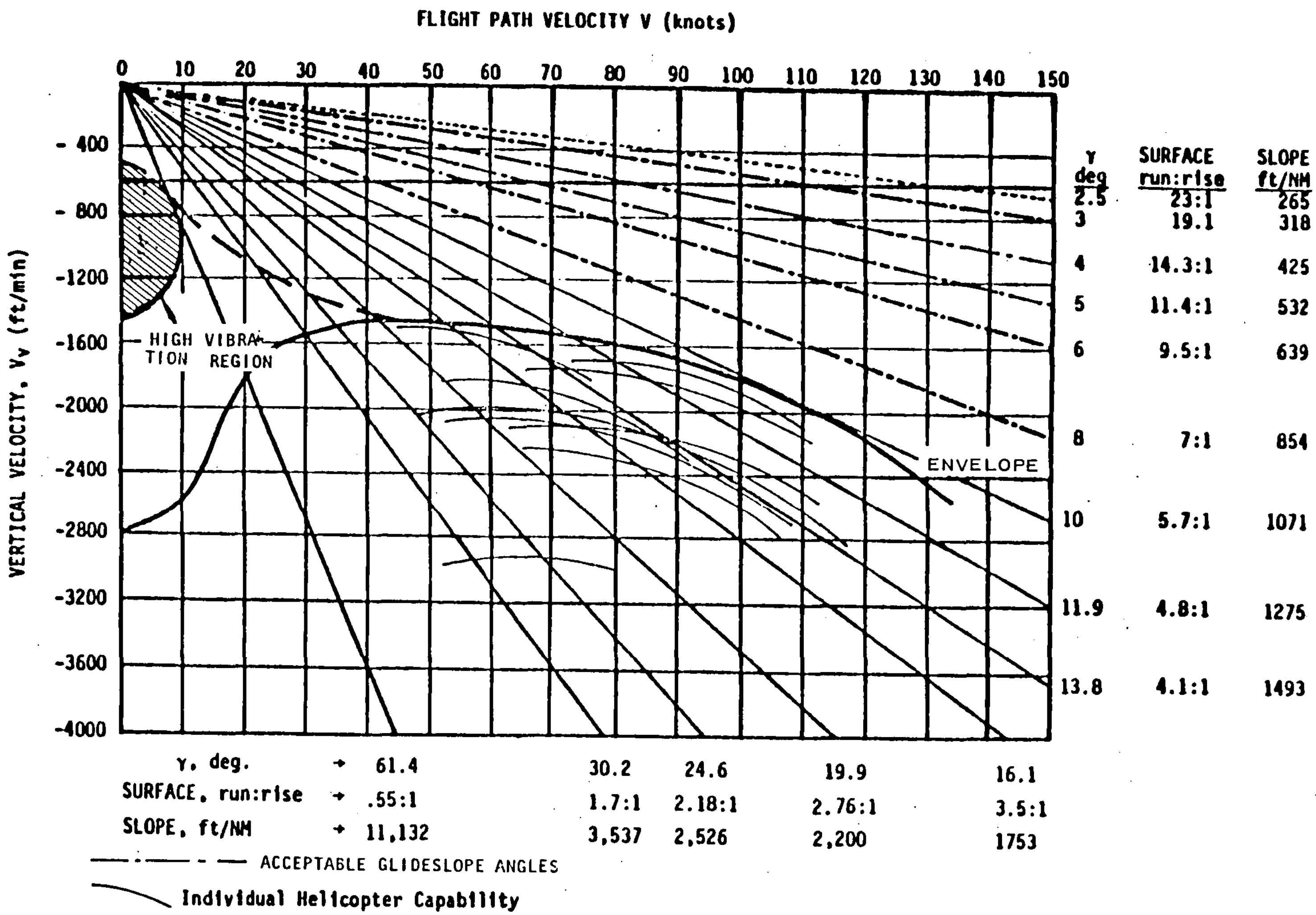
4.2.1 Guidance and Control

The guidance and control requirements for the onboard all-weather system are determined principally by the Decelerating Step Approach and Landing (DSAL) in near-zero visibility. A visual approach profile typically maintains a forward speed above 55 knots and then decelerates sharply near the final touchdown point (Reference 3). This is undesirable in an instrument approach and landing. The sharp deceleration is difficult for the pilot to perform and gives little time in the visual part of a very low-level breakout.

4.2.1.1 DSAL. Guidance, control, and display requirements are heavily influenced by the approach tasks required in the environment in which the approach is performed (Reference 4). In general, the DSAL will be composed of selectable curvilinear trajectory traversed with an approximately constant pitch attitude deceleration. This requirement demonstrates the difference between the DSAL and the visual approach.

There are similarities between initial glideslope angles of the DSAL and the visual approach. These angles represent compromises between steep angles for obstacle clearance requirements and shallower angles for aircraft performance characteristics. The DSAL may be entered from a normal cruise directly or by means of a standard spiral constant altitude deceleration. Once the initial entry airspeed has been achieved, the DSAL begins. Among the constraints on the approach angles selected are the autorotation boundaries relating descent rate to forward velocity, Figure 1, and the height velocity such as that shown in Figure 2. In addition, substantial levels of vibration may be encountered in the low velocity part of the descent depending on helicopter type. Optimum angles appear to be from 6 to 12 degrees. The system will be designed for complete instrument approach to a hover on instruments; however, usually, there will be a visual breakout, sometimes at very low levels. There is a direct relationship to the visual breakout and the steepness of the approach angle. The visibility and approach trade-offs are discussed in Reference 5.

Deceleration will be programmed based on ground velocity from radar or doppler inputs. This constant deceleration will result in a nominally constant attitude except for wind variations. The system will require control algorithms and actuation travel sufficient to compensate for the full range of gusts and wind variation to be encountered on the approach. It may be necessary to include attitude limiting in case of gust inputs above some predetermined threshold. The inputs from the 360 degree airspeed sensor will be used as a feedback to damp the system. It will be necessary to set maximum limits of wind velocity, and gust conditions in which a specific helicopter can make a safe approach with a specific load and density altitude conditions. The limits will be necessary so the sideward or rearward flight capability is not exceeded in cases where it is necessary to approach with a side or tail wind. The onboard sensors and computation capability should make it possible to measure the wind velocity and direction early in the approach and warn if performance limits will be exceeded.



Note: Helicopters cannot physically descend in controlled flight at a higher rate of descent than achieved in autorotation. This envelope curve, therefore, defines the regime of descending flight achievable by the family of IFR certificated helicopters evaluated in this report.

Figure 1. Envelope of autorotation characteristics (IFR certificated helicopters, sea level, standard day).

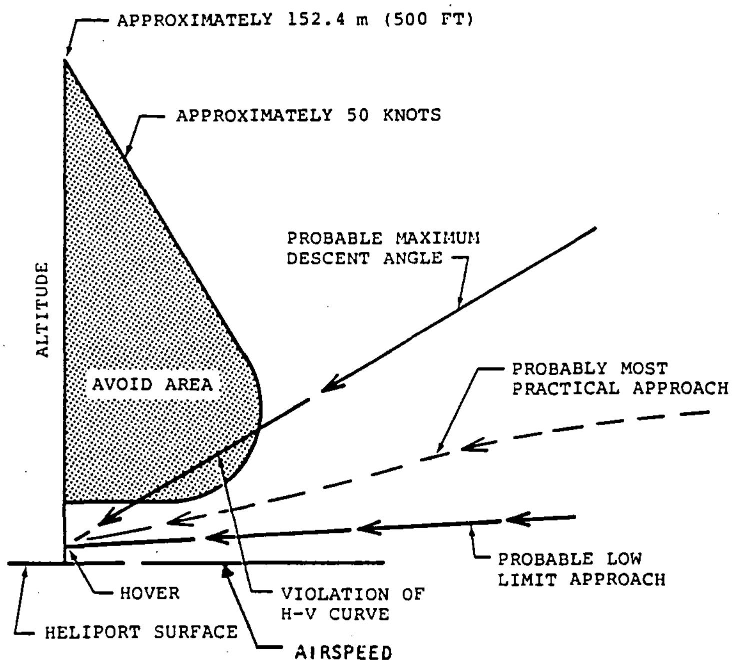


Figure 2. Typical height velocity curve.

Throughout the DSAL, the deceleration values will be less than 0.1g. The DSAL will terminate at a hover on instruments, if necessary, followed by a vertical descent and landing. Thus, the DSAL blends from a constant attitude descent profile to a hover then to a linear descent to landing.

The system function will be to sense information and provide display and control information to enable the pilot to navigate through the terminal area, identify the landing site, and perform the DSAL to a hover over the landing pad. Greater accuracy will be required than for present IFR flight. The routes in the terminal area that are designed for IFR traffic separation, collision avoidance, and best noise abatement profile must have greater 4-dimensional precision than has been required of present systems. The predicted accuracy requirements are listed in Table 1.

4.2.1.2 Helicopter Performance and Controllability. The accomplishment of the DSAL depends to a great extent on the helicopter's performance and controllability. It was not an objective of this study to address these functions, but analysis and interviews with operators have shown that they are an important factor in an onboard all-weather system.

TABLE 1. QUANTITATIVE NAVIGATION REQUIREMENTS SUMMARY

Parameter	Takeoff and Landing	Terminal Area	Cruise
1. Range Requirements	5n.mi.	25n.mi.	complete
2. Coverage Requirements Elevation	0 - 20°	152.4m (500 ft) -914.4m (3000 ft)	152.4m 3048m (500 ft) - (10,000 ft)
Azimuth	±90°	All	All
3. Requirements for Operation in Proximity of Obstacles	to within 152.4m (250 ft)	0.25n.mi. minimum separation	1n.mi. minimum separation
4. Accuracy Requirements:			
Range		100m (328 ft)	609.6m (2000 ft)
Velocity	2 kt	5 kt	10 kt
Angular	0.05°		
5. Multiple Aircraft Requirements	1 landing/min 1n.mi. longitudinal spacing	Depends on Air Traffic control capability	----
6. Multiple Pad Requirements	30.5 (100 ft) to 122m (400 ft)	----	----
7. Inertial Smoothing Requirements	1/4Kt for Hover control	Depends on navaid	
8. Reliability/Redundancy Requirements	Dual, Fail Safe, Controls - Backup Navigation System		
9. Update Rate Requirements	1/5 sec	1 sec	10 sec
10. Data Link Requirements	8000 bits/sec	8000 bits/sec	8000 bits/sec
11. Ground/Air system Tradeoff		Need Both	
12. Requirements for Signal Continuity and Fidelity, Including Proximity of Obstacles	No Multipath Use ICAO* ILS** standards	Need study of urban RF interference	----

*International Civil Aviation Organization
**Instrument Landing System

The limitations on the DSAL imposed by helicopter performance characteristics must be considered. Any proposed profile must account for the performance capabilities of the helicopter and allow for missed approaches and the possibility of engine failure.

Any flight profile to be used must also define a critical decision point (CDP). This is the point at which, if an engine fails, the pilot may choose to continue the landing or execute a single-engine missed approach maneuver. The considerations for actions to be accomplished in the event of a single-engine failure are relatively similar to those that will be encountered in visual conditions with a large number of parameters involved. For the ambient conditions, single engine rate of climb at best rate-of-climb airspeed may be positive or negative at a given airspeed. As the airspeed decreases on the so-called back side of the power curve, the rate of climb capability will be decreased. The critical decision point in the DSAL will not really be a point at all, it will be a variable that will change continously as a function of the ambient weather conditions, gross weight of the aircraft, etc. For our purpose, a critical decision point may be defined as:

> That point in space for given instantaneous conditions at which continued level flight may not be possible if the aircraft decelerates further from its current airspeed.

Based on considerations of minimum flight path clearance, the CDP will define the last possible instant at which a go-around may be accomplished. Beyond the CDP, a landing must be completed. Also to be considered is adjustment of the glide slope on very short notice to accommodate different descent characteristics that will arise from loss of an engine.

The large number of parameters involved in determining the CDP require that this information be computed for the pilot in order to keep his workload low. Certain inputs, such as gross weight, can be inserted manually; the other inputs, such as ambient weather and flight information, will be sensed by onboard sensors. Aircraft performance characteristics will be stored in computer memory. The computed functions such as flight profile envelopes, speeds, abort profiles etc., could be displayed to the pilot along with the CDP. The information could be monitored during automated approach to indicate required takeover or could be used for a flight director during manual flights.

The capability of any helicopter to approach and land while following a particular height-velocity profile without a potential hazard from engine failure is described in the well known height velocity diagram shown in Figure 2.

All rotorcraft, in their low speed and low altitude flight regimes, have combinations of forward speed and altitude that will not allow a safe landing. Usually the flight conditions will be at an altitude under 152.4m (500 feet) AGL and less than 50 knots of airspeed.

Loss of power while conducting flight into the "avoid area" will result in touchdowns that are partially or completely uncontrolled with respect to touchdown vertical velocities. The result can be anything from a hard landing to a severe crash.

Single-engine helicopters are more critical than multiengine rotorcraft because they have only the inertial energy of the main rotor to cushion the touchdown.

Multiengine rotorcraft have an advantage in these situations because generally 50 percent of the powerplant can be used to aid control of the vertical touchdown velocity. For this reason, the Height-Velocity "avoid" area is usually much smaller than for a single-engine rotorcraft of approximately the same size and allowable gross weight.

In making a zero-visibility approach, it is desirable to come to a higher hover than normal VFR, but the lower edge of the H-V curve is often between 3m (10 feet) and 6m (20 feet). A higher hover violates the avoid region of the H-V curve.

Helicopters cannot descend in controlled flight at a higher rate of descent than achieved in autorotation. Figure 1 from Reference 6 plots the envelope of autorotation characteristics of present IFR certified helicopters. It can be seen that in some cases on glide slopes greater than 8 degrees that vertical rate of descent must be limited to below 396.2m/min (1300 ft/min).

All present helicopters have minimum velocities to which they can be certified for IFR approaches. The principal reason is that below certain approach velocities, usually 55 to 60 knots, the workload required for flight on the "backside of the power curve" increases so that the pilot cannot safely perform instrument flight. It is not that the helicopter cannot descend at lower velocities (pilots often make steep low-speed approaches in good visibility, to perform certain tasks); the problem is that there are insufficient visual cues on instruments. To make low-speed approaches on instruments, it is necessary to improve the stability of the helicopter and improve the instrument display to give the necessary cues.

Much previous research has been conducted on the subject of instrument central relationships for VTOL approaches. Hoh and Ashkenas, in Reference 7, attempt to correlate previous work by generating a classification scheme to account for outside visual cues and various types of cockpit displays in determining the requirements for systems for low-speed flight and hover. They then examine past studies and place them in their classification scheme. Of particular interest to this study is their visibility level of five defined as having no visibility cues available. They then determine, from examining previous studies, that a translational rate system with direct force control, a mechanical flight director or an integrated display flight director, plus aircraft velocity information, is necessary to perform low-speed flight or hover with a VTOL. This finding is important to this study because we must gradually decelerate through low speed to a hover on instruments.

There is a relationship between control and display sophistication. Figure 3, Reference 8, gives a generalized plot of this relationship along with workload and cost factors. It has been found that this control/display relationship only holds above some minimum level of control sophistication; in other words, better instruments will not improve the pilot rating of a grossly unstable helicopter.

A combination of aircraft control and instrument display must be selected to provide handling qualities so that an average pilot can perform the nonvisual DSAL and hover with a reasonable workload. The criterion often used for specifying handling qualities is the well-known Cooper-Harper rating, Reference 9, where a numerical scale from 1 to 10 is used to represent excellent to uncontrollable handling qualities. A Cooper-Harper rating of 3.5 is considered to be satisfactory; this approximates MIL-F-83300 flying quality level 1. This will be considered the minimum acceptable in trade-offs for the onboard flight system.

Pilot ratings from flight tests generally agree with ground simulation in this field; therefore, simulation studies have been widely used for data in the study.

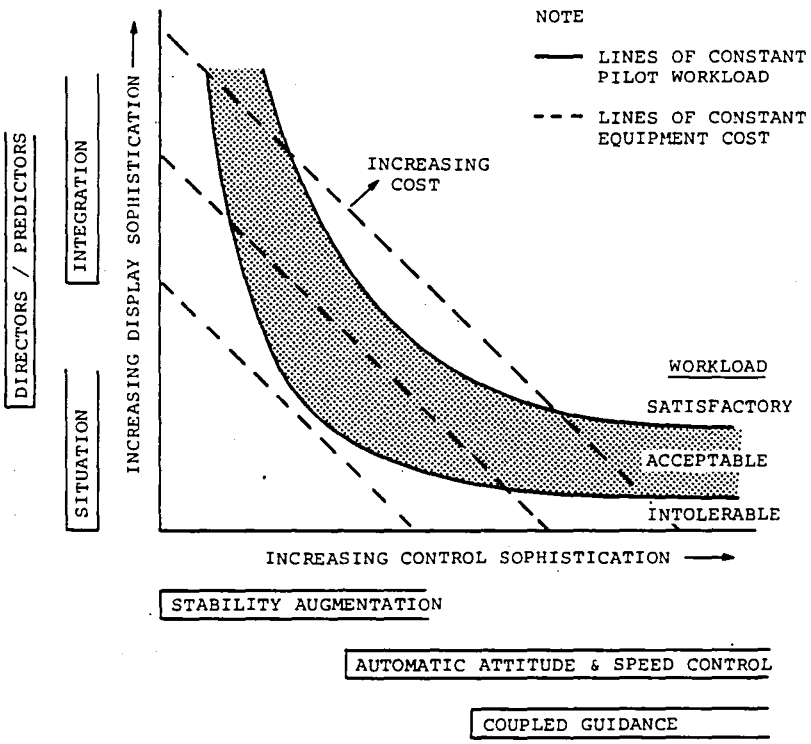


Figure 3. Relationship between control display sophistication.

One of the important considerations will be the degree of control system coupling and automation for the DSAL. Making the system automatic is a straightforward means of reducing the pilot workload; other considerations, however, may prevent this approach. An overriding consideration is cost; the civil market may not support the system if it is too expensive. Secondly, the pilot will require a peace of mind display and must remain in the control loop for taking over in case of an emergency. It may not be cost effective to provide both the peace of mind display and system automation. The third consideration is the type of sensed information; if an approach aid gives angular and Distance Measuring Equipment (DME) information in quantitative form, the coupling will be relatively easy; if the information is presented in pictorial form, such as a TV or high resolution radar image, it may be more difficult to obtain tracking signals. The pilot-in-the-loop consideration is important because there must be an abort capability at any point in the DSAL until past the CDP.

For economy's sake, the redundancy requirement for navigation and sensors will be fulfilled, where possible, by parallel but different type systems that fulfill similar but complementary functions. Failure of any one system will allow completion of the mission but in a degraded mode. For this reason, the pilot must be able to exercise certain manual control functions at any time.

4.2.1.3 Hover on Instruments. The most difficult mode of the near-zero visibility system is hover on instruments. Since we are assuming a 7.6m (25-foot) visibility range, the actual touchdown can be made visually but, for restricted area sites, the pilot must come to a hover over the landing point and make a linear descent. The slow deceleration to the hover point in space will be made on instruments. It may result in hover both in- and out-of-ground effect. To assure safety in this final few meters of the approach, the system must be designed with sensors, controls, and displays for full instrument hover; preferably it should have automatic hover capability with a degraded mode manual hover possible.

To accomplish instrument hover, sensors must provide precise ground velocity information that can be used as input both for automatic control of hover as well as a direct and augmented display readout.

Many experimental simulation and flight test programs have been conducted for instrument hover with various degrees of success. Reference 10 reports on a flight test program in which a UH-1 helicopter was hovered on instruments using a contact analog display augmented with a hover symbol. Flight tests were conducted with four configurations of controls:

- Fly-by-wire unaugmented
- Damper mode
- Attitude hold mode
- Attitude and altitude hold mode

Results indicated that subjects could hover on all four control configurations but with a higher workload than on visual. It was also found that the instrument hover improved directly as a result of increase in control sophistication.

Reference 7 reports on a successful simulated "blind" hover using either a mechanical flight director or an integrated display flight director with aircraft velocity information.

Reference 11 discusses landings with a CRT presenting an image from a forward-looking television camera. Successful landings were made into a 45.7m (150-foot) square landing pad. Workload was reported as very high and hover and touchdown control was reported as very poor.

It has become routine to accomplish automatic approach to hover in many U.S. Navy and U.S. Coast Guard missions. Some of these systems accomplish a programmed automatic approach to a hover from an initial point in space to a hover slightly downwind of a marked target point. The system uses information from an air data system, vertical reference system, accelerometers, heading system, radar altimeter, and doppler radar. The heart of the air data system is a low-speed omnidirectional airspeed system that is accurate to ±2 knots in any direction. The system essentially uses air mass data for control until some altitude point where the pilot gradually transition to ground velocity inputs to come to a hover.

The above-listed research programs indicate that the technology is available for instrument hover; the major question is, can the civil market afford it?

4.2.2 Area Navigation

Operation of rotary wing aircraft in higher density airspace under instrument conditions requires more accurate navigation, altitude, and time control of aircraft than has been necessary in the past. In addition to the requirement for precise flight path control, there must be provisions to avoid obstacles and severe weather. Navigation is very much interrelated with air traffic control; there must be some means of continuous tracking and reporting of aircraft position. The aircraft must also be equipped for operating in icing conditions.

Rapid advances have been made in the past few years in rotary wing navigation capability. Most of these have been due to the advent of microcomputer technology which permits the continuous computation of position, range, bearing, course deviation, and other information. Destination and a number of waypoints may be selected by the pilot. The inputs to the computer can be from a variety of radio navigation or onboard sensors.

In present day systems, these navigation aids are used to bring the pilot to within visual range of the landing site. The final approach is then made visually. In the proposed system, to meet the requirements of the mission model, it is necessary to navigate and approach to a position over the landing pad on instruments; this requires an accuracy not available from any existing system. Also, the lack of visibility requires that redundant systems be available to assure safety.

The principal trade-offs to determine the optimum system are accuracy, reliability, coverage, all-weather operation, and cost. Display type, ease of operation, use saturation level, and workload are also factors to be considered.

4.2.2.1 Accuracy Requirements. Table 1 lists the accuracy requirements of the navigation systems. The data are mainly from Reference 12 modified for the near-zero visibility requirement.

4.2.2.2 Reliability. The reliability of the system must include not only the reliability of the onboard equipment but the reliability and dependability of ground installations. The Mean Time Between Failure (MTBF) of nearly all modern airborne navigators is quoted as several thousand hours and ground equipment operation is rarely interrupted. However, the complete dependence on the onboard navigation and approach system for mission completion requires redundant systems to assure safety.

4.2.2.3 Coverage. The area coverage of a navigation system depends on several factors. Ultra-high-frequency systems are effective only within the line of site of the transmitter. Low flying rotary wing aircraft are often shadowed by rough terrain and by the earth's curvature. Systems affected include VHF Omnirange (VOR), Microwave Landing System (MLS), radars, and ultra-high-frequency (UHF) beacons. Coverage will also depend on transmitter power and placement of transmitters. In hyperbolic systems, accuracy is poor on the baseline between a master and repeater station. To come to a hover on instruments requires precise guidance. If the system is onboard, it requires short-range information not ordinarily obtainable.

4.2.2.4 Weather. Without doubt, the most difficult technical and human factors problem is to provide accurate guidance and displays for the last few hundred meters of the approach, the part that is presently accomplished visually. Several systems such as low light level television (LLTV), forward looking infared (FLIR), and several types of high-resolution radar are candidates to provide precise guidance and pictorial displays for the terminal phase of the mission. These systems operate at a higher frequency than conventional navigational systems and thus require special study, especially in the area of weather attenuation.

The candidate systems must operate in low visibility caused by fog, rain, snow, or clouds. The aerosols in the atmosphere that cause the visibility limitation may also cause severe attenuation of the navigation system signals. Figures 4a and 4b, (Reference 13) show the attenuation of optical-frequency radiation due to fog and clouds. It can be seen that for stable fog and clouds, the optical and IR attenuation is severe. In these conditions, direct-view sensors (such as television or forward looking infrared) are little better than the naked eye. Figures 5a and 5b (also from Reference 13) show that at 10 GHz (X band) microwave frequencies have good penetration of fog and rain, but the attenuation increases with frequency and there is severe attenuation at millimeter wavelengths (94 GHz). These weather effects are the most important trade-offs in selecting sensors for the all-weather system.

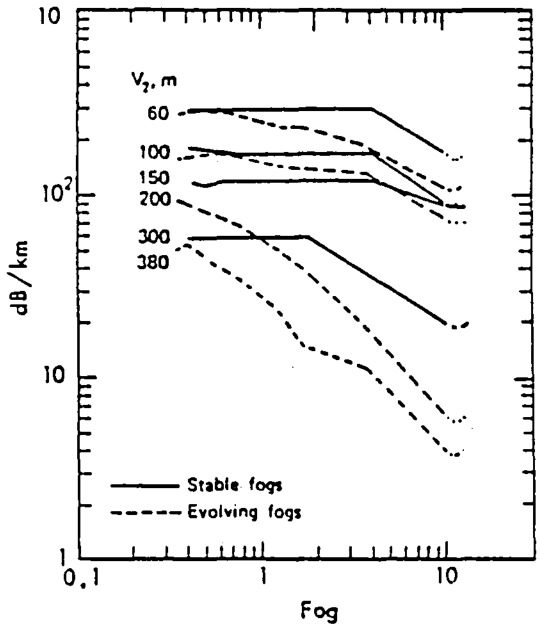
4.2.2.5 Other Characteristics. In addition to the trade-offs mentioned above, there are many other factors involved in choosing a navigation and guidance system; they include:

- System Capacity. The system needs to have unlimited capacity. A DME station saturates when interrogated by about 200 aircraft (Reference 12), and certain beacon transponder systems can only respond to one or a few signals simultaneously.

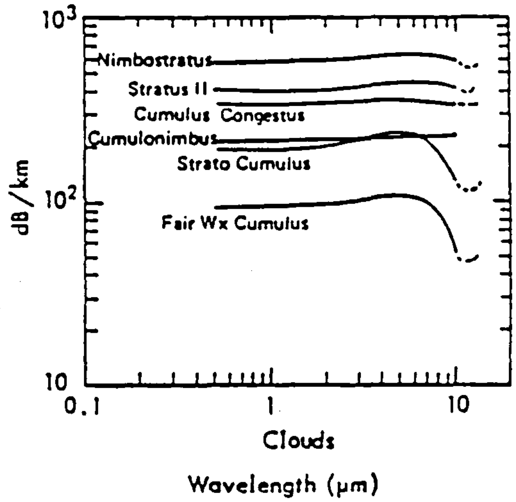
- Noninterference. Onboard systems must not interfere with each other or ground station operation. Ground transmitters and responding beacons must not interfere with each other or airborne equipment.

- Reference System. Systems typically give data in reference to self position. For example, VOR/DME gives rho-theta coordinates are referenced to the transmitter, Loran-C gives position with respect to hyperbolic grid lines. With the advent of microcomputer technology, however, it is relatively easy to transform data to whatever map coordinates are desired.

- ATC Reporting. Accomplishment of a rotary wing all-weather flight system that permits direct route navigation to and approach and landing at urban and remote sites without ground-based aids must include some means of positive air traffic control. This control system must interface with Conventional Takeoff and Landing (CTOL) Air Traffic Control (ATC). Since rotary wing aircraft operate at low altitudes, line-of-site radar tracking is impractical. Therefore, any navigation means

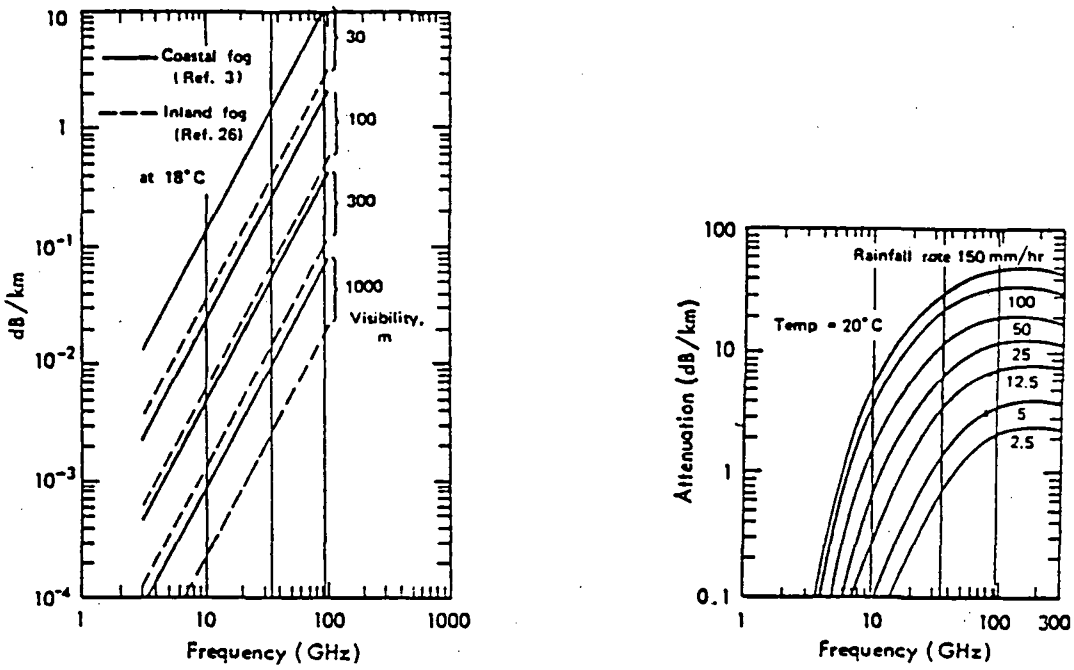


(a) Fog



(b) Clouds

Figure 4. Optical attenuation due to fog and clouds.



(a) Fog (b) Rain

Figure 5. Radio frequency attenuation due to clouds, fog, and rain.

must include or interface with some means of reporting position to ATC.

- Update Rate and Signal Quality. It is often desirable to derive velocity from navigational position signals. If the update rate is too slow or the signal is noisy, it may not be possible to derive velocity.

- Direct Route Capability. To accommodate the great number of missions performed at different and often changing landing sites, the system must enable direct and adaptable navigation routes between sites as long as ATC control is exercised.

- Vertical Guidance. With large numbers of helicopters operating IFR on flexible routes, it will be necessary to have precision vertical control to accommodate crossing patterns and terminal area guidance.

- Obstacle Sensing. The low altitude precision routes will require an onboard means of obstacle detection and avoidance.

- Collision Avoidance. The traffic density will make onboard "see-and-be-seen" collision avoidance a necessity, except possiblly where ATC controls isolated flights in an area.

- Weather Avoidance. Operation in all-weather conditions requires that an onboard means of storm and severe weather detection be available.

- Icing Protection. The routine operation in fog, rain, snow, and clouds will make ice detection and removal a requirement wherever the temperature is below freezing.

4.2.3 Terminal Area Navigation and Heliport Requirements.

The operation of rotary wing aircraft to helicopters and remote limited-use landing sites in visibility ceilings of 30.5m (100 feet) or less requires special attention to the location and design of the landing site. The features that may affect the design of the onboard system include size of the landing pad, cleared area for ground or hover taxi, parking area, adjacent obstacles, 360-degree approach and takeoff obstacle, clearance planes, missed approach point (MAP) clearance planes, wind and wind shear effects, altitude above the surface, and any noise restriction zones surrounding the site. Other considerations may be emergency landing sites in the area, color contrast and markings for use of visual sensors, and contrast and reflectivity to infrared and microwave sensors.

The heliport and surrounding area will have to meet criteria for precision approach approval by the FAA. Presently, helicopter precision approaches are permitted only to airport runways with ground-based landing aids, Reference 14, U.S. Standard for Terminal Procedures (TERPS). Heliports are presently certified only for nonprecision approaches or Precision Approach Radar (PAR) approaches.

In urban areas, and elsewhere, environmental factors such as noise will determine altitudes and flight paths. It is certain that there will be a requirement for much greater 3-D spatial and time precision in routes than has been required in past helicopter IFR operations. A study has been conducted to determine the effects of obstacles and noise on helicopter routes and approach paths in urban areas, Reference 12. Figure 6 shows the utilization of airspace around a heliport near the center of Boston; the obstacle and noise control areas for 152.4m (500 feet) are shown. Similar plots can be shown for other altitudes. Figure 7 shows the obstacle clearance approach angles that are possible at all azimuth angles. The actual approach angles that can be used may be limited by emergency landing sites, wind, and other factors in addition to noise and obstacles.

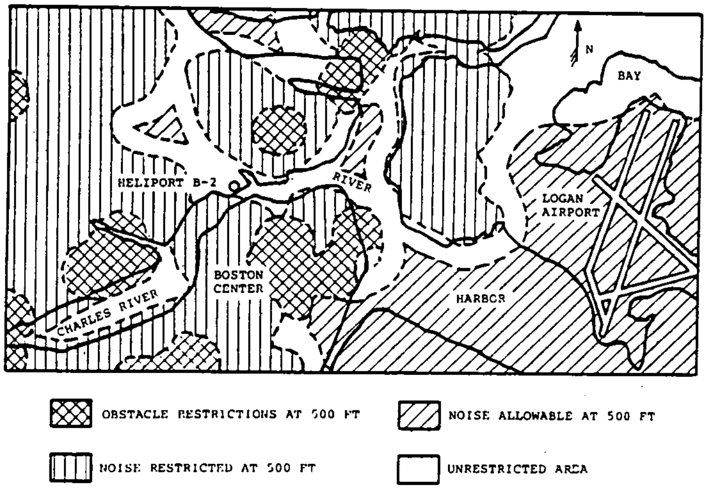


Figure 6. Boston Aerospace Utilization at 500 feet MSL.

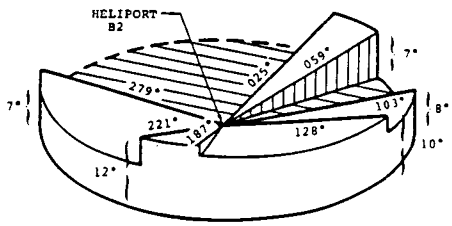


Figure 7. Obstacle clearance approach angles.

The noise on approach can be minimized by certain path control procedures. Reference 15 explains that the noise footprint can be reduced, compared to an arbitrary constant glide slope, by following a noise abatement flight profile. The basic difference in the noise abatement profile is that the descent is initiated before reducing airspeed. Both procedures give approximately the same airspeed during the approach, with the quieter technique using a glide slope which is a few degrees steeper. Once the pilot has transitioned from cruise to the approach glide slope, he can tailor his airspeed and rate of descent to fit local conditions, avoid unsafe regimes, and still guarantee minimum noise. This noise-abatement flight technique reduces the ground area exposed to a given noise level by as much as 80 percent. Figure 8 shows this for a conventional straight-in approach.

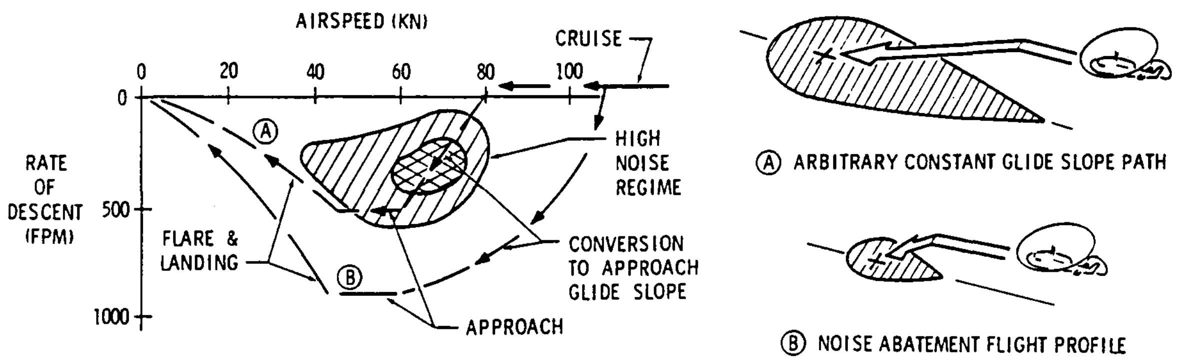


Figure 8. Effect of flight path control on noise footprint.

The major considerations for an onboard navigation and guidance system are how to achieve the precision in an instrument system and a display so that the combined Airborne System

Error (ASE) and Flight Technical Error (FTE) permit safe flight within the segmented and sometimes curved corridors leading to landing sites.

The imaginary surface for heliports, taken from Reference 16 is shown in Figure 9. Of particular significance is the 8:1 slope or 12.5 percent gradient of the approach surface. The Required Obstacle Clearance (ROC) is from 76m (250 feet) to 91.4m (300 feet) in the approach surface area. This clearance plane determines the performance required of the helicopter on takeoff and landing and also the performance required of onboard obstacle sensing equipment.

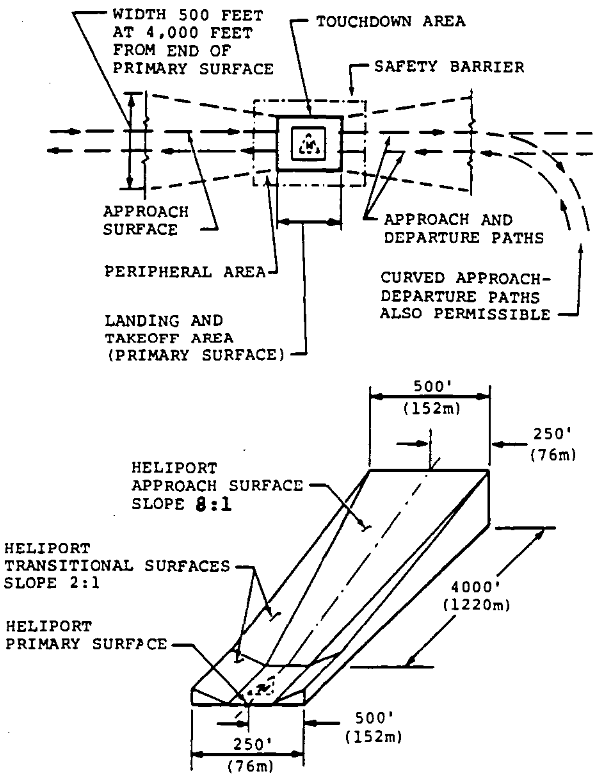


Figure 9. Imaginary surface for heliports.

The limiting factor in setting the obstacle gradient for the heliport will be the takeoff performance. Weight, altitude, temperature, and wind combinations affect takeoff performance as well as the IFR handling qualities of the helicopter. Present IFR helicopters have a minimum allowable flight speed. On a normal IFR takeoff, clearance must be available to accelerate to the safe minimum speed before ascending into IMC conditions. With ceilings below (100) feet, this will not be a practical maneuver. Aircraft performance considerations are discussed at length in Paragraph 4.2.1.

4.2.4 Display Requirements

The displays of the ANGS must provide the pilots with information that permits greater accuracy in navigation, guidance, and control than has been possible in the past. In addition, in order to perform the flight task, information must be presented for flight planning, air traffic control, system status, peace of mind, and obstacle and landing site information.

The area navigation information should be presented on a Horizontal Situation Indicator (HSI). A Cathode Ray Tube (CRT)-type display with modern symbol generation capability is the most promising type display. The survey and follow-up interview results show that pilots like the pictorial aspects of the weather radar horizontal PPI display.

The addition of area navigation information, such as present position, track and distance to waypoint, and destination information (superimposed with the radar image) was suggested as desirable by several pilots. Since the weather radar is almost certain to be a basic part of the onboard system, the radar CRT is the leading candidate for the integrated horizontal display indicator.

The HSI should display the outlines of the air traffic corridor and adjacent traffic. The adjacent traffic will probably be detected by an onboard sensor. The HSI must present the traffic in a manner so that avoidance is possible, e.g., if the radar and navigation information are shown on an 80km scale, traffic within an 8km range must be shown on a smaller scale or the pilot will not be able to distinguish separation, closing paths, and distance of nearby traffic. It would be desirable if track direction, and possibly command avoidance symbols, could be presented. Weather information, such as storm centers can be presented as in present weather radars. Color is desirable for storm center detection as well as for track and symbol information. It would be desirable to present weather situation information from external sources if available, e.g., areas where icing is expected.

The integrated HSI should serve as a tool for flight planning and modification of the plan during flight. Cursors should be available to designate checkpoints detected on the weather or high resolution radar for insertion into the navigation computer.

A combination of obstacle displays in both the vertical and horizontal planes offer the best overall assurance of obstacle avoidance. If obstacles are detected by onboard sensors, then their position can be shown by symbols superimposed on the integrated HSI display. Computed steering symbols can be shown on the vertical display to indicate the best path for avoidance.

Terminal area navigation requires display of the flight path with greater precision than is necessary in area navigation. The flight corridors are narrow and are sometimes curved and segmented. Precise altitude control is necessary for avoidance of obstacles and crossing traffic lanes. The flight paths are often referenced to local geography; the path to a landing site may be down the middle of a river or between two hills.

If a high resolution radar is used, the display should present typical radar Plan Position Indicator (PPI) imagery integrated with such information as command track, obstacle location, and abort routes. If the system has control coupling to aid the pilot, situation information (as well as command and abort information) is required so the pilot can take over control at any time.

Display of traffic in the area will be required for collision avoidance. This information can be relayed from ATC, if available, but more probably will be accomplished directly on a "see and be seen" basis. The display must provide avoidance information, preferably by augmenting symbols that give target position and path.

A terminal area display must show the landing site, and it is very desirable that before the initial approach point is reached that the pilot be able to detect whether the landing site is clear of other helicopters or other vehicles. This requirement may not be critical at an attended site where ground personnel can inspect the site and communicate with the aircraft; but if the system is used for remote sites, the pilot will be apprehensive unless he knows the pad is clear.

The DSAL phase of the flight will be the most difficult display task. There are many display possibilites, including symbolic and pictorial types. There has been much work in this area.

In the DSAL mode, direct view pictorial displays offer the great advantage of increasing pilot confidence, Reference 17. Pilots object to having to follow commands without adequately knowing the approach status, Reference 18. Additionally, failure modes are more readily detected. Pictorial displays, however, must be supplemented with skeletal symbology at a minimum for command, position, rate, and acceleration data, which would include quickening. For example, in a pure contact analog display, it is difficult to judge height; this would also be true of a radar display. Both airspeed and ground-speed sensing must be provided and integrated into display symbology. Translational rate status and command may also be provided, Reference 7. In order to use high resolution radar for a direct view approach and landing display, perspective must be generated to parallel the real world situation. The HELMS display would be an excellent candidate for this purpose. The previous flight evaluation of this display is discussed extensively in Paragraph 4.4.3.3. The principal question seems to be whether or not short range imagery of the landing site (from 0 to 61.0m (200-foot range)) can be displayed with sufficient detail and on a scale such that position and translational cues can be interpeted. Even if this final phase of the approach should be automated, the pilot needs to be able to interpet the display sufficient to be able to take over if required. Symbolic augmentation of the display will also be desirable.

Obstacles in the flight path must be detected and displayed. The method of display is a subject for investigation. Most terrain avoidance and obstacle information in present systems (principally military) are shown on a vertical display. Obstacle information has also been shown on horizontal displays, at least one being in color (Reference 19). Obstacle sensors for the onboard system are discussed in Paragraph 4.4.1.5.

The best candidate for hover display for the system is the integrated HSI. The high resolution radar can have a scale that shows only a few meters range, 360 degrees around the aircraft. One of the questions is: "Can this information be used to show position on the landing pad and X-Y translation with enough definition to hover, assuming a very stable aircraft?" This is an important question because it may determine whether landing can be completed after failure of automatic control and flight director features of the system.

4.2.5 Air Traffic Control Requirements.

This study of advanced navigation and guidance systems for all-weather rotorcraft does not have the specific objective of analyzing or making recommendation for a future Air Traffic Control (ATC) system for helicopters. However, any future capability to operate IFR, independent of fixed reference navigation systems, will require an updated ATC system. The onboard system under study must interface with this ATC system and its design will undoubtedly be influenced by the procedures adopted and the specific technologies for implementation.

Several major problems exist. The radar surveillance system, used for present CTOL traffic control, is a line-of-sight system that does not cover the low altitude areas in which helicopters operate, even around terminal areas; the Very High Frequency (VHF) communications used have the same line-of-sight deficiency; traffic patterns and procedures are designed for CTOL's only.

The FAA has recognized these problems and presently has short- and long-range plans for improvements, Reference 20 and 21. The plans are aimed at using present technology where possible to achieve reporting and control beyond radar surveillance. A test program is planned offshore in the Gulf of Mexico to evaluate a Loran-C Flight Following program (LOFF), where the helicopter position in latitude/longitude and altitude, along with an identifying code will be automatically reported to a central control point ashore. The ground system will consist of a minicomputer with associated peripherals and a display. Complete communications (VHF) coverage of the LOFF area is achieved by a repeater station on an oil rig that receives helicopter transmissions and relays them to the shore station by microwave relay. Scheduled routes are initially planned with ±4 n.mi. widths under VOR/DME coverage to 40 n.mi., then ±50 n.mi. beyond. Altitude separation for crossing patterns is 304.8m (1000 feet). Eventual route separation is planned to be ±2 n.mi. throughout the area with 152.4m (500 feet) altitude separation.

A simulation of independent helicopter IFR routes at hub airports was recently completed by NASA and the FAA, Reference 22. The simulation used Area Navigation (RNAV), MLS and Cockpit Display of Traffic Information (CDTI). Results indicated that "helicopter routes were acceptable to the subject pilots and were noninterfering with fixed-wing traffic." Merging and spacing maneuvers were successfully carried out by the pilots, but controllers had some reservations concerning the acceptability of the CDTI procedures.

In advanced planning by the FAA, consideration is being given to secondary radar surveillance, more accurate RNAV systems, and satellite communications.

Another significant test program has been the Northeast Corridor (NEC) operational evaluation project which was carried out jointly by the Helicopter Association International (HAI) and the FAA. The NEC extends from Boston to Washington, D.C.; an area navigation RNAV route structure was formulated using VOR/DME. The structure included two parallel one-way routes ±2 n.mi. wide between Boston and Washington, D.C., with single spurs to Allentown and Albany and thirteen "point-in-space" (PIS) helicopter discrete RNAV instrument approach procedures (IAP's). See Appendix B for examples of routes.

The NEC evaluation successfully proved the value of discrete helicopter IFR routes independent of fixed-wing traffic. The relatively close spacing of VORTAC's and waypoints permitted traffic to maintain position within the ±2 n.mi. corridor width. The final report, Reference 23, states that "it is very likely that even narrower route widths would be possible with an improved accuracy RNAV system such as NAVSTAR Global Positioning System (GPS) or perhaps Loran-C."

The features of the onboard system that relate to ATC are:

- Along and cross-track positioning accuracy
- Altitude accuracy (barometric and absolute)
- Point-in-space position
- Ability to change flight plan at ATC direction
- Obstacle sensing and display
- Collision avoidance and display
- Holding pattern accuracy
- Cockpit display of traffic

All of these function will be discussed in detail in later sections.

4.2.6 System State of the Art

Recognition needs to be made of the present IFR instrument design and procurement practices, because any successful improvement in IFR capability must be built on the existing technology base and regulatory rules.

Presently, there is very little integration of instrument systems in rotary wing aircraft. The practice is to purchase each navigator, radar, flight director, etc., as a separate unit. If computation is required, it is common for it to be accomplished in each individual system. Only in the newest systems has minor integration been accomplished, such as control coupling to guidance systems and area navigation to weather radar display.

4.2.7 Advanced Technology Considerations

Modern digital-microcircuit techniques are certain to be widely used in future IFR systems. Extensive use of microcomputer computation and control will vastly increase functional capability. The ultimate goal will be a fully integrated system where different units are interfaced to share common data busses for improved efficiency in computation, control, and reliability. Present rotary wing instrument technology is moving rapidly to digital systems such as RNAV and digital radar displays. An effort will be made in the study to use the latest technology in such a manner that it can be interfaced with present equipment and also be used in future integrated systems. An example is to use equipment built for a common data bus but also with inputs and outputs for use on an individual basis.

4.2.8 Regulatory Agency Considerations

The system or systems recommended by this study must be certified to the operational and safety regulations of the FAA. There are two aspects of these regulations to be considered. One is the fundamental role of the agency in assuring safety: any system, failure of which can cause a flight to end catastrophically, must have a backup system, unless the failure probability is very remote. The second is the set of rules that defines limits based on present equipment capability, rules that can reasonably be expected to change if system capability improves.

The safety rules will have a significant effect on control and navigation system redundancy where visibility is virtually zero and there can be no backup visual mode. A failure logic analysis is discussed in the tradeoffs for candidate systems in Section 5.

The set of rules that define present limits were reviewed when candidate systems were examined. Particular attention was paid to FAA programs and plans for improvement and modernization of helicopter regulations. Included in the analysis are the FAA Helicopter Operations Development Plan (Reference 24), HAI-FAA Helicopter Work Shop Final Report, and the Project Plan for All-weather Heliports were also used. Attention has been given to these plans in considering the alternate techniques and systems for the ANGS onboard system.

4.2.9 <u>Cost</u>

Civil helicopter operations are principally profit-making enterprises. Operators must use cost-effective equipment to compete. Any additional cost for IFR equipment to extend operations to lower minimums must pay for itself in increased revenues. The survey shows that many operators believe a significant increase in cost could be justified; however, many others are skeptical and cite cost as the greatest impediment to achieving all-weather capability. Consquently, cost will be considered a major trade-off consideration.

In order to perform trade-offs, it is necessary to know the relative costs of the various systems. Since many of the systems under consideration exist only in R&D form or, in some cases, only on paper, good cost data do not exist. Therefore, it is necessary to estimate the cost. Two types of cost will be considered, investment cost and operational support cost.

Investment costs will be the estimated purchase cost of an item after it is in production. No R&D cost will be considered. The production cost of an item in development will be estimated by comparing the system with a production item of similar complexity.

4.3 <u>CANDIDATE SYSTEMS</u>

Many different sensors and components have application for the ANGS. The characteristics of each must be reviewed to determine feasibility. The suitability for integration into the system must then be determined.

4.3.1 <u>Controls</u>

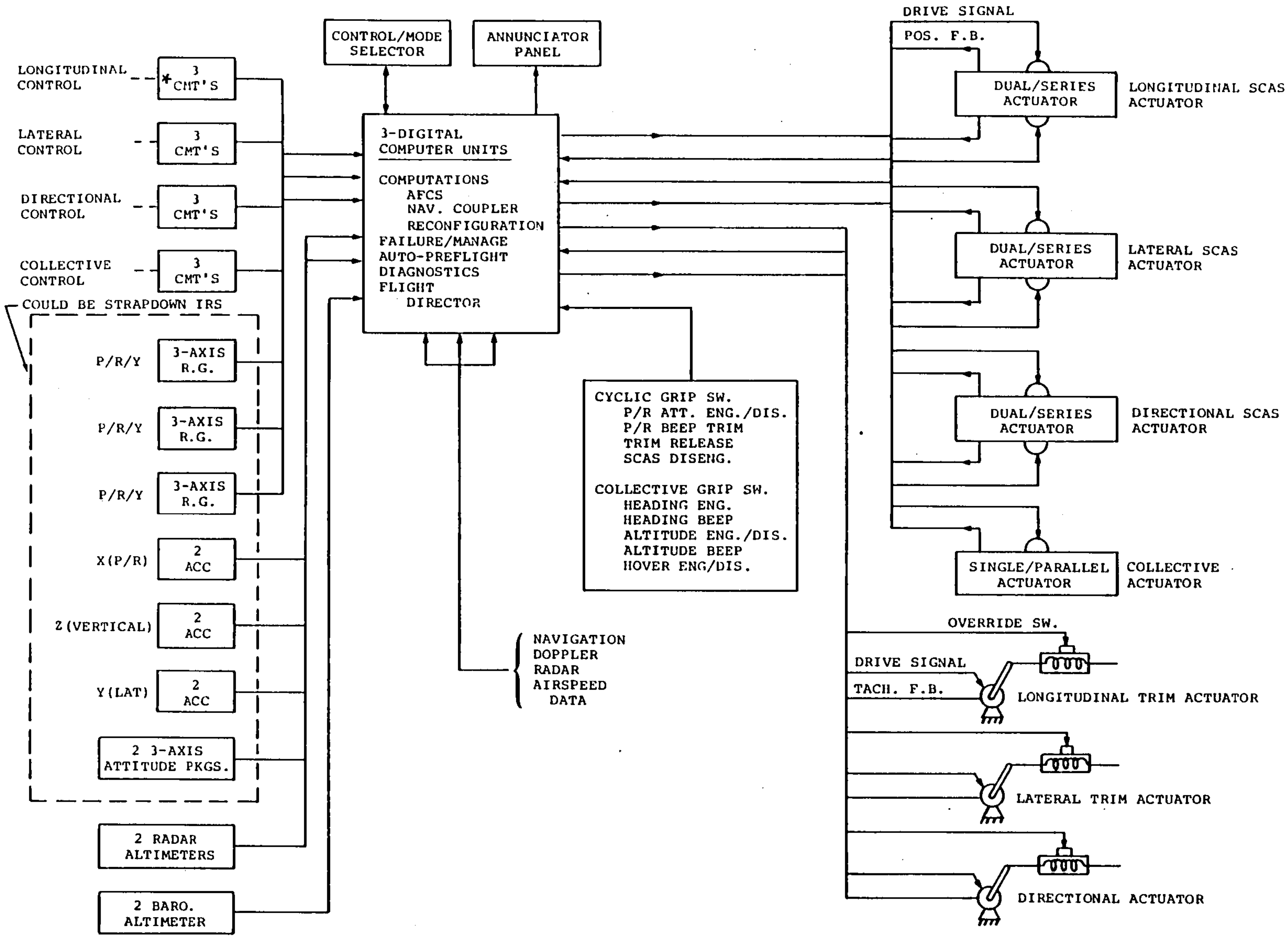
The requirement for improved stability of the low visibility system aircraft has been discussed at length. The military has shown that technology exists to design control systems for the DSAL function. The principal question is: "Can a system be designed that will meet performance requirements and certification standards of the FAA and that can be afforded by the civil market?"

Present modern civil helicopters of medium size and larger all have available production dual automatic flight control systems with fail-safe features. These control systems all include various stability augmentation, automatic trim, coordinated turn, and self-test features. The trend is toward digital systems that by use of microcomputer control, can have large capacity for couplers, programmers, and computed functions. The most expensive portion of a modern automatic flight control system is generally the servo trim and hold actuator components. The digital electronics portion, even if it is sophisticated and redundant, represents a lesser proportion of system cost. Since most modern helicopters already have the actuator components, a considerable amount of computation, programming, and coupler features needed for the ANGS can be added for modest additional cost.

The proposed control system is based on the existing dual control system of the baseline aircraft. The principal additions are triplex redundant flight computers with flight director and approach profile computations. The system is shown in block diagram form in Figure 10. The system has an architecture in which the first failure does not affect system performance. The roll and pitch dual series servos and trim functions are derived from parallel computation that are examined and compared by the computer to prevent hardovers and provide the fail-safe feature. Any first failure is automatically detected and turned off with full control capability remaining. Successive failures gradually degrade system performance, always in a fail-safe mode. The parallel trim actuators provide slow but large correction inputs for trim changes in the aircraft. Should mission needs dictate large changes of trim position, degradation will result from failure of these actuators. Examples of situations demanding large automating trim chages are:

- Overall change in airspeed of ≧40 knots
- Change of heading while hovering in winds ≧40 knots
- Large changes in lift due to gain or loss of ground effect or vertical shears, such as at building edges or cliff's edge.

The system shown uses triplex digital processors to provide management of all signals, self-test, and failure management.



47

*Control Motion Transducer

Figure 10. Control system block diagram.

The reversion to degraded modes is managed better since available signals and command lines can be reconfigured in optimum ways, perhaps using Kalman filtering to estimate variables using other than the normal signal sources. Also analytic redundancy can be used in fault management. Table 2 gives system failure effects.

TABLE 2. SYSTEM FAILURE EFFECTS

Item	Effect of Failure
Stability Augmentation System (SAS)	First failure results in less authority - slight increase in pilot workload
Radar	Approach abort
Computer	First failure no-effect 2nd failure - approach abort
Doppler or Radar Velocity	Increased workload at final 200 feet
Radio Nav Aids	Increased workload during area approach
Air data	Abort if wind is high otherwise increased workload
Radar Altimeters	First failure no effect 2nd failure abort final 200' if breakout not achieved
Barometric Altimeters	First failure no effect 2nd failure uses radar altimeter unless over vertical objects (urban area) then abort

The system provides 4-axis attitude and collective hold with a pilot fly-through capability in all axes. Coupled operation causes the system to follow computed flight director commands in pitch, roll, heading, and collective. Pilot fly-through can override the coupler at any time.

The flight director computer (FDC) receives inputs from the sensors and, using a stored program and pilot-selected functions, generates steering commands for the flight director displays and the flight control system. An example of the programming function is the DSAL. The programmer can generate a programmed path based on a scheduled turn into the IAP from some approach gate entered by the pilot from observation of the area navigation or the radar display. From the initial gate, the FDC (from a stored program) signals the control system to turn into the IAP at the proper altitude, and set up the DSAL along the preselected glideslope and with a constant controlled deceleration. Simultaneously, the flight director will be controlled so that if it is necessary in a backup mode (or if he prefers) the pilot could fly the approach using the flight director. The path will also be shown on the integrated HSI.

4.3.2 Area Navigation Systems

There are many Area Navigation Systems that could possibly be used for ANGS. Some of them are ruled out of this study because of complete dependence on local ground equipment at each site such as Multilateration systems that depend upon precision ranging measurements to ground installations. Others are ruled out because of unavailability in most parts of the US, such as Decca. The systems examined are the ones that are available as onboard systems or use onboard systems that receive signals from established navigation systems with ground transmitters that cover wide areas.

4.3.2.1 VOR/DME/TACAN The VHF omnidirectional range (VOR) and distance measuring equipment (DME) systems provide the basic guidance for en route air navigation in the United States. VOR provides a bearing referenced to the ground station and DME provides distance.

VOR operates in the VHF (112-118) MHz band with channels now spaced 100 KHz apart and soon to be reduced to 50 KHz spacing. The airborne receiver that has a horizontally polarized antenna measures the phase difference between a 30 Hz omnidirectional signal and a directional signal rotated at 30 Hz to give bearing to the ground station. The overall system accuracy, including avionics, has an accuracy of ±4.5 degrees (95 percent).

DME is a pulse-ranging system that operates in the UHF (960-1215 MHz) band and provides distance-measuring information with an accuracy of 0.5 n.mi. or 3 percent of slant range, whichever is greater (95 percent). TACAN (Tactical Air Navigation) is a military omni-bearing and distance-measurement system using the same pulses and frequencies as DME. Vortac is the colocation of VOR and TACAN. The standard displays for the system are a panel-mounted bearing indicator showing direct bearing or a left-right needle showing deviations from selected bearing. The distance is commonly read out on a digital counter.

The ANGS IFR helicopter will have need of VOR/DME capability even though it has alternate onboard systems for precise navigation and approach. The VOR/DME basic capability can be used as a degraded mode system to approach an airport if other navigation systems fail. Probably the major use of VOR/DME is for inputs to the computer-generated R-NAV system.

4.3.2.1.1 VOR/DME R-NAV. A recent development in area navigation for helicopters is to use an R-NAV System that takes inputs from VOR/DME and computes position and track to destination waypoints selected by the pilot.

4.3.2.1.2 VOR/DME Disadvantages. The VOR/DME system is unsatisfactory for primary navigation for the ANGS because it is a line-of-sight (LOS) system and cannot be received at low altitudes in many of the remote sites that helicopters operate. This limitation prevents offshore reception at many of the distant oil rig sites. Many remote sites, even in relatively flat terrain, are out of LOS of two VOR stations, and the system has severe limitations in rough and mountainous terrain.

4.3.2.2 Loran-C. Loran-C is a pulsed hyperbolic navigational system, originally developed by the military that has been selected by the U.S. to provide radio navigation for marine use in the coastal and confluence zone (CCZ). It has been widely used by offshore helicopters and, in some cases, over land as an area navigation system. Loran-C was mentioned in the operators survey as the most preferred helicopter navigation system.

A Loran-C chain normally consists of a master and two or three shore stations seperated by 600 to 800 miles. Figure 11 (Reference 24) shows the near-term coverage for continental United States. One station, designated the master station, transmits a pulse that is received by the other stations and rebroadcast after a fixed time delay at each station. A receiver receives the signals from two or more stations and calculates position with respect to the stations, by time delay and phase information on the signal. The transmitter operates in the 90 to 110 KHz frequency band. Ground wave range is typically 600-1400 n.mi. over seawater. The skywave signals can be received at a much greater range but are much less accurate. The absolute accuracy is at least 0.25 n.mi. (2 drms) (Distance Root Mean Square) in defined ground wave coverage areas using automatic receivers of current design (Reference 24). The reported repeatable accuracy, which is the capability to return to a previous site, is 12.2m to 91.5m (50 to 300 feet).

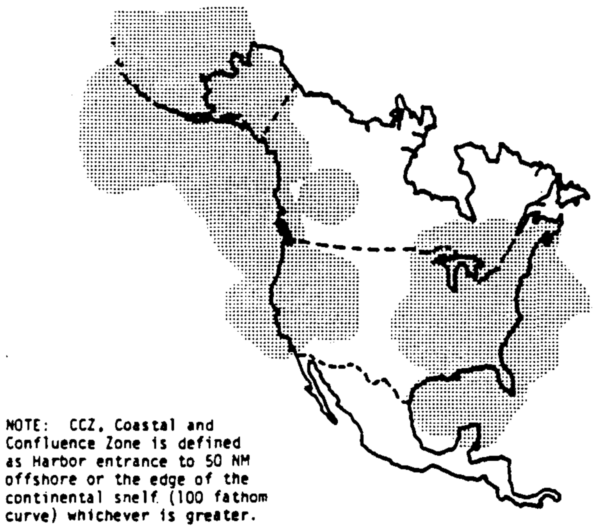


Figure 11. Near-term Loran-C coverage.

Modern Loran-C receivers have microcomputer control to automatically search for the stations, select the proper cycle, and track the signal. They have memory that stores Loran-C data and waypoint information. The computer calculates latitude/longitude from time-distance data and also the reverse. Nine or more waypoints can be programmed, with range and bearing shown to the next waypoint. Other functions common to modern navigational systems are available in many Loran-C navigators.

The accuracy of Loran systems is dependent on position with respect to the chain stations. Atmospheric noise is a source of error and varies with signal-to-noise ratio, which varies with range. When plotting position from signals from two stations, accuracy is poor near the baseline of the two stations. Proprogation anomalies can also be a source of error, although for operation in a specific area these anomalies can be compensated for.

There have been several evaluations of Loran-C for airborne use and the FAA Helicopter Operations Development Plan (Reference 24) includes a specific plan to evaluate Loran-C to determine its suitability for helicopters and to recommend guidelines for FAA implementation of its use in helicopters.

Reference 25 reports on the flight evaluation of Loran-C as an aid to landing for general aviation. The general conclusions were that Loran-C appears to offer the signal availability, reliability, stability, accuracy, and coverage necessary to provide continuous navigation capability from airport surface to any flight level. Flight tests into conventional airports in Vermont were made using a standard TDL 711 Loran-C set in a light fixed wing aircraft. After a computer memory change was made to improve the accuracy during the flight test, 54 approaches were made with a standard deviation in cross track of 60.6m (199 feet). Probability of error ≦182.8m (600 feet) was 100 percent. This is a case of repeatable accuracy.

Reference 26 reports on an evaluation of the system accuracy of the AN/ARN-133 Loran-C navigator and a demonstration of its use in the Northeast Corridor for nonprecision approaches, and as an aid to point-in-space approaches. It also reports on its use for navigation over water to ships and offshore oil rigs.

A comparison of measured AN/ARN-133 total system accuracy (at NAFEC) compared to AC 90-45A requirements is shown in Table 3:

TABLE 3. LORAN-C ERROR COMPARED WITH AC 90-45A REQUIREMENTS

	Crosstrack		Alongtrack	
	AC 90-45A (n.mi.)	Loran-C Measured (n.mi.)	AC 90-45A (n.mi.)	Loran-C Measured (n.mi.)
En route	2.5	0.6	1.5	0.2
Terminal	1.5	0.5	1.1	0.6
Approach	0.6	0.5	0.3	0.5

The navigation performed was within the reduced en route widths of the Northeast corridor. Measurements were taken while transitioning to and from the Northeast Corridor utilizing the Sikorsky, Mack Truck, RCA, and New York Airways routes. The track keeping error in the spur routes was comparable to the en route Northeast corridor results. The following overall performance obtained is shown in Table 4.

TABLE 4. LORAN-C NAVIGATION ACCURACY IN NORTHEAST CORRIDOR

Error Quality	Maximum ±2σ Spur Route Data* (n.mi.)
Total System Crosstrack Error	0.95
Flight Technical Error	0.25
Airborne System Error	0.70

*These ±2σ error values include radar tracking errors.

The Loran-C navigator provided accurate and repeatable guidance to offshore oil rigs regardless of oil rig cluster density. The total system crosstrack errors on the long flights over water (150 to 200 n.mi.) ranged from 0.2 to 0.25 n.mi. and along-track errors ranged from 0.30 to 0.42 n.mi.

The 2 drms repeatable errors ranged from 115m (378 feet) to 517m (1698 feet). It was reported that the Loran-C navigator reduced work load during the oil rig approaches.

Reference 27 reports on a West Coast Loran-C flight test. In this test, which was of a single TDL-711 navigator, the navigator did not meet the accuracy requirements of AC 90-45A for nonprecision approaches. The error performance in approaches to five different airports is shown in Table 5.

TABLE 5. NAVIGATION SENSOR ERROR PERFORMANCE

	CROSSTRACK nm		ALONG TRACK nm	
	Mean	2σ	Mean	2σ
AC90-45A REQS	---	.30	---	.30
Klamath Falls (FMG)*	.07	.24	.04	.13
Lake Tahoe (FMS)	-.33	.11	.39	.27
Lake Tahoe (FMG)	.17	.15	-.48	.22
Grand Junction (FGS)	-.21	.40	.00	.15
Reno (FMS)	-.11	.09	.76	.33
Stead (FMG)	.20	.45	.22	.26
Stead (FMS)	-.85	.19	-.18	.37
Test Aggregate	-.10	.49	.14	.71

*F-Fallon, Nev., G-George, Wash., M-Middletown, Cal., S-Searchlight, Nev.

The authors report indicated that bias shifts (a warping of the Loran grid), geometric dilution of precision (GDOP) caused by unfavorable line of position crossing angles, and signal propagation errors all contribute to the inaccuracies. It was also observed that errors in waypoint or station selection could be catastrophic unless there was a backup system for checking gross position. The report also explained that since the test was conducted, software modifications had been performed that should improve the system accuracy considerably.

4.3.2.2.1 Loran-C Low-Cost Review. A study has been recently completed, Reference 28, to determine if it is practical to develop a General Aviation Loran-C Receiver that can perform all functions necessary for R-NAV within the U. S. National Airspace System. The goal was for costs to be competitive with other available area navigation equipment or to meet a cost to the user of $3000.

A summary of the selections from the trade-off analysis is given below:

- Conventional, rather than two-station range-range, position determination methods were selected.
- The system will operate in the master independent mode if the master station signal is lost. The system will track all receivable stations within a chain.
- Dual chain operation will be provided.
- Propagation anomaly compensation will be completely automatic and will cover the entire United States.
- All waypoints will be designated by bearing and distance to a navigation reference point (usually a VOR station).
- A minimum capability for storage of four waypoints is required. (Since there is no cost impact, nine waypoint storage will be provided.)
- Dual (top and bottom mounted) antennas will be provided to improve reception during periods of high P-static.
- Either a linear or hard limited receiver can meet both performance and cost requirements.
- Two fixed frequency notch filters are needed for rejection of near-band interferences.

· A single microprocessor, the Intel 8088, is recommended.

The Loran-C navigator would be fabricated in two boxes, a Receiver Control Unit 12.5 x 7.6 x 4.8 inches with a weight of 8.6 pounds. A control display panel that fits into the instrument panel and two E-field antenna coupler units, one of which mounts on the top of the aircraft and one on the bottom. The dual antenna installation is used to reduce P-static noise.

The calculated accuracy of the low-cost Loran-C unit is 250 feet (RMS). It was concluded that the unit could be available to the user within the $3000 cost goal.

4.3.2.2.2 Loran-C Application to ANGS. The Loran-C system has much promise as an area navigator for the ANGS. Its advantages and disadvantages are summarized below.

Loran-C Summary

Advantages	Disadvantages
Low Cost	No coverage in U.S. Central and Rocky Mountain states and in many other parts of the world.
No line-of-sight problem	Accuracy poor near two station baseline.
Good accuracy for Area Navigation	Anomalies in propagation.
Available in most areas	Errors in waypoint or station selection could be catastrophic.
Easy to use	

4.3.2.3 Omega/VLF. Omega is a world-wide navigation system for use by civil and military air and marine users. It is a VLF (10-14-KHz), continuous wave, phase comparison, circular, or hyperbolic system. Eight stations can provide worldwide coverage. The accuracy of the system depends on geographic location, station pairs used, propagation corrections, and time of day. The phase of the Very Low Frequency (VLF) signal is quite stable, but diurnal variation in the velocity of propagation requires compensation. A major source of error is the broad-band atmospheric noise at the receiver. The reported accuracy of the system is 1-2 n.mi. RMS, Reference 29.

In the 10.2 KHz Omega system, isophase lines or lanes are formed about every 8 n.mi. A two-frequency receiver, using also the 13.6 KHz lines of position, can provide lanes 24 miles apart by using the beat between the 10.2 and 13.6 KHz (3.4 KHz). A user of the Omega system must know his position within the accuracy of his lane width or he will have an ambiguous position.

There are also a number of Navy VLF communication stations operating in the 14-30 KHz range that can be used with Omega receivers for navigation. The VLF transmitters emit a phase stable, high power signal; by using a multiple fixed tuned receiver, a common intermediate frequency for phase measurement, and a computer, navigation position can be obtained. The VLF station method is also subject to the lane ambiguity problems discussed above.

The equipment required for Omega/VLF is a receiver/processor, control display unit, and either an E or H field antenna and coupler. Weight of a typical system is from 25 to 40 pounds. Presently, Omega-airborne sets are more costly than Loran-C equipment, but there are predictions that VLSI circuitry will substantially reduce the cost.

The Omega/VLF system has the advantage of worldwide coverage, but the accuracy is insufficient for navigating over land in U. S. air space nor does it have the accuracy for precision approaches. The problems of lane ambiguity can be solved by using multiple-frequency receivers, but such receivers are more complex than single-frequency receivers and costs are higher. The basic Omega/VLF system is not a good candidate for the onboard navigation and guidance system.

4.3.2.3.1 Differential Omega. Differential Omega uses a ground station at a known geographic location to measure the Omega propagation error and transmit it to a user in the local area for correction of his own position. The error due to propagation variation would be reduced to the difference in the error at the aircraft and at the reporting station. The error would be on the order of one-half mile at 200 miles separation between the stations. The differential mode has the potential of reducing the position error to 335 to 580m. The remaining substantial error, plus the disadvantage and cost of the ground system, makes differential Omega a poor candidate for the onboard navigation and guidance system.

4.3.2.4 GPS. The NAVSTAR Global Positioning System (GPS) is a DOD space-based navigation system. GPS, when fully developed, will consist of 18 satellites in six 12-hour orbits each with 3 satellites. The system will provide the user with continous 24-hour precise position, velocity, and time information, any place on the globe, in all-weather conditions. The system contains a ground control segment and the user segment.

The control segment tracks the satellites, determines orbital parameters, and transmits them to the satellites. The satellites continously transmit their own position, and clock accuracy and information as to the entire system position.

The user position is determined by measuring its range to four satellites by measuring the transmission time of the signal from each satellite. The user velocity and clock frequency offset are determined by measuring the rate of change of psuedo (or delta) range to the four satellites.

Since the system is global and is accurate enough for weapons delivery, the Department of Defense desires to deny its use to potential enemies. This is accomplished by deliberately contaminating the satellites' signals and providing authorized users with the necessary information to recover the signals. Thus, the GPS system will provide guaranteed accuracy only to the military users who have the code to recover the signals.

The satellite signals are transmitted on two frequencies, 1575.42 MHz (L1) and 1227.6 MHz (L2). L1 and L2 are modulated by either (or both) a 10.23 MHz precision (P) signal and/or by a 1.023 MHz clear/acquisition (CA) signal. Each of the binary signals is formed by a P or C/A code, which is module-2 added to 50 bps data. The P and C/A signals are module-2 added to L1 and L2 in-phase quadrature. The user duplicates the code being used, and the transmission time from the satellite is determined by the offset that must be applied to synchronize it with the code broadcast from the satellite. The unfiltered 3D accuracy of operation with the P code can be expected to be about 16m (1σ) and with the C/A code about 32m (1σ), Reference 30.

The C/A code accuracy has been better than anticipated during early flight tests causing the Defense Department to incorporate a capability to selectively degrade C/A code "worst case" position accuracy to 200m Circular Error Propability (CEP), Reference 31. DOD has announced that this degradation signal will be relaxed in time with decrease in threat to national security. No time is given, so the civil operator cannot depend on better than 200m CEP accuracy with the basic GPS system as planned.

4.3.2.4.1 Differential GPS. There is a method for improving the accuracy of the degraded C/A signal; it is called differential GPS. The differential GPS uses a ground unit at a known local site to receive satellite signals and continuously determines errors present in received navigation signals by comparing computed position with the known coordinates of the calibrated site. The transmission error is then transmitted to the user set for correction of its own position.

Three possible types of differential GPS:

- Data link
- Pseudolite
- Translator

The data link type receives GPS signals and determines error corrections by comparing its benchmark position with its computed position. These error corrections are data linked to GPS-equipped helicopters in the area to correct their onboard position solutions. The data link differential system requires the ground installation and the data link equipment in addition to the basic GPS receiver.

The pseudolite type differential system computes corrections by the same method as the data link type. It also generates its own PN code and navigation message and transmits it to the user on the GPS L2 frequency along with correction data for the GPS satellites. This is, in effect, a ground-based or pseudo satellite. The pseudolite has the advantage of not requiring an extra data link on the aircraft but at the expense of a more complex ground installation. The pseudolite type may also require an extra antenna on the aircraft.

The translator type affects the frequency of GPS signals received at the ground station and retransmits the signals to the airframe receiver on another L band frequency, Ln. The airborne set computes the corrections by knowing the position of the ground station. In this method, the ground equipment is simple, but the airborne unit is much more complex than is necessary for the basic GPS receiver. The airborne unit requires two antennas: a multichannel GPS receiver, and a translator to retranslate the ground station signal.

Table 6 from Reference 31 gives a summary of calculated GPS conventional and differential mode performance. The 2σ values are shown for comparison with FAA navigation system accuracy standards that are shown in Table 7. The report indicates that the calculations were made using a C/A code receiver with a substantial noise component. It is pointed out that several software techniques could be used to reduce receiver noise effects. These techniques could be expected to reduce the receiver noise by a factor of 2 or 3. This would improve the differential mode accuracy significantly.

TABLE 6. CALCULATED GPS PERFORMANCE SUMMARY

GPS Signal	2σ Single Axis Error (Meters), DOP = 2.5	
	Conventional Mode	Differential Mode
P Code	18	2.6
C/A Code	28	10
Degraded C/A Code*	400	18

*Hypothetical

TABLE 7. FAA NAVIGATION SYSTEM ACCURACY STANDARDS

Operational Phase		Minimum Altitude	Accuracy (2 drms)	
			Lateral	Elevation
En Route/Terminal		152.5m (500 ft)	4 NM	500 M
Approach and Landing	Nonprecision	76.2m (250 ft)	2 NM	100 M
	Precision Category I	30.5m (100 ft)	±9.1 M*	±3 M*
	Precision Category II	15.2m (50 ft)	±4.6 M*	±1.4 M*
	Precision Category III	0m (0 ft)	±4.1 M*	±0.5 M*

*2σ

The GPS has potential for use as an RNAV system for terminal area navigation and for a final approach system. It has the advantage of having universal coverage and potential capability for excellent 3-dimensional accuracy.

4.3.2.4.2 GPS RNAV. The incorporation of a navigation computer into the GPS set permits the calculation of 3-dimensional position plus ground speed, ground track, and precise time. It can also have the capability of distance and bearing display to nine or more waypoints that can be entered by a keyboard panel. The unit can be configured to drive Numeric, CDI, or HSI type displays.

A test of the GPS differential mode was made at the Yuma Proving Grounds test range during early GPS system tests. The tests were made using a five-channel receiver in a test set up where the differential ground station was received on the fifth channel. The tests were conducted with a UH-1H helicopter around a box pattern with 4 legs of approximately 10 Km each. In the nondifferential mode, errors were from 20m to 40m; with the differential mode, the errors dropped to 5m, Reference 30. This demonstrated that the improved precision calculated for differential GPS can be achieved in practice.

User equipment for GPS has been produced with four levels of sophistication. Three military versions have been produced, a 4-channel "X" set that has high accuracy in high dynamic environments. A second "Y", a 1-channel set, has been designed for low dynamic vehicles. A single-channel manpack set has also been produced. All of the military sets receive both the P and CA code signals.

A fourth unit, called the "Z" set, has been produced for civil users; it is a low-cost set for low dynamic users and receives only the CA code on a single channel. This is the user set that has the most promise for the helicopter market. The set consists of a receiver-processor, RF amplifier, and a control-indicator. Waypoints can be entered from the control-indicator unit; bearing and distance to the next waypoint are computed and displayed. The outputs could be interfaced with a navigation display.

There have been a number of low-cost user studies, Reference 30. The type Z set, which had been developed for Phase I of the GPS program as a military low-cost prototype, was targeted at a production cost of $10,000 (1973 $).

4.3.2.4.3 GPS Helicopter Potential. The GPS has application to all-weather helicopter IFR systems on several levels of sophisticaton. The universal coverage, 3-dimensional positional measurement and time capability, immunity to weather, vertical velocity measurement capability, and in some cases high accuracy, make it a very promising system. Glen A. Gilbert, Reference 32 and 33, has written extensively about its use for helicopter operations and has recommended an extensive development and evaluation program to prove its value in improving helicopter navigation and guidance.

It appears that the guaranteed minimum accuracy of 200m CEP, using the degraded CA code, will be suitable for an enroute RNAV system. This 200m (660-foot) accuracy may also be suitable for some terminal area navigation; but where precise routes are necessary to avoid obstacles or control noise, better accuracy may be necessary.

The use of the differential mode will improve the accuracy sufficiently to make nonprecision approaches. It has the potential to make Category II approaches but a display/ flight director system will be necessary to assure a combined system/ flight technical error small enough to assure safe approach to a heliport. Present calculated error for degraded CA code differential mode is too great for use with the near-zero visibility system.

If it could be resolved that civilian users would have access to the P code, then a P code differential mode would have possibilities as an approach system for the near-zero visibility operation.

The anticipated widespread use of GPS has the promise of high volume production of user sets; this should lower the cost of civil aviation units. The low-cost Z set has promise of eventually being cost competitive with Loran-C and Omega navigators. The use of the differential mode, however, will increase the cost of the airborne user set from 20 to 50 percent, Reference 31, plus the cost of the ground installation which may be 200 percent of the airborne unit cost. In cases where large numbers of helicopters operate repeatedly from a site, the initial and maintenance cost of the ground unit could be amortized among many users; the ground unit would be a major handicap for less frequently used sites. The initial cost would be significant, but probably the continual verification of performance and maintenance would be the most costly item. The necessity of the ground unit does not completely fulfill the requirement for helicopters to be independent of ground aids.

The potential future use of the differential P code for precision approaches would require the more expensive X or Y type sets. There would be the necessity for flight path computers, couplers, and flight directors as will be required for any other Category III approach system. The existence of 3-dimensional position, velocity, and time from the GPS signal may eliminate certain altimeter and ground velocity sensors necessary with other navigation systems. A comparison of GPS and other competing navigation and guidance systems is contained in Paragraph 4.3.3.

4.3.2.5 <u>Nondirectional Beacons (NDB)</u>. Because of its simplicity, reliability, and low cost, the NDB will remain useful as a primary or backup component of IFR systems well into the future. Operating through frequencies of 0.19 to 1.75 MHz and with ranges of 15 to 75 nautical miles, the NDB's (sometimes called compass locators) are used in conjunction with airborne receivers having directionally sensitive antennas (Automatic Direction Finder or ADF.)

The usable range for a particular beacon will vary as a function of skywave and groundwave propagation, and aircraft altitude. Relatively large system errors can also accrue from these ambient conditions, as well as from lack of sophistication of the typical ADF installation. Nonetheless, NBDs are attractive for offshore use because of their small size and cost. Numerous installations are therefore practical within an area of operations. NDB/ADF approaches are thus an excellent backup for the ANGS.

4.3.2.6 <u>Doppler Radar</u>. A Doppler Radar Navigation is an onboard self-contained dead-reckoning system that measures aircraft velocity that is used along with a directional sensor to compute position, track, waypoints, and other navigational parameters. The system operates at a frequency of approximately 136Hz. Velocity is obtained by measuring the doppler shift in multiple beams to obtain X Y velocity. Doppler navigation has many advantages for the onboard system; they include:

- All-weather operation.
- Completely self-contained. (No limits to coverage)
- Continuous velocity information. (Can be used for approach and hover controls.)

The major disadvantages are:

- Dependent for azimuth information on external sensor (usually largest contributor to position error).
- Position information degrades with distance.
- Vertical reference information is required to correct velocity information to earth coordinates.

There are three major contributors to the position error of doppler navigation: the doppler radar, the heading and attitude reference system, and the computers. Modern systems generally have a CPF of from 0.5 to 1 percent of distance traveled. Typically, 0.3 percent of the error would be contributed by the doppler radar and computer with most of the rest of the error being contributed by the heading reference system. A typical modern doppler navigation will weigh from 20 to 30 pounds. The cost of the complete navigator in quantity is expected to be $25,000 to $35,000.

It may be possible to accomplish the navigation calculations in another computer so that only the doppler radar components of the doppler navigator are required. The doppler radar components alone could be expected to weigh 15 to 25 pounds and cost $15,000 to $25,000.

4.3.2.7 Inertial Navigators. The inertial navigator is a self-contained dead-reckoning system in which gyros and accelrometers are used to determine the movement of a vehicle through space. Conventional systems use gimballed platforms that are kept level by rotating gyroscopes generating torquing signals to keep the platform aligned to local level. Accelerometers mounted on this leveled platform detect aircraft acceleration from which velocity and position are computed. Some of the newest inertial navigators are strapdown systems in which three gyros and three accelerometers are mounted in a unit that has a fixed orientation to the longitudinal, lateral, and vertical axis of the aircraft. The gyro and accelerometer outputs are measured with respect to the body axis and earth referenced velocity, and position changes are computed.

A recent significant development is the use of the Ring Laser Gyro (RLG) to replace the rotating gyroscopes. The RLG works on the principle of measuring the interference pattern of two contrarotating laser beams. Rotation about the axis of the gyro causes instantenous variation in the length of the light paths and a change in the interference pattern made by two beams that is measured to determine acceleration.

The principal advantages of the inertial navigation for the ANG onboard IFR system are:

- It is completely self-contained.
- It gives continuous computed velocity and position.
- Weather has no effect. No signal interruption due to static or EMI.
- Most accurate means of measuring heading and vertical velocity.
- Accurate ground referenced acceleration and velocity signals are available for use in flight control system.

Among the disadvantages are:

- Position and velocity information degrade with time independent of vehicle motion.
- Equipment is expensive to purchase and service.
- System must have precise initial alignment.

Present inertial navigators that are candidates for civil helicopter IFR systems weigh from 40 to 60 pounds. The further development of the RLG and the use of VLSI integrated circuits promise to decrease this weight in the future. The projected price range of present systems is $75,000 to $100,000.

If an IFR system is developed that has a central computer or a control computer that has the capacity to compute navigation parameters, the computer section of the internal navigator could be eliminated saving approximately 15 pounds in weight and $25,000 in cost.

4.3.2.8 Hybrid Navigation System. The navigation system for the onboard IFR system requires high accuracy and low cost. It also requires redundant navigators to enable continued flight after one failure. If two different but complementary systems are used, it is possible by computer mechanization to integrate their outputs in hybird fashion to achieve more accurate and reliable results than can be achieved by using either of the systems alone or the two independently (e.g., a Loran-C system and a dead-reckoning system such as a doppler or inertial navigator). The dead-reckoning augmentation of the radio navigator system could greatly improve performance during signal loss, propagation anomalies, GDOP due to bad geometry, etc. On a flight of considerable duration, the distance or time error buildup in the doppler or inertial system can be corrected by estimation of position with the Loran-C signal. An inertial or doppler output is also very useful for earth-referenced velocity inputs to the flight control system; these velocity parameters may not be obtainable from radio navigation systems because of infrequent update or the necessity for smoothing filters to reduce momentary perturbations.

The hybrid navigation technique usually uses a Kalman filter to make estimates of position on the basis of assumed error models for the subsystems. The filter processes the output of each subsystem to update an optimum estimate. Equipment errors can be estimated as well as the subsystems output errors. The optimum subsystem estimates are used to compute an optimum output for the hybrid systems. The update can be accomplished by reset of one or both systems or, more often, each individual subsystem or component is externally compensated in the computer.

The use of Kalman filtering for hybrid navigators has promise for the onboard system; however, each case must be analyzed carefully to determine if the cost and complexity is justified. The accuracy with which the error model is known for each system is important. The linear state dynamics of the navigation system, the measurement errors, and the statistics of the random processes involved are sometimes not well enough known to enable good results. An example would be where random diurnal errors in a hyperbolic radio navigation system were not well enough known to make Kalmen filtering possible. Since such errors cannot be stastically predicted, some form of sensitivity analysis is necessary to verify system performance.

The nature of the navigation inputs, type and duration of mission and several other factors may determine whether a hybrid navigator is justified. For example, if an inertial navigator that has a 1 n.mi./hr CEP is used on a 1-hour flight with a radio navigation aid which also has a 1 n.mi. accuracy in the termination area, it is doubtful that the computed total error would be significantly smaller than the error with either system. Each of the navigation systems discussed in this section has the potential of being combined with any other system in hybrid fashion.

The hybrid technique has the following potential advantages:

- Two or more navigation systems can be integrated to give better accuracy than any one system.
- Since a backup navigation system is required for redundancy, only the cost and weight of the computer and Kalman filter need to be added.
- Pilot workload is potentially reduced because he need monitor only one navigation output, which is always the optimum output.

The disadvantages are:

- Additional cost and weight.
- A failure in the computed hybrid output may not be detected because of pilot attention to the combined output (it is assumed that each individual output will also be displayed).

The cost of the hybrid navigation Filter/Computer system is difficult to estimate. The proliferation of microprocessors with continually increased speed and power makes it possible to acheive significant digital filter and computer power in a small package. It is quite possible to implement the hybrid navigator in an existing central or flight control computer. An estimate of $10,000 and 5 additional pounds will be used for the hybrid navigation feature.

4.3.3 Comparison of Area Navigation Systems

To determine which is the most effective area navigation systems for the onboard IFR sytem, a trade-off analysis must be made quantifying the value of each characteristic to the effectiveness of the total system.

The performance characteristics of several of the area navigation systems under consideration are given in Table 8 taken from Reference 29.

The value of each characteristic may be weighted subjectively by the specific requirements, e.g., a navigator might give very accurate position but require a ground transmitter at each landing site; for this reason, it would receive a low rating for the onboard system.

TABLE 8. COMPOSITE PERFORMANCE COMPARISON OF MODERN RADIO NAVIGATION SYSTEMS

	Vortac	Loran-C	Omega	Differential Omega	Radar	Doppler	JTIDS RELNAV	NNSS	GPS
Volumetric coverage	Line-of-sight (100 NM)	1200 NM, to ground	Global, to ground	100-200 NM, to ground	Unlimited	Unlimited	Line-of-sight	Global, to ground (9)	Global, to ground
Signal reliability	High VHF, L-band	Fair 100 KHz	Fair (10-14 KHz)	Fair (10-14 KHz)	Moderate (5-16 GHz)	Moderate (13 GHz)	High (L-band)	High (150, 400 MHz)	High (1230, 1575 MHz)
Data content	Relative Rho/Theta 2D Pos	Absolute 2D Pos	Absolute 2D Pos	Relative 2D position	Relative Rho/Theta, 2D Pos	2D Position 3D Velocity	Relative 2D Pos; 3D Pos (1), 2D Vel Absol 2D Pos (2), time	Absolute 2D Pos	Absolute 3D Pos, 3D Vel time
Accuracy	±1.65, 1σ ± 1 NM ±600 Ft, 1σ (DME)	1500 Ft, 95% Prob (predictability) 50-300 Ft (repeatability)	1-2 NM RMS	1100-1800 Ft	Variable	0.1-0.25% 1σ (Velocity) 0.5-1% CEP (Position)	(3)	170 Ft CEP (4) 420 Ft (5)	25 Ft Hor Pos (6) 35 Ft Vert Pos (6) 0.1 Knot Vel (6)
Application versatility	Air, short distance approach	Air, surface med dist Weap Del	Air, surface, underwater, long dist	Air, surface, under water, short dist terminal	Intermittent Pos Fix, Weap Del	Air, long dist, dead reckoning	Air, surface, med dist, Coll avoidance, weap del	Surface, intermittent Pos fix	Air, surface, space, long dist, terminal, weap del
User equipment cost	Low	Moderate	Low	Low	High	Moderate	Moderate (7)	Moderate	Moderate to high (8)

(1) 3D data available for favorable geometry of sources only.
(2) If position references are available
(3) Under optimum conditions, 100 ft CEP considered likely.
(4) Dual frequency receiver, exclusive of own velocity error effect.
(5) Single frequency receiver, exclusive of own velocity error effect.
(6) Predicted for highest performance receiver and full 24-satellites configuration
(7) RELNAV function is software addition only to basic communication terminal.
(8) Different performance quality level equipment being developed.
(9) Typically, fix obtainable every 90 minutes

The principal area navigation requirements for the onboard system are reviewed below:

- Should be self-contained and not be dependent on local ground installations.
- Should have wide coverage.
- Should be accurate enough for precision route and point-in-space control.
- Should be low cost.
- Should have application for Approach Control.
- Should have good signal reliability.

In an attempt to quantify the systems value, a number of 0 to 5 is assigned with each rating identified as follows.

5 - Excellent
4 - Very good
3 - Good
2 - Poor
1 - Very poor
0 - Of no value

TABLE 9. RATINGS FOR AREA NAVIGATION SYSTEMS FOR ON-BOARD SYSTEM

	Vortac	Loran-C	Differential Loran-C	Omega/ VLF	Differential Omega/VLF	GPS	Differential GPS	Doppler	Inertial Navigator	NDB
1. Self-Contained	2	4	1	4	1	5	1	5	5	1
2. Coverage	1	3	3	5	5	5	5	5	5	1
3. Accuracy	1	3	4	1	3	4	5	2	3	2
4. Cost	5	5	3	3	2	3	2	2	1	2
5. Approach Control	0	1	2	0	0	2	3	0	0	1
6. Signal Reliability	2	3	3	3	3	4	4	4	4	3
	11	19	16	16	14	23	19	18	18	12
AVERAGE RATING	1.8 Very poor to poor	3.2 Good to very good	2.6 Poor to good	2.6 Poor to good	2.3 Poor to good	3.8 Good to very good	3.1 Good to very good	3.0 Good	3 Good	2 Poor

4.4 TERMINAL NAVIGATION AND APPROACH SYSTEMS

Among the candidates for terminal navigation and approach control are GPS (which has already been discussed), radar, Forward Looking Infrared (FLIR), television, and various microwave ground approach systems.

4.4.1 Radar

One of the comments from several operators was that weather radar was very useful for navigation along shorelines and for approach to ships or oil rigs. They like the direct view feature of the radar. The weather radar, with modifications to increase its tracking accuracy and other high resolution radar concepts, have promise for the ANGS.

4.4.1.1 Radar Design Considerations. If a radar is to be used to identify check points en route, serve as a terminal area navigator and precision approach aid, as well as a peace-of-mind display for the pilot, it must have excellent resolution. The pilot must be able to recognize terrain features and details such as roads, structures, streams, fields, fences, trees, and the landing site outline with enough detail so he can fly within precise air traffic control corridors for terminal area navigation and approach.

The resolution of a radar is related mainly to the frequency and antenna size. The ability to discriminate two objects is proportional to the beam width. Two targets are generally considered to be recognizable when they are separated by one-half the radar beam width. The beam width is proportional to λ/ℓ, where λ is the wave length and ℓ is the antenna length in the dimension of interest. It can be seen then that to design a high resolution radar we need either to increase the frequency (shorter wave length) or increase the size of the scanning antenna or both.

To determine the resolution required, we must examine the size and spacing of objects to be recognized. Our specified landing pad size is 30.5m (100 feet) square. In order to recognize the outline, it can be assumed that nine resolution elements or three resolution elements wide are needed, each being 10m (33 feet) across, see Figure 12. At 1 n.mi. range, the radar beam width would have to be 0.31 degree.

The range resolution would need to be comparable to the azimuth resolution so a very short pulse width would be required. The approximate length of antennas in the X, Kn, Ka bands and at 94 GHz for a 0.3-degree beam width are shown below.

Band	Freq GHz	Wave length cm	Antenna length
X	9.3	3.2	6.4m (21.2 feet)
Kn	16.5	1.8	3.6m (12 feet)
Ka	35	0.85	1.7m (5.6 feet)
mm	94	0.32	.6m (2.1 feet)

In the approach mode, a fast scan that updates information at least 5 times per second is needed. The problems of navigating near clusters of oil rigs, making turns for down-wind approach legs, and the precision segmented routes expected to urban sites of the future all require a 360° scan. The only practical antenna locations for a 360° scan are underneath or above the fuselage. Most helicopters have very little ground clearance for bottom-mounted antennas, and the main rotor restricts ordinary scanning antenna mounts on top. Considering the location restrictions and the need for a high speed scan, it is obvious that if the antenna is to be of a conventional radome-enclosed type, it needs to be as small as possible. The 0.6m 94 GHz system is obviously the most practical antenna. It has further attractions in that at that high frequency radar components are smaller and lighter than at the lower frequencies. However, because of limited use, the components are frequently more expensive than lower frequency components.

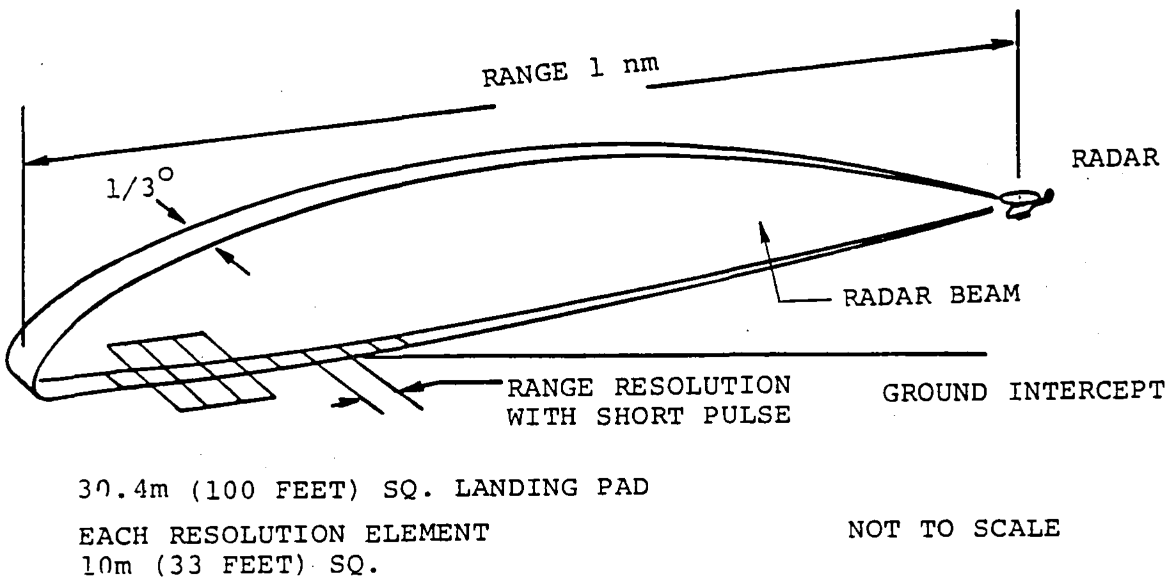


Figure 12. Resolution elements required for landing site detection.

The problem of weather penetration must be examined. The range desired for terminal area navigation and ATC purposes is 10 n.mi. A heavy rain rate used for the model is 25 mm/hr; Figure 5a, taken from Reference 13, shows that at 94 GHz there is an attenuation of at least 10 dB/Km. This prohibits the use of even a powerful radar for 10 n.mi. range at that frequency. The attenuation is so severe that a 94 GHz frequency radar, with the short antennas and small size, is very questionable for the mission. The detailed design and calculation of its range in specific rain rates is beyond the scope of this study, but it is obvious that a 94 GHz radar would be successful only in much lower rain rates and shorter ranges. Figure 5b, from Reference 13, also shows that coastal fog, which limits vision to 30m (98 feet), will also attenuate 94 GHz signals nearly 10 dB/Km so this frequency does not look promising for use in dense fog either. The curve shows that X band radars, at 9 to 10 GHz frequency, are the only ones not severely attenuated by dense fog and moderate to heavy rain. An X-band radar with 1/3-degree beam width requires an antenna of approximately 6m (19.6 feet). Reducing the resolution to 1/2 degree, which can probably be done, will require an antenna approximately 4m (13.1 feet). Such a long fast-scan antenna of conventional type is impractical by conventional means on present rotary wing aircraft because of weight and aerodynamic drag. An attempt has been made to overcome this problem by incorporating the antenna into the main rotor blade.

There have been ideas proposed for helicopter high resolution radars that depend upon complex signal processing techniques, including electrically scaned conformal antennas. Information could not be obtained for this study on any such system in which the concept had been proven or seemed even remotely feasible from the hardware standpoint.

The principal trade-offs, for a radar for the ANGS, are between high frequency for small size and weight, but with severe moisture attenuation and a lower frequency system with good weather penetration but with large antennas. A brief description of millimeter systems and rotor radar systems follows with a summary of the advantages and disadvantages of each.

4.4.1.2 Weather Radar. The requirement to detect storm centers and other conditions hazardous to helicopter flight can be performed by present-day weather radars. In addition to their weather function, these radars have become one of the primary approach aids to oil rigs in IMC weather.

A typical modern weather radar has the following characteristics:

Antenna - Flat Plate 25.4 cm (10 inches) to 45.7 cm (18 inches)
Azimuth scale ±60 degrees maximum
Elevation tilt ±15 degrees
Beam width 6 to 9.5 degrees
Scan rate 28 deg/sec
Stablization, pitch and roll accuracy ±1 degrees
Frequency X band 9375 MHz
Power 10Kw peak power
PRF/pulse width short range 720 P.P.S/0.5 μ sec
long range search beacon 240 P.P.S/2.35 μ sec
Indicator Display
Color CRT approx 10 cm (4 inches) x 12.7 cm (5 inches)
Display Range 3.7km (2 n.mi.) to 444 Km (240 n.mi.) in 8 steps
Minimum Range 548m (600 yards)
Alpha Numerics Navigation Display, Check Lists, etc.
Radar weight approximately 30 pounds

The radar antenna is mounted in a nose radome and is stablized in pitch and roll. The display is mounted at a convenient location for viewing by both pilots. The radar is used for weather avoidance, and navigation and approach. The system is also used for navigation and approach using the beacon detection mode.

Weather radars are widely used in the offshore oil industry. The pilots like the pictoral display feature and encourage the placement of navigation plots on the CRT combined with radar imagary. This results in a combined display of present position, and track error, waypoints, and destination. Ground targets can be selected for updating the navigation system and weather can also be displayed.

The early black and white display versions of weather radars have been studied extensively in operational experiments References 34, 35, 36, 37 and 38. The tests include both off-shore and land based approaches using the basic radar in the skin track mode, passive reflector mode single and multiple active beacon modes and various combinations of the techniques.

The general results show that the weather radar sensor can be used for IFR approaches to over-water sites such as ships or oil rigs in minimums of 61.0m (200-foot) ceiling and 800.m

(0.5-mile) range visibility. This capability was achieved with two-pilot operation. Over land it was necessary to use an active beacon in order to discriminate a landing site, and if in an area of strong targets, it was difficult even with the beacon.

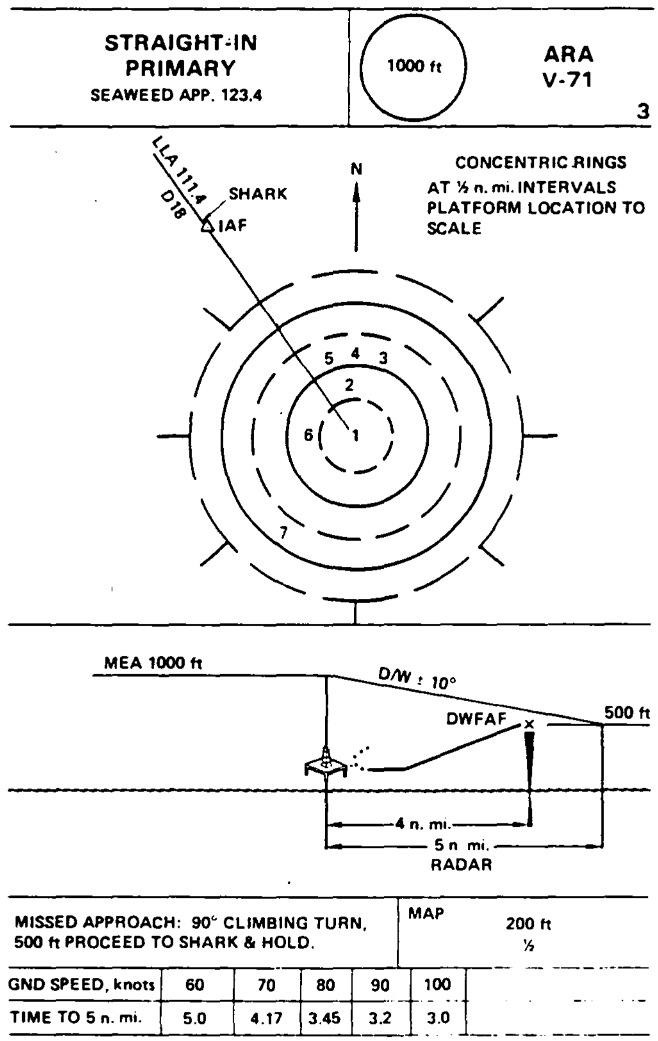


Figure 13. Helicopter airborne radar approach plate.

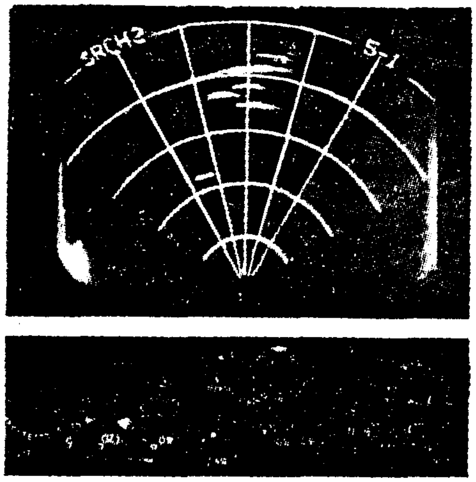


Figure 14. Oil rig Targets on Weather Radar Display on Final Approach

The principal problem in discriminating clusters of targets at sea and targets on land is the poor azimuth and range resolution. Azimuth resolution is proportional to a radar antenna beam width, and range resolution is proportional to pulse length. For the X band weather radar with a 30.4 cm (12 inches) wide antenna (Reference 34) the azimuth beam width is reported to be approximately 7.5 degrees. At a range of 10 n.mi., the beam width is 0.9 n.mi. (1800 yards), and two targets spaced closer together than that distance will be seen as a single target. The range resolution at 10 n.mi. is .4 n.mi. (800 yards). Figure 13 (taken from Reference 34) shows the approach plate for a cluster of oil rigs in the Gulf of Mexico. Figure 14 shows the targets on the weather radar on final approach. The report states, the target oil platform, rig No. 1, is shown dead ahead of the aircraft at about 4-1/4 n.mi. Radar display "blips" for oil platforms No. 2, 6 and 7 are seperated; however, display "blips" for platforms No. 3, 4, and 5 are still merged as one target due to poor resolution and excessive gain control. Also showing, on the radar display, merged as one target at about 5-1/2 n. mi. are two ships that are passing through the area. The targets appear as an arc on the display because of the poor resolution. This makes it difficult to recognize groups of point targets.

Reference 39, which reports on evaluation of a similar radar, gives the following results in tests of approaches to an oil rig in the Gulf of Mexico:

1. "Radar-range error in the primary mode on the 5-n.mi. range scale was 0.006 ± 0.053 n.mi.; on the 2.5-n.mi. range it was -0.003 ±0.050 n.mi."

2. "Radar-range error in the beacon mode on the 5-n.mi. range scale was 0.115 ±0.059 n.mi.; on the 2.5-n.mi. range scale it was 0.123 ±0.052 n.mi."

3. "Radar bearing error in the primary mode on the 5-n.mi. range scale was -1.27 ±3.33 degrees; on the 2.5-n.mi. range scale it was -0.92 ±2.38 degrees."

4. "Radar-bearing error in the beacon mode on the 5-n.mi. range scale was -0.57 ±4.07 degrees; on the 2.5-n.mi. range scale it was -0.90 ±5.01 degrees."

5. "Flight technical error of -9.50 degrees was the largest contributor to total system error on the final approach."

6. "Crosstrack errors due to "homing" on final approach were primarily a result of crosswinds rather than radar errors."

7. "The following types of operational blunders occurred during the tests: target misidentification, procedure turns in the wrong direction, descent below minimum descent altitude, and missed approach turns in the wrong direction."

4.4.1.2 Improvements to Weather Radar. A very useful recent addition to weather radars is a color display capability and the addition of a navigation plot from area navigation system inputs superimposed on the radar display. The addition of waypoints, which can include initial approach points for oil rig approach for instance, is a valuable aid in transitioning from the enroute phase of the mission to the terminal phase. The radar CRT has also been found valuable for displaying alpha-numerics for such functions as check lists.

The weather radar can also have various symbols generated on the CRT for aid in mission performance. Reference 38 reports on the flight test of a movable azimuth cursor that can be adjusted to indicate desired track or other heading-related information.

The preliminary conclusions from the study were that "The use of the radar cursor improved course acquisition and ground tracking significantly with pilotage errors and total system cross-track errors reduced by one-half or better."

Another promising development to improve the present weather radar is an effort to design special reflectors to be used as reference points for an approach to an onshore landing site. As mentioned above, the basic radar does not have sufficient resolution to detect reflectors from the natural clutter caused by cultural objects such as trees and vegatation and man-made structures. Reference 40 reports on the use of dihedral passive reflectors using the earth as an elongated third plate to achieve a wide horizontal angle and limited vertical angle to use as approach targets. The reflectors are discriminated from ordinary background clutter by radar signal processing. Basically, the unique return from the reflector is detected by a pulse width discriminator and pulse pair decoder circuit. The detected signal is then shown in its proper location as a point on the display without the surrounding clutter. Early flight tests have shown promise.

Existing weather radars, such as have been discussed above, will fully meet the weather detection function for the near-zero system. Although their use as an approach aid for offshore work, a function they were not really designed for, has shown outstanding capability, the poor-resolution, slow-scan rate, and limited-scan angle clearly make them unsuited for the near-zero visibility system where identification of restricted area landing sites on land and precision approaches are required. There are radar concepts, however, that can possibly be combined with the weather radar to create a dual mode radar to solve many of the problems of near zero-visibility flight.

4.4.1.3 Millimeter Radar. The principal athomspheric windows in the millimeter band are at 35 and 94 GHz.

The mm radar system would likely be a conventional scanning beam pulse-type radar. For the mapping function, the beam would be a fan shape cosecant squared beam or a modified version of such a beam. The antenna could be nose mounted similar to the weather radar antenna, or it could be mast mounted on the rotor. The nose mount is preferable from the installation complexity and drag standpoint.

The range versus rainfall rate of a 35 GHz radar with parameters that might be used in a helicopter are shown in Figure 15. The data were taken from Reference 41.

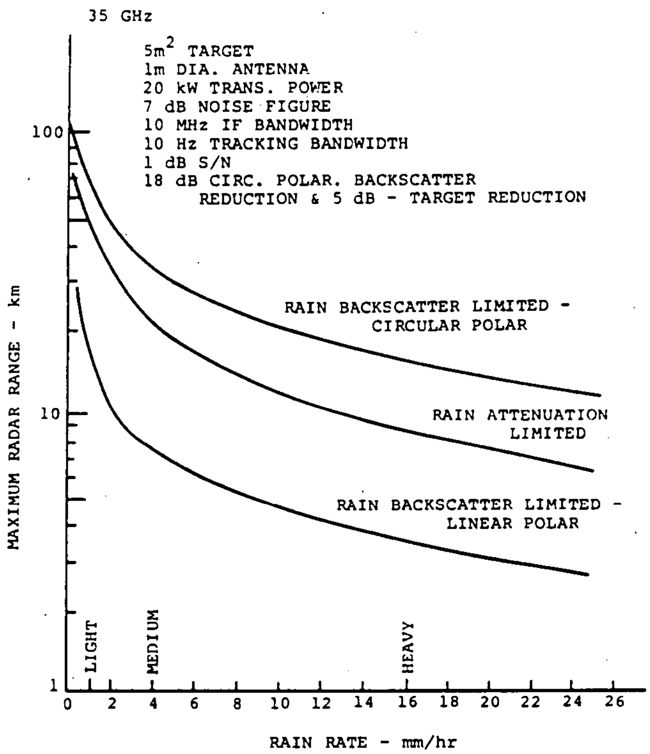


Figure 15. Maximum radar range vs rain rate.

The 94 GHz band is the frequency most commonly proposed for use in helicopters because of the lightweight and small components. However, the 94 GHz frequency is even more heavily attentuated by weather than the 35 GHz frequency.

Figure 16 is a plot of microwave attenuation versus frequency for 25mm/hr precipitation, and Figure 17 gives calculated range versus frequency for a radar that might be used in a helicopter with no precipitation and at 25mm/hr precipitation calculated from data from References 42 thru 47. Reference 46 was used to develop figures 16 and 17. It can be seen that there is a serious question of excessive signal attenuation and consequent limited range of mm radars in the heavy rain that may be encountered in the near-zero-visibility system.

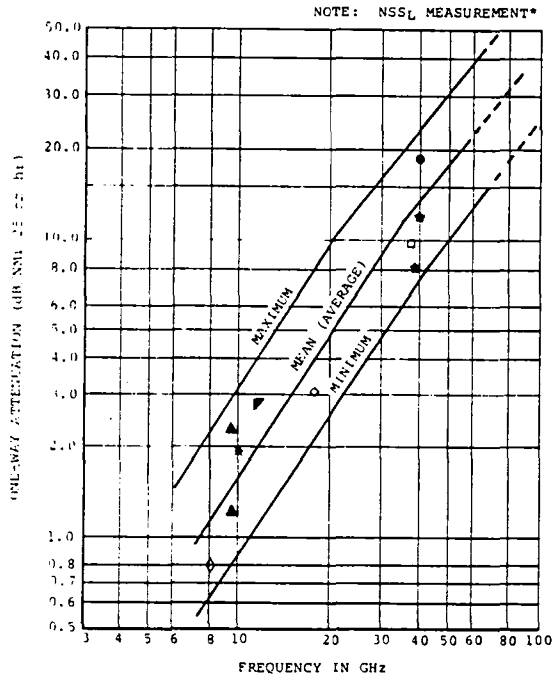


Figure 16. Attenuation vs frequency 25 mm/hr precipitation.

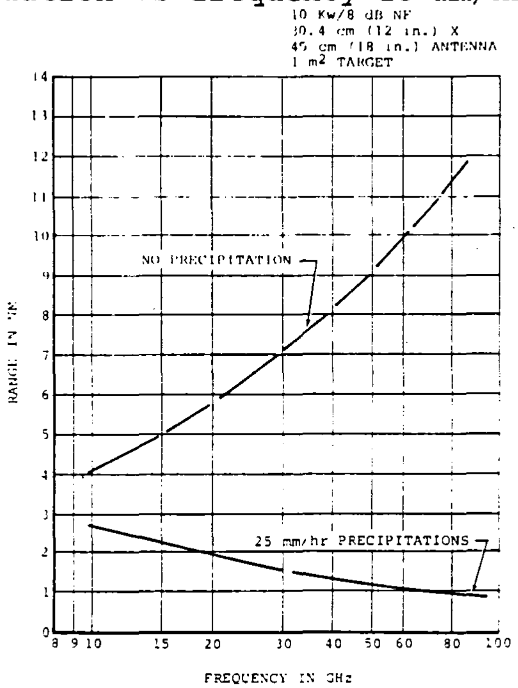


Figure 17. Range vs frequency with/without precipitation.

4.4.1.4 Rotor Blade Radar. One concept that has shown promise for a high resolution helicopter radar is to mount the scanning antenna into the main rotor blade and let the natural rotation of the rotor scan the antenna (See Figure 18). Two U.S. systems described in References 48 and 49 and have been designed and tested, and a similar system in England is described in Reference 50. Little data are available about Reference 49, but the other systems have been described extensively.

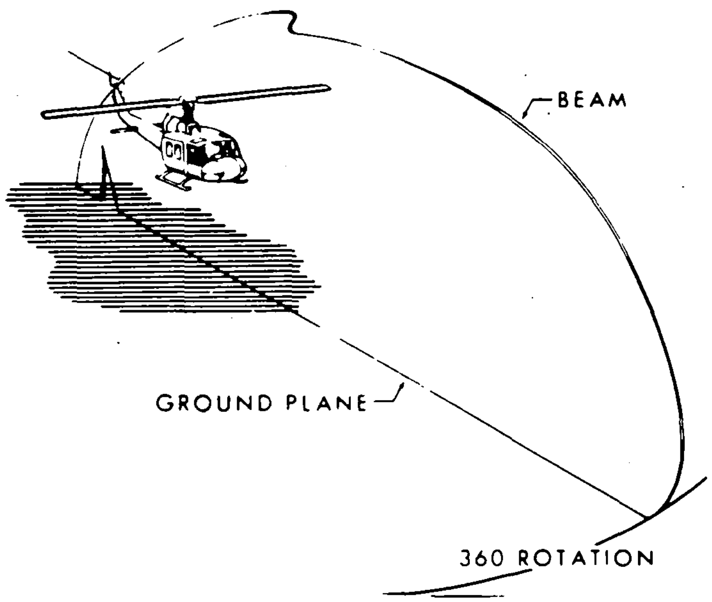


Figure 18. Rotor radar typical antenna pattern.

4.4.1.4.1 <u>HELMS</u>. The Helicopter Multifunction System (HELMS) system, described in Reference 48, was designed for the U.S. Army and was evaluated extensively. HELMS was a multifunction radar that performed high resolution ground mapping, approach, terrain avoidance, weather avoidance, station keeping, moving target identification, and fire control. The ground mapping, approach and terrain avoidance modes (which have application for civil helicopter use) will be discussed.

A unique feature of the HELMS was the use of two antennas for complementary functions: (1) the long linear antenna mounted on the rotor blade providing high azimuth resolution at a very high scan rate, and (2) a small nose-mounted steerable antenna with electronic processing to achieve a very accurate elevation bore sight to be used for glide slope control. Table 10 lists the HELMS characteristics.

TABLE 10. HELMS HIGH RESOLUTION RADAR CHARACTERISTICS

Frequency	16.50 - 17.00 GHz (manual tuning)
Pulse Rate	18.750 ± 0.250 kHz (except for 9.375 ± 0.150 kHz (10 km range, TA and WX modes)
Pulse Width	50 ± 10 ns (@ 18.75 kHz PRF) 100 ± 10 ns (@ 9.375 kHz PRF)
Peak Power	30 kW
High-Resolution Receiver Bandwidth	22 ± 3 MHz
High-Resolution Receiver Noise Figure	11.5 dB maximum
Display Size	5-inch diameter DVST
Display Resolution	120 lines/inch (shrinking raster) minimum
Display Ranges	0.6, 1.2, 2.5, 5, and 10 km
Blade Antenna Gain	27 dB (minimum)
0.3° Beam width (AZ) 40° (elevation)	$\geq$18 dB down within 2° of beam $\geq$25 dB down elsewhere

A 12-foot long leaky wave guide antenna was installed along the leading edge of the blade of a UH-1 helicopter and covered with a fiberglass radome designed to be part of the leading edge airfoil, see Figure 19. The antenna pattern was a fan-shaped beam 1/3 degree in azimuth and approximately 40 degrees in elevation. It was scanned with the rotor at 1800 degrees/ second or 5 cycles/second. The 40-degree elevation pattern was wide enough to compensate for the ±8 degree blade pitch, necessary for helicopter control, to give uniform ground coverage in all forward flight attitudes. The narrow azimuth beam width, short 50-nanosecond pulse length, and rapid scan gave a nonflicker display of outstanding detail. Figure 20 shows a HELMS radar image taken below 100 feet on an approach to an airport. Note the runways, taxi strips, four hangers to the left, with rows of helicopters parked on the ramp. The small rectangular object to the right of the runway is a small landing pad. It can be seen that the landing pad is clear.

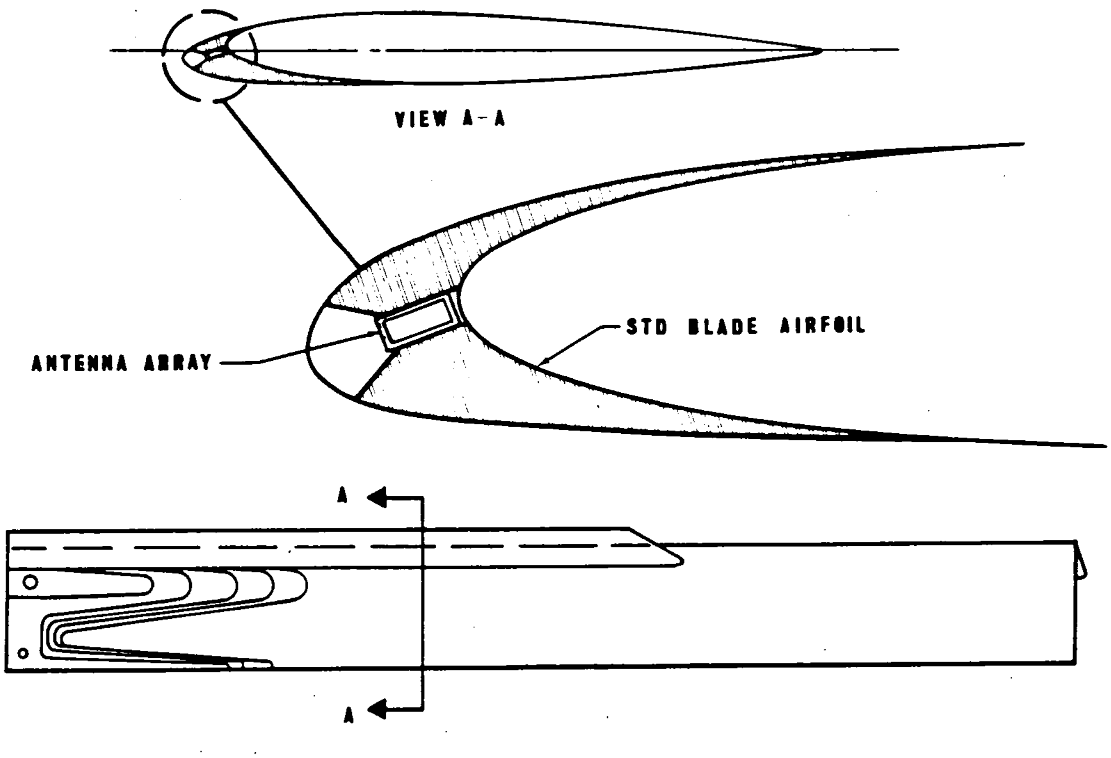


Figure 19. HELMS rotor radar antenna.

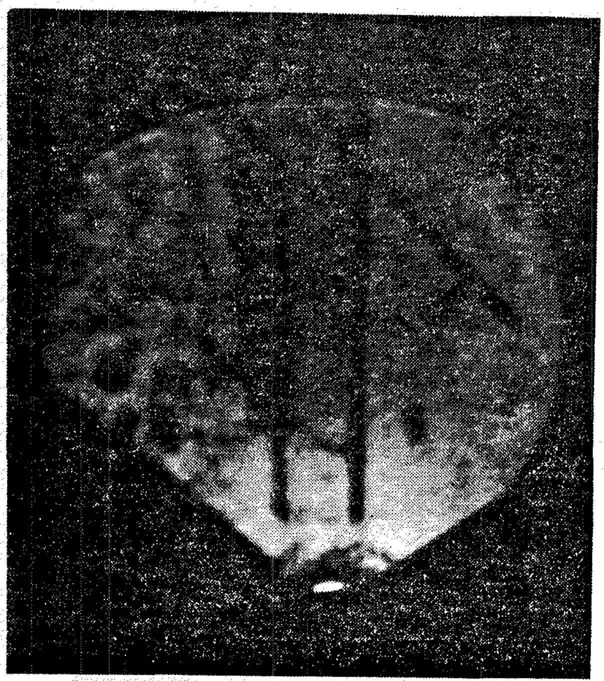


Figure 20. HELMS approach to airport.

One of the outstanding features of the radar was the unique approach mode in which an approach path control symbol was shown on the expanding scale radar display. The elevation monopulse nose antenna was ground stablized along the desired glide path angle, see Figure 21. The transmitted pulse from the blade antenna was received on the monopulse nose antenna to give the range to the flight path ground intercept that was shown as a range circle on the high resolution radar image, Figure 22. The common transmitter shared pulses to the blade and nose antenna. Every ninth pulse was emitted from the nose antenna.

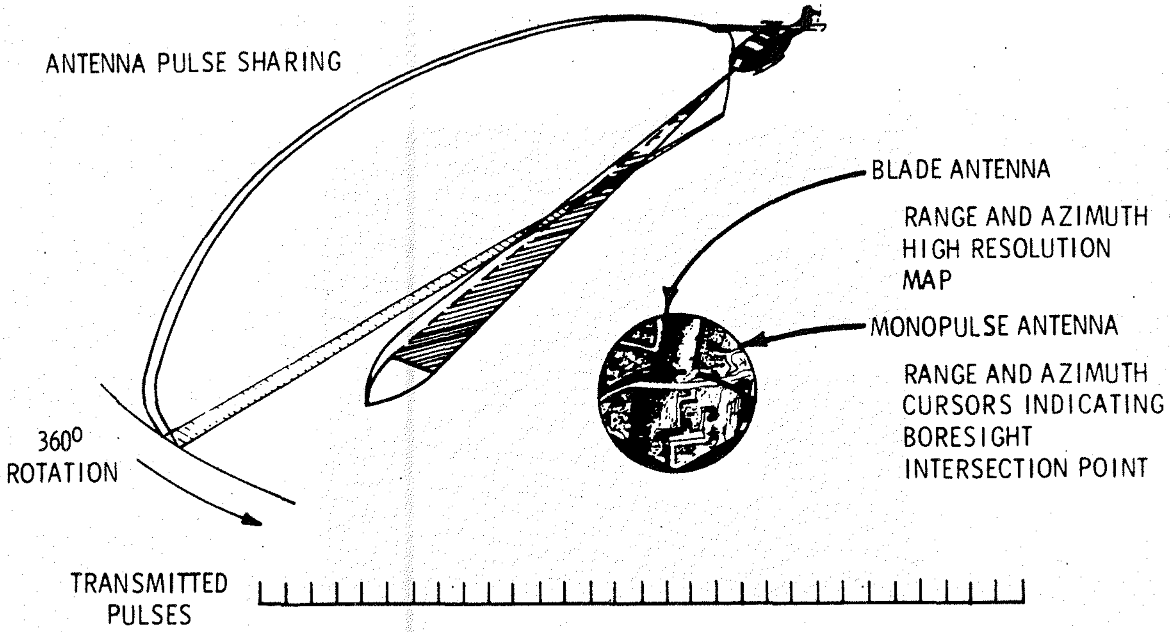


Figure 21. HELMS approach mode concept.

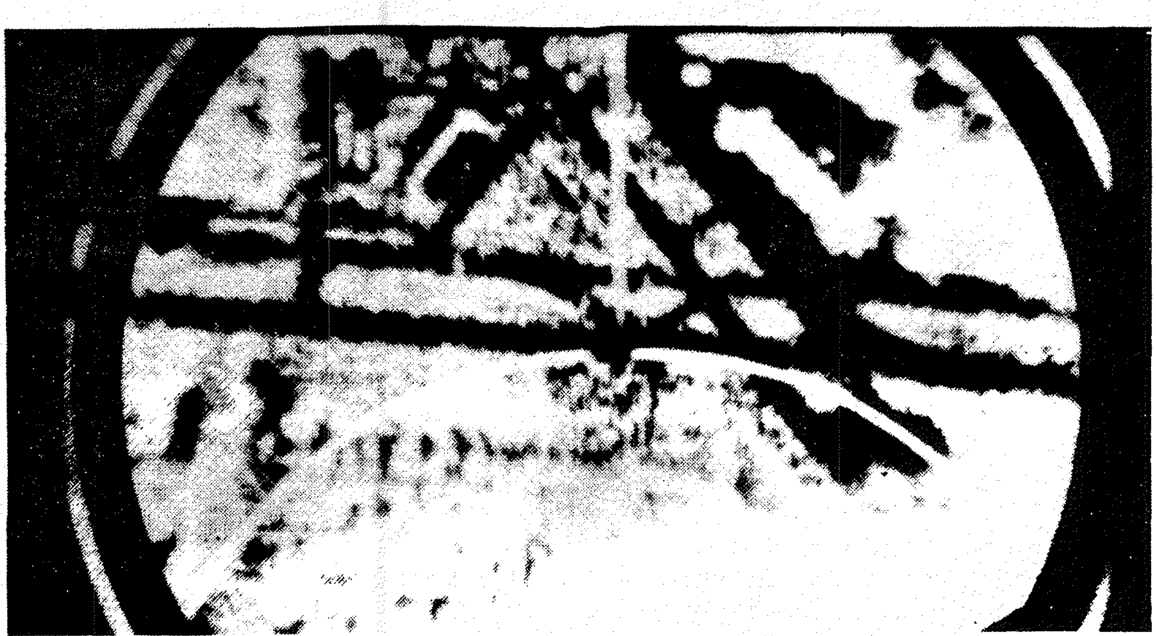


Figure 22. Ground intercept range circle HELMS display.

A unique expanding scale display was used in conjunction with the glide slope marker in the approach mode. Figure 23 illustrates a typical HELMS approach.

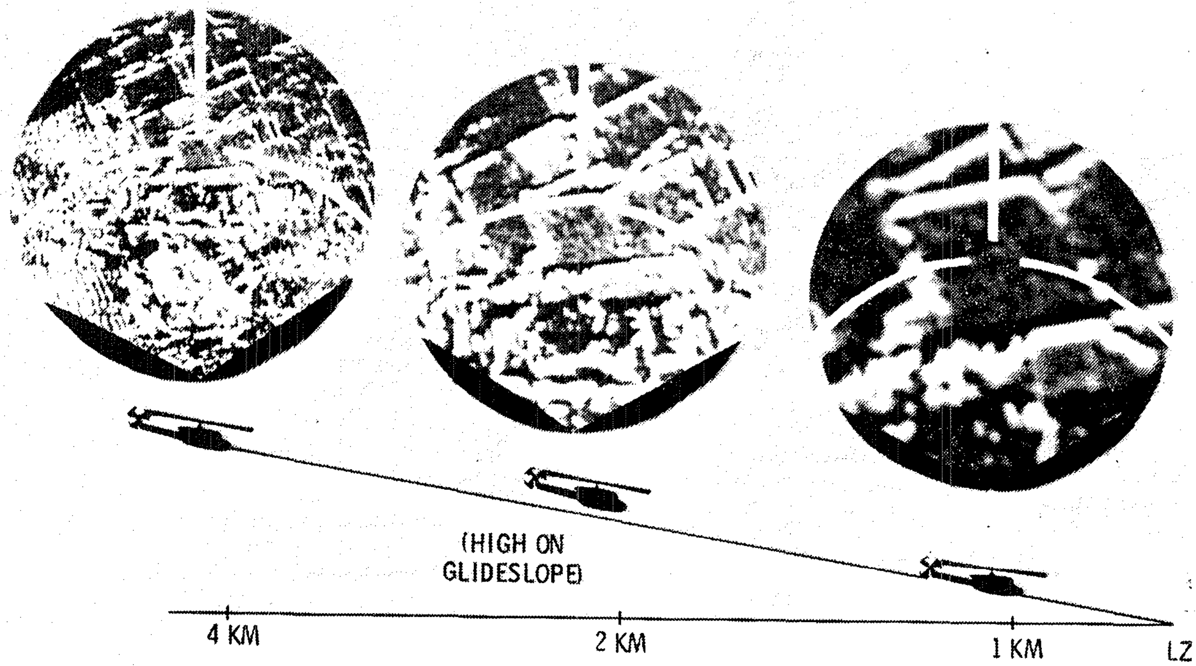


Figure 23. HELMS approach with expanding scale display.

The HELMS approach mode has demonstrated a one-sigma deviation of approximately 1/3 degree on the instrumented FAA range at NAFEC, Atlantic City, New Jersey. Figure 24 illustrates the consistency of the glide slope control by comparing several approaches. More importantly, the test pilot reliably and consistently made self-contained approaches to remote unimproved areas as well as operational airfields. The approach accuracy is essentially the same for unmarked or augmented (beacon or corner reflectors) sites. Of the four selectable glide slopes of 3, 6, 9 and 12 degrees, the 6 and 9 degrees were most used because they closely approximate normal VFR glide slopes. All the Military Potential Test (MPT) criteria for this function were met with the exception of pinnacle approaches, which is a restriction of the present system design. One significant aspect of the approach mode was that by always presenting a "real-world" view of the range and azimuth to the landing sites, the pilots had more time to concentrate on attitude and glide slope corrections. They made only gradual corrections for azimuth track error, thus significantly reducing their instrument workload relative to tracking azimuth and elevation such as with an ILS approach. Note that Figure 24 shows that the pilots did very little "hunting" about the intended glide slope and ground track, but instead maintained small constantly decreasing errors.

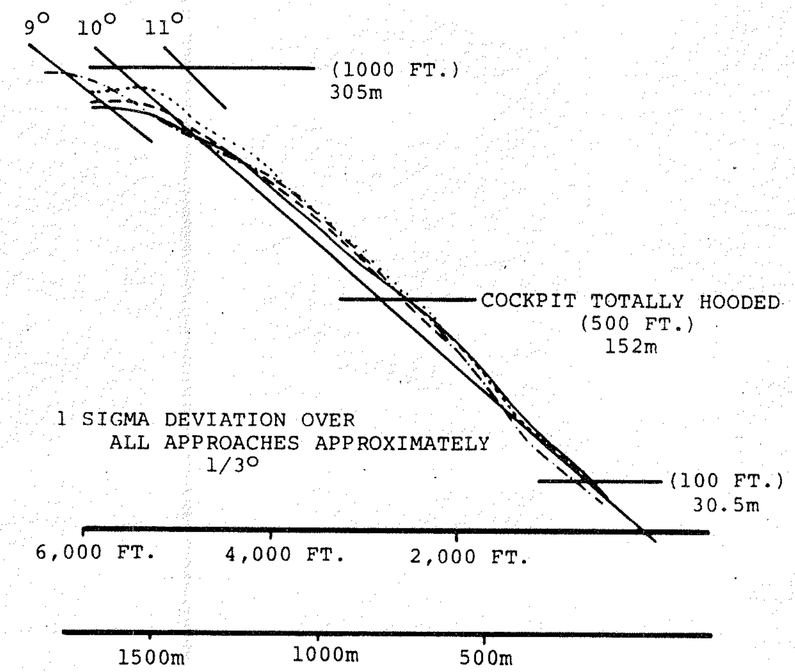


Figure 24. HELMS hooded approach results.

Figure 25 is a display photograph of an approach into an open field. Note the two small rectangles to the right of the azimuth cursor that are clearly defined as two concrete pads approximately 4.5m (15 feet) x 9m (30 feet). Note the fields outlined by fences. The arrow points to a clump of trees and the radar shadow behind them. An important feature of the high resolution radar image was that on low approach, such as in the picture, the shadows of trees and other obstacles were clearly evident. It can be seen that the area in the upper right of the image covered with trees or rough terrain that cast shadows and is not a satisfactory landing area. It can be seen that the field just in front of the helicopter is a smooth area, as is the field outlined by the fence to the left. If the approach is completed on the path shown by the marker circle, the touchdown will be made just short of a clump of trees identified by the shadow just beyond the range circle.

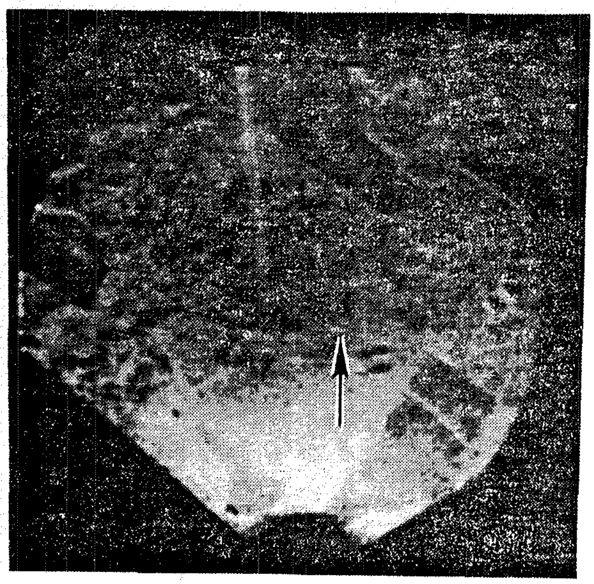


Figure 25. HELMS approach to open field.

Another rotor radar experiment pertinent to the requirements for the near-zero IFR system was a navigation experiment over flat North Texas farm land. One of the limitations of navigating by high resolution radar is that in many areas there are few features that are distinguishable by radar. Examples are, over flat uniform desert terrain which extends to the limit of the radar, then the full display would be filled with uniform random clutter, and the pilot would have no clues as to his position. The same would apply to flying over water or a flat expanse of dense forest, although streams or other features usually exist in forest areas. Reference 51 describes an experiment where hooded flights were made with HELMS around a course over flat farm land using the rotor blade radar as a navigation aid. The experiment is described in the report as follows:

"The route was selected to include enroute checkpoints representing many of those which may be used under normal contact flight. The total distance of the route was 48.3 miles. A prescribed list of en route checkpoints was prepared within the one-mile corridor from the command course. Two subjects, both qualified pilots but inexperienced radar operators, were used for the flight tests. Each received a 35-minute familiarization flight prior to the initial test.

"The primary task was one of navigation and required the subject to provide the pilot with the necessary directional information to fly the command route indicated on a 1:24,000 scale topographic map. All flights were conducted utilizing the one-mile scale PPI radar image under the hood. No other flight information was given to the subject, except the 1:24,000 scale topographic map. Two flight routes were used, one the reciprocal of the other.

"The test results of the final flight for the two subjects are shown in Figure 26 to illustrate the degree of precision that can be expected using the radar with normal pilotage techniques (dead reckoning, time, and heading). It may be seen that the flights were executed well within the one-mile corridor limits established prior to the flight tests.

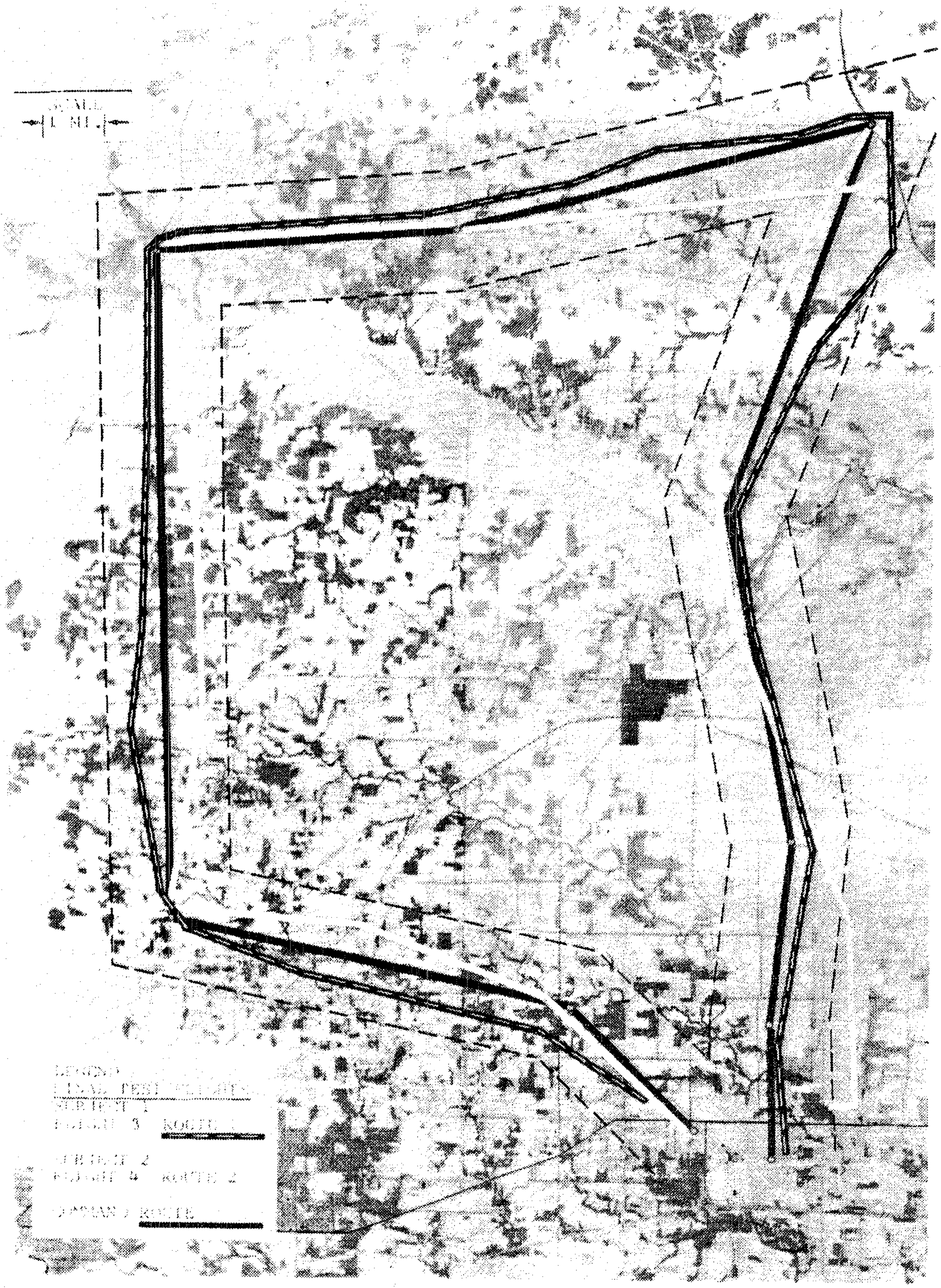


Figure 26. HELMS hooded navigation test results.

"The flight test demonstrated interpretability of the display without any external navigation aids under restricted visibility conditions. The data collected on this series of flights suggested that the operators rapidly learned the best method for utilizing the display based upon the mission requirements."

4.4.1.4.2 RSRE Radar. References 50 and 52 describe a helicopter system developed by the Royal Signals and Radar Establishment (RSRE) that is similar in concept but different in many design details to the HELMS project described above. The significant differences are that the RSRE radar operates at 8.9 GHz and therefore has better weather penetration than the HELMS and the antenna is mounted in the trailing edge of the rotor blade.

The characteristics of the radar taken from Reference 50 are shown in Table 11.

TABLE 11. ROTOR BLADE RADAR

Frequency	8960 MHz					
Peak Power	80 KW					
Aerial Length	3.9 meters					
Gain	31.5 dB					
Az Beamwidth	0.5°					
El Beamwidth	40°					
Rotation Rate	1300°/Sec					
Display Radius (Centre PPI)*	0.5*	1*	2*	5	10	Variable 0-10* *Km
Pulse Width	50	50	50	50	100	50 (0-50 Km) 100 (5-10 Km) NSEC
PRF	20	20	20	20	10	20 (0-5 Km) 10 (5-10 Km) kHz

*All displays radius and ranges are doubled in OFF-SET PPI Mode

* *Maximum Time-Base Duration is 24 μSecs. All Range Scales less than 3.7 Km in Centre PPI, 1.8 Km IN OFF-SET PPI are scan-converted

The RSRE rotor radar has not at this point had a means of measuring approach angle incorporated, although it is reported that a nose interferometer antenna and a color display are planned.

The design of the trailing edge antenna is shown in Figure 27 taken from Reference 50. The blade is designed into the trailing edge of a Wessex I helicopter. The 13-foot long X band slotted waveguide array was mounted behind the main spar and radiated energy through a fiberglass dielectric trailing edge. The 3 dB point beam width of the antenna is 0.5 degree in the azimuth and 40 degrees in the elevation plane. Since the average pitch angle of the blade is always positive, asymmetrical reflectors are used to control the beam center line. Wires embedded in the skin provide the necessary match at the dielectric interface. The trailing edge design has the advantage that no erosion or deicing problems exist but it does require a major modification to the blade.

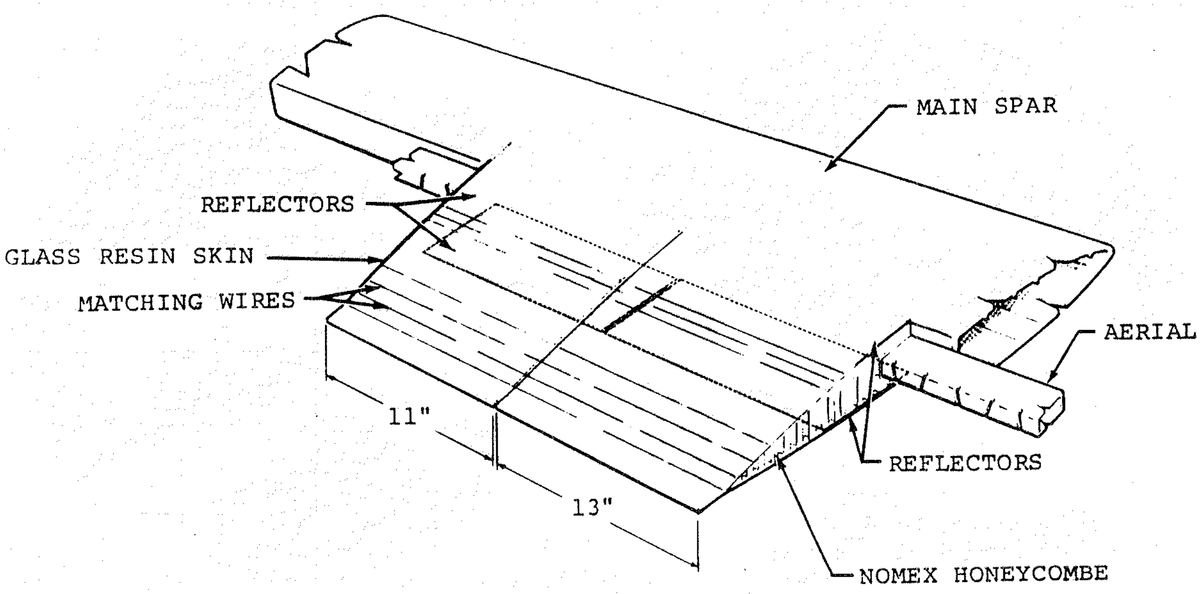


Figure 27. British rotor blade trailing edge blade antenna.

The flight tests of the RSRE radar have been very encouraging. It is reported in Reference 50 that it "shows great promise for en route navigation and landing site approach in virtually any weather condition." Figure 28 shows a flight over Southhampton Water Fawlly Jetties using the 5 Km/radius display. The details of shore outline jetties and even ships tied up at the jetty are clearly shown. Figure 29 shows the image obtained flying over Waterloo Bridge on the river Thames in London. Blackfriars, Westminster, and Lambeth Bridges are clearly shown along with the main road and building features. Reference 50 reports "Aircrew response has been enthusiastic. 'Blind' navigation exercises have been very successful, and on occasions the pilot has relied upon it to find his way over terrain in unexpected poor weather conditions."

There have been verbal reports of recent flight to offshore oil platforms in the North Sea Reference 53. It was reported that the system had excellent navigation capability in making approaches right up to the edge of the landing platform.

4.4.1.4.3 Rotor-Mounted Antenna Design Considerations. It is desirable in some cases to mount radar antennas on helicopter rotors in order to acheive a fast scan and narrow azimuth beamwidth without having to construct a heavy antenna mechanism. Reference 54 reports on a design trade-off study to examine several antenna concepts. They are summarized below:

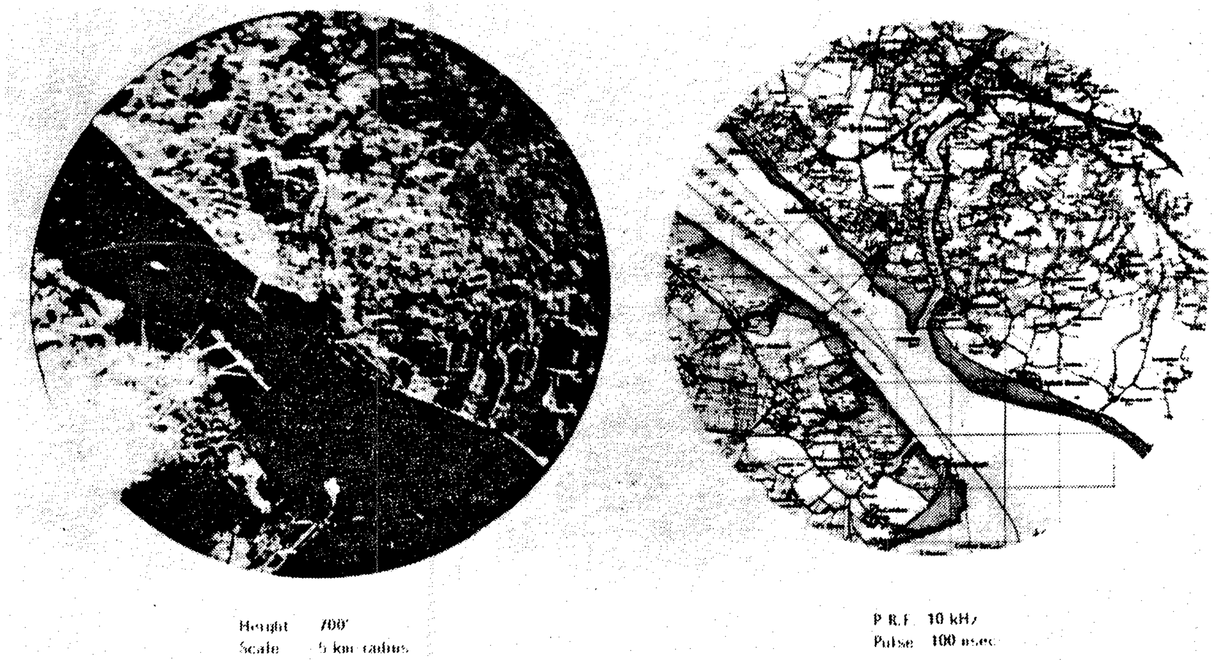


Figure 28. Flight 23 24 4 78 Southampton water fawlly jetties.

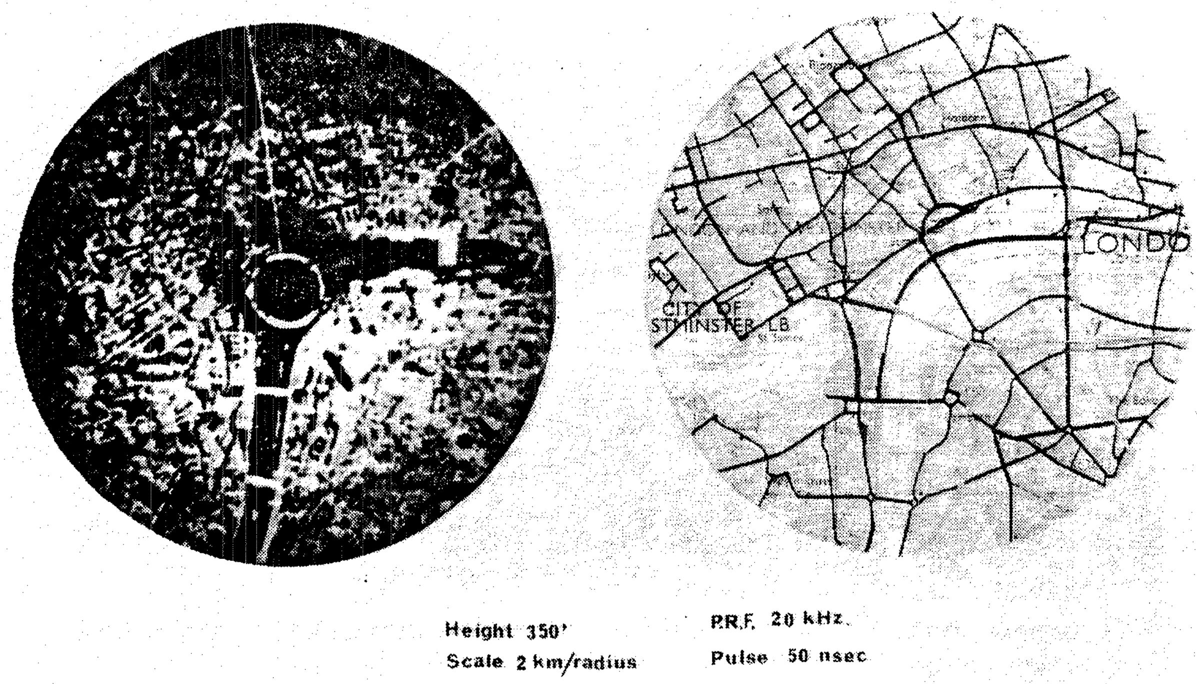


Figure 29. Flight 39 28 November 78
over Charing Cross.

4.4.1.4.3.1 <u>Mast-Mounted Dish Antenna</u>. Configuration Description: A dish antenna would be mounted in a spherical housing located above the rotor and attached to the rotor through a standpipe (see Figure 30). The radar package would also be mounted in the housing with the antenna. Power would be fed through a slipring at the base of the mast. This configuration would be suitable for a millimeter radar.

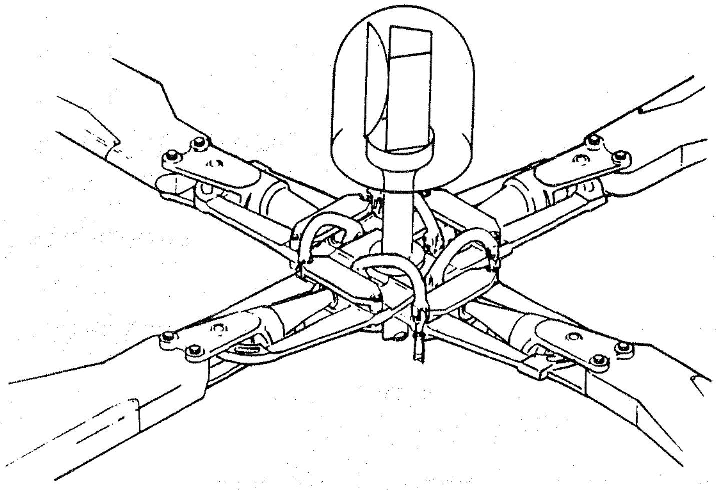


Figure 30. Radar and dish antenna on rotor hub

Major Advantages:

- Installation does not interfere with rotor blade deicing.
- The antenna and radar are easily removable/replaceable.
- Minimal rotor modifications are necessary.
- Radar and antenna are not located in the flapping or feathering system.
- Adaptable to most rotor systems.

Major Disadvantages:

- The weight of the housing may have adverse effects on the rotor system dynamic response.
- Aerodynamic performance will be adversely affected (higher drag).
- Dish antenna size is limited by practicability to less than two feet diameter.
- Tends to be heavier than other configurations.

4.4.1.4.3.2 Mast-Mounted Linear Array. Configuration Description: A linear array would be mounted in an oval or round cross-section housing located above the rotor and attached to the rotor through a standpipe (see Figure 31). The radar would be mounted in a housing at the base of the standpipe. Power would be fed through a slipring at the base of the mast.

Major Advantages:

- Installation does not interfere with rotor blade deicing.
- The antenna and radar are easily removable/replaceable.
- Minimal rotor modifications are necessary.
- Radar and antenna are not located in the flapping or feathering system.
- Adaptable to most rotor configurations.

Major Disadvantages:

- The housing may tend to "fly."
- The dynamic response of the housing itself may have adverse effects on the antenna performance.
- Helicopter aerodynamic performance will be adversely affected (higher drag).
- The antenna housing must be aeroelastically designed to avoid resonances with primary forcing functions.

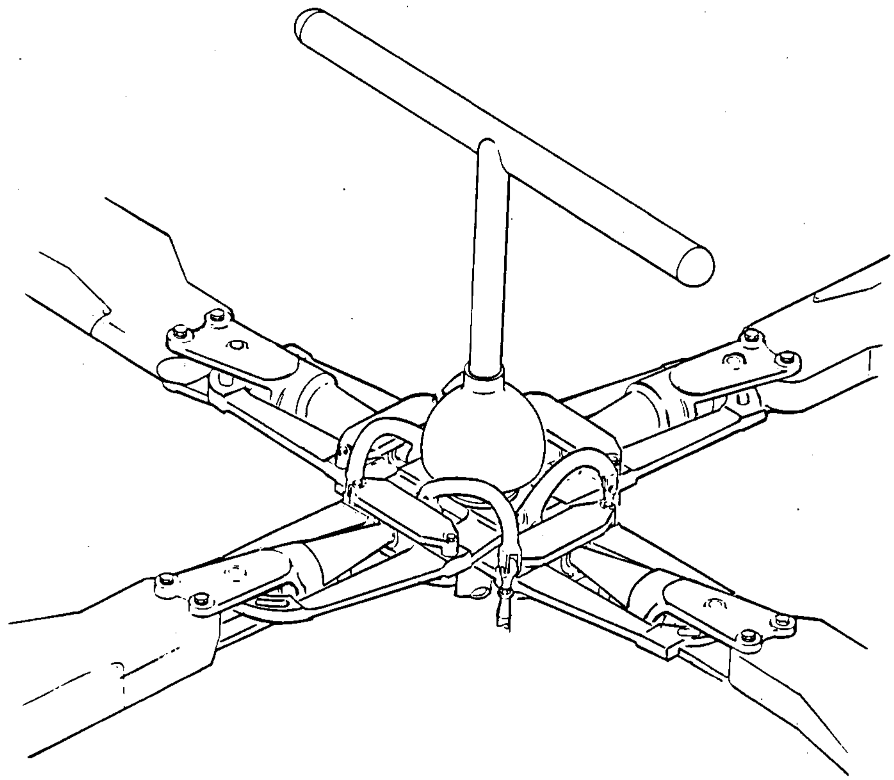
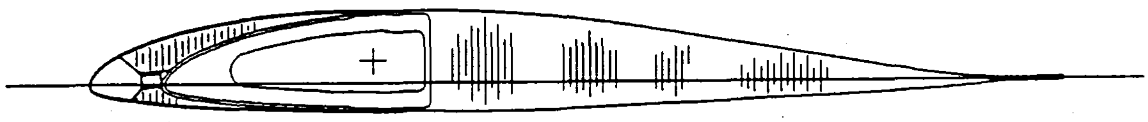


Figure 31. Linear array antenna on rotor hub.

4.4.1.4.3.3 Linear Array in Blade Leading Edge. Configuration Description: A linear array would be mounted either on or within the rotor blade leading edge (see Figures 32a and 32b). An antenna mounted on the leading edge of the antenna would be contained within a fairing that reshaped the rotor blade airfoil. An antenna mounted within the leading edge would be buried in a redesigned blade such that the aerodynamic contour remained unchanged. The radar could be mounted on the rotor head. Power would be supplied through a slip ring at the base of the mast.



(a) Antenna on leading edge.

(b) Antenna in leading edge.

(c) Antenna in trailing edge.

Figure 32. Antenna blade mount concepts.

Major Advantages of an Antenna Mounted on the Blade Leading Edge:

- A blade-mounted antenna would add little or no aerodynamic drag.

- Long antennas can easily be supported by the blade structure.

- Blade structural changes are not required.

Major Disadvantages of an Antenna Mounted on the Blade Leading Edge:

- New generation airfoils are not forgiving of contour modifications; therefore, acceptable leading edge modifications are limited.

- Rotor blades with curved leading edges would cause difficulties when mounting a linear array.

- Special tooling would be required for each blade configuration.

- All blades in the rotor system would require the same aerodynamic modifications and weight distribution.

- Antenna is located in a region subject to particle and water erosion - requires nonmetallic erosion protection.

- This configuration is not readily compatible with rotor blade deicing.

- The antenna is located in the flapping and feathering system.

Major Advantages of an Antenna Mounted within the Blade Leading Edge:

- No aerodynamic penalties would be incurred.

- Long antennas can easily be supported by blade structure.

- Does not require aerodynamic modification to all blades in a rotor. (Could fly with standard blades if blade balance is acheived in design.)

Major Disadvantages of an Antenna Mounted within the Blade Leading Edge:

- Rotor blades with curved leading edges would cause difficulties when mounting a linear array.

- Internal mounting requires redesign and requalification of the rotor blade for retrofit.
- Antenna is located in a region subject to particle and water erosion - requries nonmetallic erosion protection.
- This configuration is not readily compatible with rotor blade deicing.
- The antenna is located in the flapping and feathering system.
- Special tooling would be required for each blade configuration.

4.4.1.4.3.4 <u>Linear Array in Blade Trailing Edge</u>. Configuration Description: A linear array would be mounted on the aft side of the spar, buried within the rotor blade afterbody (see Figure 32c). The radar could be mounted on the rotor head. Power would be supplied through a slip ring at the base of the mast.

Major Advantages:

- The antenna is not located in a region of particle and water erosion.
- No aerodynamic penalties would be incurred.
- The antenna would be secure from foreign object damage.
- The antenna would be installed in a low strain area (i.e., approximately on the neutral axis).
- This configuration is compatible with rotor blade deicing.

Major Disadvantages:

- Internal mounting requires redesign and requalification of the rotor blade for retrofit.
- The antenna is located in the flapping and feathering system.
- Special tooling would be required for each blade configuration.
- The antenna must be shielded from lightning to prevent the buried conductor from guiding a lightning stroke inside the nonconducting afterbody which could cause an explosion which would destroy the afterbody.
- Nonmetallic rotor blade skins are required.
- Installation not compatible with conductive coating normally used on composite rotor blades.

4.4.1.5.3.5 <u>Linear Array in Blade Root</u>. Configuration Description: A linear array would be mounted to the rotor in the vicinity of the blade root (see Figure 33). Depending on the rotor type used, the array could either be in or out of

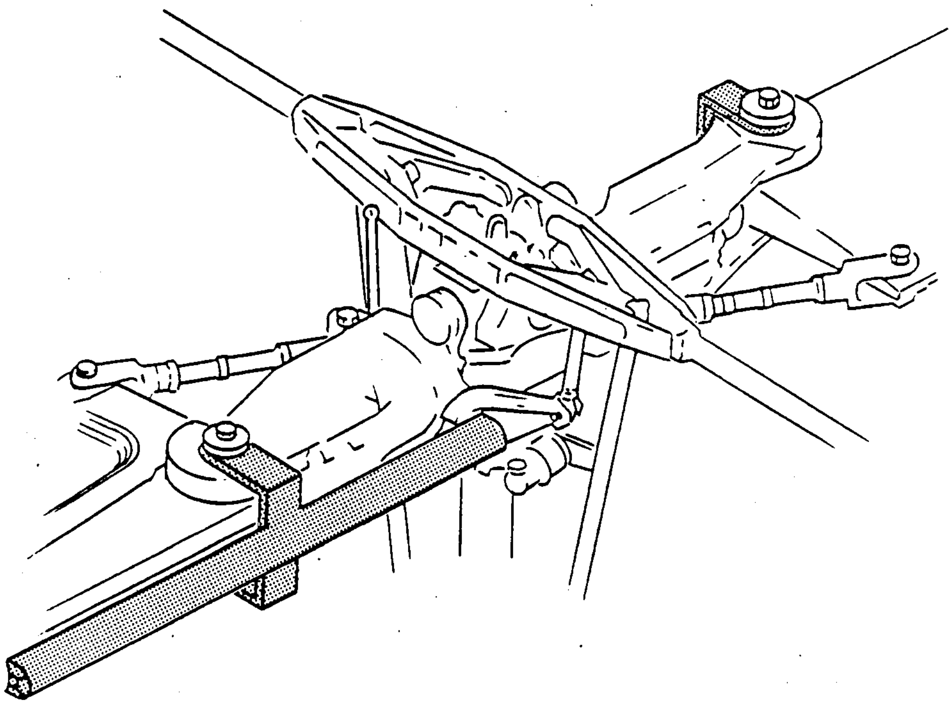


Figure 33. Linear array in blade root.

the feathering system. The array would be located in a fairing that was located in plane with the rotor and just forward of the blade root. The radar could be mounted on the rotor head. Power would be supplied through a slip ring at the base of the mast.

Major Advantages:

- Installation does not interfere with rotor blade deicing.
- The antenna is easily removable/replaceable.
- Minimal rotor modifications are necessary.
- Adaptable to most rotor configurations.
- Very small aerodynamic penalties.

Major Disadvantages:

- The practical length of the antenna is limited to about twice the hub length from the center of the mast.

- The antenna is mounted in a region subject to particle and water erosion.

- The antenna housing must be aeroelastically designed to avoid resonances with primary forcing functions.

4.4.1.4.4 Feed System. Mounting the antenna on the rotor presents the problem of connecting the antenna to the radar RT unit. The HELMS and RSRE systems used feed systems extended through the main masts with rotating joints to transition from stationary to rotating sections of the waveguide. Limited motion rotary joints were used to bridge the limited motion hinges on the rotor hub. The RSRE system also included a short section of flexible waveguide.

The feed system to the rotor is somewhat more complex and costly than the feed system to a fuselage-mounted antenna, particularly if the RT unit is close to the antenna. Because of the distance and extra rotary joints, the losses in the feed system to the rotor are greater than in the shorter feed system. One possible design to overcome the feed system limitations is to mount the RT unit on the rotor hub so that the feed system is short and simple. This has the advantage of reducing the cost and transmission losses in the feed system but it adds the cost of an electrical power slip ring. Also, some means, probably a fiber-optics link, is required to transfer received video information to the display. Mounting the radar on the hub is more complex than a fuselage mount, and different packaging might be required to best fit different rotors.

4.4.1.5 Independent Landing Monitor Radar. A type of radar has been explored to provide a high resolution image of the runway for Category III landings for CTOL aircraft. These Independent Landing Monitors (ILM) radars are similar in principle to the high resolution radars discussed above. They are short-range pulse-ranging radars that use a narrow beam width antenna to scan in the forward sector. They have been successful in showing a perspective view of the runway, which allows the pilot to confirm runway clearance on approach. Because of the wide runway, they do not require as good resolution as is necessary for the rotary wing near-zero-visibility IFR landing. Since the ILM radars only scan in the forward sector and in other respects are similar to the radars we have discussed, they will not be described in detail.

4.4.1.6 Radar Minimum Range Operation. Special attention must be given to the design of a radar to give a clear image and reliable operation in the very short range. The present weather radars do not function below approximately 545m (1800-foot) range. The HELMS system did not give reliable information below a 30.5m (100-foot) range. The principal problem is switching the antenna from the transmitter to the receiver fast enough to capture and measure the range of the pulse that is reflected from only a few feet.

One solution to the problem is to use a bistatic technique that would transmit a pulse on one antenna and receive it on a second antenna connected to the receiver. A rotor antenna design that would permit antennas on opposite blades, facing the same direction, would be useful for the bistatic concept.

4.4.1.7 Radar Gain Control. The use of a radar for approaches to touchdown will require special care in design of the gain of the radar. The reception at several kilometers during early approach will require much greater gain than will be required the last few feet of the approach. The gain must be reduced or the antenna side lobs will give a return causing serious degradation of the resolution. There are well-known techniques that can be used for reducing gain with decreasing range.

4.4.1.8 Radar Comparisons. The above description shows that the MM band radar and the X band radar using a rotor-mounted antenna are the two most promising concepts for the "near-zero" visibility IFR System. Table 12 gives a comparison of the two systems.

TABLE 12. COMPARISON OF MM AND X BAND ROTOR BLADE RADAR

Advantages	Disadvantages
94 GHz MM RADAR	
High resolution	
Lightweight	Poor weather penetration
Small antenna	Expensive
X BAND ROTOR BLADE RADAR	
High resolution	Requires modified rotor blades
Lightweight antenna mounted on existing rotor scanner	Requires RF feed system to blades
Fast 360° scan	
Same frequency as weather radar	Broad elevation beam-width
Good weather penetration	Short range due to narrow beamwidth and fast scan
Low cost components	Few hits per scan on target

4.4.1.9 Passive Reflectors at Landing Site. The radar approach may be aided by the use of passive reflectors or active beacons at the landing site. Passive reflectors are low in cost and can be small in size. The reflectors can be positioned on or adjacent to the landing site to create a pattern easier for the pilot to recognize than the unenhanced imagery. This would be especially true if the site were in a grassy field or other uniform landscape such as desert sand.

It is possible to orient individual units of a pattern of directional reflectors so that the entire pattern will be visible when centered on the glide slope but specific reflectors will not be visible when up-down, right or left of glide slope. By this passive reflector means, the pilot can detect deviation from the glide slope and make control adjustments to return to the center of the glide slope path.

The radar passive reflector slope indicator can be aligned with a visible light slope indicator so that at near touchdown, the pilot can transition from the radar to visual. If the radar image were presented on a Heads-up-Display (HUD) the transition from instruments to visual would be easier and the workload would be decreased.

Active beacons can be used at the landing site to enable detection at increased range and to improve recognition of the site in a clutter background. The beacons may be coded so that indivudual locations may be identified. The resolution for multiple beacons is approximately the resolution of the radar, assuming the receiver circuits are not overloaded by the beacon return. It is possible to increase tracking accuracy of low resolution radars, such as the present weather radar, by beam sharpening techniques. This would permit greater precision in approaching overwater targets, such as oil rigs, or to beacons in cluttered backgrounds.

4.4.1.10 Radar Landing Site Tracker. The high-resolution radar promises to give an excellent radar image of the landing site on approach, and the use of a stabilized monopulse nose antenna will give glide slope angle and range to a landing site. It has been proven, in the HELMS program, that the pilot can interpret this information on a perspective display to manually control glide slope. It may be desirable, however, to read out range, bearing, and distance in order to completely automate the approach, provide flight director inputs for the pilot, or generate other displays to reduce the workload.

It is a common technique in military radar systems to track a specific target. If the target has a larger signal strength than the surrounding background clutter, it is relatively simple to build a video tracker to lock onto the strong signal and measure its position.

If the target is buried in clutter, however, it becomes more complex, then the pilot must designate the landing site on the radar display by a cursor. The system must have the capability of storing the unique video signature of the landing site in computer memory and then tracking the signature by comparing it with the stored pattern. This feature would take considerable development.

The chosen landing site can be enhanced with passive reflectors, or active beacons if desired, to make it possible to use the simple video tracker at any site.

4.4.2 Telvision and FLIR

Among the candidates for approach aids for the ANG system are direct-view imaging systems such as television or Forward Looking Infrared (FLIR). The most attractive feature of such systems is that they present a pictorial image with perspective geometry which is easily interpeted by the pilot. Both low light level television and FLIR have been used extensively by the military for survillence and target acquisition and, to a lesser extent, as a flight aid. The results have shown, Reference 11, that cruise flight and approaches can be readily performed with television, but that slow-speed flight and hover can only be accomplished with a high workload unless an electronic control system is used to fully stabilize the helicopter.

The TV or FLIR camera can be fixed-mounted looking forward, or it can be mounted on a turret so its look angle can be varied in azimuth and elevation. The fixed mount is generally unsatisfactory because the pilot wishes the system to turn towards the landing site before he makes his turn into final approach. When turret-mounted, there is a problem of directional control; the pilots workload is normally too high for him to direct the camera by a hand control. A head-mounted display and head-tracker can be used so the camera is directed to where the pilot looks, giving a one-to-one registration of the display with the real world, Reference 55.

Problems of display interpretation with TV or FLIR displays are often caused by the camera being offset from the pilots eyepoint, the field of view is too narrow, and there is insufficient resolution to see the detail required for hover. Additional problems are caused by the necessity of shifting back and forth from the direct view display to symbolic instruments on an approach.

4.4.2.1 Television. A television system consists of a video camera that detects a pictorial image displayed on a CRT. The scene is imaged on a photo cathode by a lens where it is read by electronic-scanning means. The field of view of the system is determined by the focal length of the lens and the geometry of the image plane.

The gain of the camera tube can be increased thousands of times by the use of an image intensifier tube that amplifies the light to give the camera a low light level capability at starlight levels. The quality of a television image (ignoring noise) depends to a large extent on the resolution and dynamic range (distinct brightness levels) of the image. Resolution of the TV picture depends on many factors such as number of scan lines used, system optics, the pickup tube, the video processor, and the display. The contrast existing in the scene being viewed is also very important to the resulting picture quality.

Low light level television systems have been improved to the point that it is presently possible, in good weather conditions, to obtain detection and recognition of vehicles such as trucks or helicopters at 300m meters using a lens that subtends an angle of 30 degrees. This capability should make it possible to recognize a landing site at a range greater than one thousand meters.

The best potential for the use of television is for the terminal approach; the television could provide (assuming it could penetrate the weather) the detail necessary to make a terminal approach much as is done visually.

Atmospheric Attenuation

Energy in the visible and IR parts of the spectrum is attenuated by scattering and absorption as it propagates through the atmosphere. Figure 4, from Reference ,13 shows the attenuation in the optical range in fog and rain. The report states that television and FLIR are little better than the eye in penetrating these fog and rain conditions. Reference 56 reports on a study that has analyzed television for use as an Independent Landing Monitor (ILM) for fixed wing landings and concludes it is not a suitable sensor because of poor range in weather.

The absorption and scattering of the visual signal by the aerosols in the atmosphere during low visibility reduces the photocathode illumination on the camera pickup tube. The reduced illumination, and attendent increase in noise, reduces the dynamic range of the pickup tube. Also, the limiting resoultion is proportional to the square root of photocathode illumination, Reference 56, so the resolution is also reduced. The result is that the television image degrades in fog and rain, the times when a clear image is most required for the low visibility mission.

4.4.2.2 FLIR. A FLIR system detects and displays infrared energy emitted from objects in the field of view of the system.

The field of view can be varied by the lens used. Forty degrees is commonly selected as a field of view for a flight display. The display is presented on a CRT in TV format. The part of the spectrum most often used is the 1 to 14 micron portion.

There are three atmospheric windows in this band 1-2.5, 3-5 and 8-14 micron where transmission is higher than adjacent wavelengths. Most systems use the 8-14 micron region. The attenuation in clear air is primarily due to CO_2 and H_2O in the gaseous state in the atmosphere.

Objects are detected by the FLIR according to the emitted or reflected IR energy. When the sun is shining, the iridescence from sunlight may be sufficiently high so that reflected energy is larger than the emitted energy. At night and in low visibility conditions, radiant energy predominates. At dawn and dusk or in fog or rain, the emitted and reflected energy may be of comparable magnitude and a phenomenon called wash-out may occur.

Attenuation due to scattering is a result of aerosol particles having sizes approaching and exceeding the wave length of the energy of interest. The total one-way transmissivity of the atmosphere is due to H_2O absorption, CO_2 absorption and partical scattering.

Figure 34, from Reference 56, shows transmissivity as a function of range for several weather conditions over the 8-14 micron spectral region.

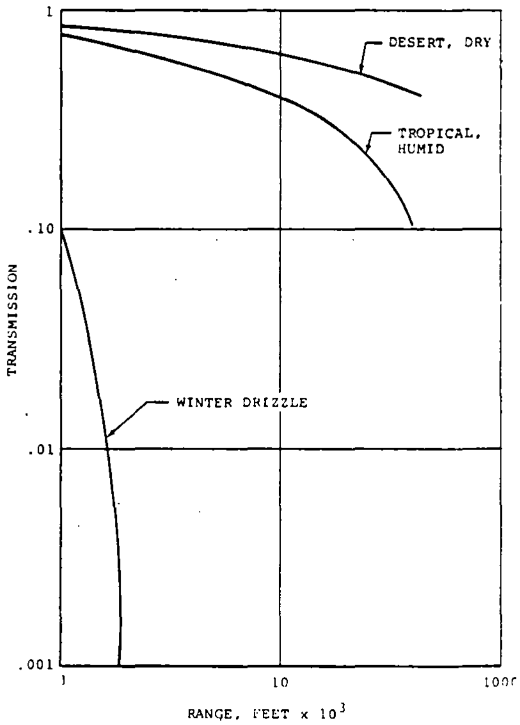


Figure 34. Transmissivity vs range 8-14 micron spectral region.

The decrease in transmission in winter drizzle is indicative of the problem of using FLIR in rain conditions. After a period of cold rain, the temperature of objects (that do not have an internal heat source such as a combustion engine) tend to even out with each other and with the background so that the temperature contrast and, therefore, the IR emission difference is low. This results in a very low contrast image or the wash-out phenomenon; this condition along with the attenuation in the atmosphere, causes a very poor FLIR image in low visibility conditions when it is required for approach and landing.

4.4.2.3 Television - FLIR Potential. Television and FLIR are attractive because of their pictorial display qualities. However, their use for terminal navigation and approach sensors for the near-zero visibility system are questionable because of severe signal attenuation in fog and rain. There may be application for TV or FLIR in special circumstances where night operations are required and heliport lighting is impractical. The minimum ceiling limits for such application would need to be set at from 15.2m (50 feet) to 30.5m (100 feet).

4.4.3 Microwave Landing Systems (MLS)

Emphasis in this study is on onboard techniques for navigation and guidance, but in situations of high density traffic to a fixed site, MLS systems have some promise as approach systems. There are several types of MLS that are candidates.

4.4.3.1 International Standardized MLS. The International Standardized MLS has been chosen by the International Civil Aviation Organization (ICAO) to eventually replace the existing ILS. MLS is a ground-based time-reference scanning beam system which by use of an airborne receiver gives azimuth and elevation angles and DME to the ground unit. The coverage is approximately ±40 degrees in azimuth and up to 30 degrees in elevation. By mounting the ground unit on a turntable, 360° azimuth coverage can be achieved.

The system uses a pair of narrow fan-shaped beams in azimuth and a pair of wide beams in elevation, both sets scanning back and forth in alternate directions. In every scanning cycle, the aircraft receives two pulses for both elevation and azimuth. The time interval between "to and fro" pulses is proportional to the angular position of the aircraft with respect to the runway. Data are encoded on the signals by time division multiplexing through differential phase shift keying.

The DME accuracy has been found to be better than ±60 feet (18.2 meters) by the ICAO, Reference 57. The MLS angular functions have been tested and found to have accuracies better than the present Catatory II ILS.

A flight evaluation of the angular functions of the MLS to an airport runway using manual control in an unstabilized UH-1H helicopter are reported in Reference 58. The elevation and azimuth angles were presented on a common HSI instrument and included a CDI indication. Approaches were successfully flown at three, six and nine degree glide slopes and a 20 degree offset radial. The conclusions indicate general pilot acceptability of the four profiles flown. The mean pilot recommended maximum glide slope for dual-pilot "angle only" manual MLS approaches as about 9 (8.7°).

The mean minimum altitudes occuring during missed approach were 13.1m (43 feet), 23.4m (77 feet) and 35.9m (118 feet) for 15.2m (50 feet), 30.5m (100 feet), and 45.7m (150 feet) decision heights, respectively.

Reference 57 reports on an analysis of the use of MLS for approach to an offshore platform. It was concluded that approaches could be made in minimums of 45.7m (150 feet) above sea level, or 15.2m (50 feet) above the heliport and with a visibility range of 1/4 mile.

4.4.3.2 Co-Scan. One configuration of MLS called Co-Scan is a Kμ band scanning beam system that gives glide slope angle, azimuth angle, and DME. Typical of such systems is the U.S. Army Man-Portable Scanning Beam Landing System (MPSBLS). Reference 5 describes a flight evaluation of the MPSBLS in which steep angle approaches to landings were made in a UH-1 helicopter in simulated IMC to zero-zero conditions. The system specifications are shown in Table 13.

TABLE 13. MPSBLS EQUIPMENT SPECIFICATIONS

Size (less pedestal):	
	29.5 in H, 16.5 in W, 16.5 in D.
Weight (including pedestal, less batteries):	
	59 pounds.
Power consumption:	
	150 watts total from any 24 VDC source.
Coverage (localizer, glide slope, DME):	
	± 30° in azimuth, 0 to 20° in elevation
DME error (manufacturer's specification):	
	15.2m (50 feet) or ±2% of range.
RMS angle error (manufacturer's specification):	
	0.3° localizer, 0.2° glide slope
Update rate: 4 Hz.	
No. of channels:	
	10 (15.412 to 15.688 GHz ground to air).
Antenna beamwidths:	
	localizer - 6° x 20°
	glide slope - 4° x 60°
	DME - 6° x 20_o

Manual approaches were performed using a 4-cue flight director which provided computed steering cues, based on MLS glide slope information and airframe dynamics, to provide left-right cyclic, fore-aft cyclic, and pedal and collective control commands. Raw data were also presented on an HSI instrument. The approaches were accomplished along a programmed constant decelerating path to a stable hover over the desired landing point. The data showed that when the hover point was reached, it was within 1 to 5 feet of the desired glide slope. Glide slopes were flown at 6, 9 and 12 degrees with a deceleration of approximately 0.05G's. The pedal command is actuated when airspeed is below 45 knots; above that, turns are coordinated by centering the ball in the conventional manner. The glide slope of the MPSBLS can be intercepted from 200 to 1000 feet altitude.

The system has the capability of programming a missed approach. By selecting the desired MAP heading before initiating the approach, the pilot can at any time select a go-around mode that will give flight director cues for the MAP maneuver.

The approach to zero-zero hover with the MPSBLS has also been automated using an electronic control system and a coupler in the helicopter.

4.4.3.3 MADGE. The British have developed Microwave Aircraft Digital Guidance Equipment (MADGE) that has been used for helicopter approaches in IMC conditions. The system consists of a ground station and an airborne unit.

Information derived by the equipment for display on aircraft instruments includes:

- Azimuth position of the aircraft on approach, relative to a landing site datum or a selected angular or linear offset from that datum.
- Elevation of the aircraft relative to a selected glide slope or standardised flight-path.
- Slant range of the aircraft from the ground station, and aircraft velocity to or from the ground station.
- Flag warnings and indications of specific positional situations and the validity of the derived information.

Principles of Operation

- Angle measurement is by means of multiple interferometry. The angle of incidence of signals from an interrogating aircraft, relative to a datum perpendicular to the interferometer array, is determined by measuring the phase-difference between the signals received by each antenna in each interferometer pair.
- Range is determined by measuring the elapsed time between an aircraft interrogation and the receipt of a reply from the ground station.
- For offshore operation, elevation can be calculated on the ground using range and height data, instead of being measured by interferometry.

General Characteristics of the system are as follows:

Frequency	5.0 to 5.25 GHz
Azimuth Coverage	90 degrees front and rear system can be mounted on turntable for 360-degree coverage
Elevation Coverage	25 degrees
DME	Accurate to 2m (6.5 feet)

Flight evaluation has been conducted to oil rigs in the North Sea, Reference 59. Approaches were made on a 3-degree glide slope to a minimum safe altitude, beginning about a mile from the rig. The pilot flies at the safety height, which can be 45.7m (150 feet), on a course offset from the rig by 300 (984 feet) at the closest point.

4.4.3.4 MLS Potential. The use of MLS is not promising for the ANGS because of the sophisticated ground unit that is required. The estimated quantity cost of the units ranges from $75,000 to $150,000. In addition, there would be considerable monitoring and maintainence of the unit to assure proper functioning. The system may be cost effective for use on major heliports where traffic is high.

The U.S. Army accomplishment of zero-zero approach with MPSBLS is one of the major pieces of evidence that it is possible to make manual approaches in zero visibility using flight director and HSI instruments, and also that automatic approach in a helicopter is possible using externally sensed azimuth and elevation angles along with an accurate DME.

4.4.4 Lighting

One means of aiding the helicopter in close approach and landing is by the use of illiumination at the site. At high use heliports, such as oil rigs or urban sites, it is possible to use high intensity lights to outline the heliport, or to provide Visual Approach Slope Indicators (VASI) that gives visual indication of glide slope angle. Reference 60 reports on the development of a visual landing aid Pulse Light Approach Slope Indicator PLASI.

The PLASI system uses a lens system with red and white lights. When centered on the glide slope, the pilot sees a steady white light. When below the glide slope, he sees a pulsating red light with steadily increasing pulse rate as deviations increase to 2.5 degrees below the glide slope; when above the glide slope, a pulsating white light is seen with a steadily increasing flash rate to 2.5 degrees above the glide slope.

The visible light is scattered and absorbed by moisture in the atmosphere, seriously reducing the range at which the lights are visible. Even in the worst visibility conditions, high power lights are visible a few feet. Usually, visible range to the heliport can be doubled with strong lights.

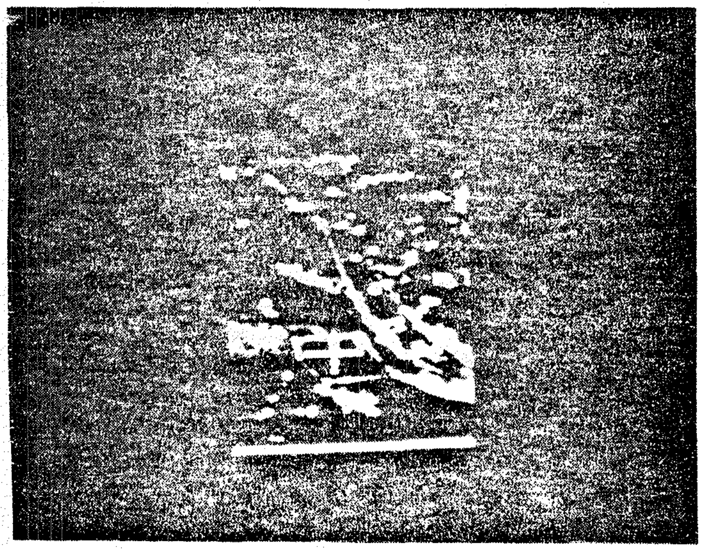
Active lights on the helicopter are sometimes useful, particularly at night, but the scattering of light by fog and moisture can sometimes tend to blind the pilot and reflections from objects are often obscure and confusing to the point, the pilot may not correctly identify his position.

One of the most promising possiblities is to use slope indicator lights matched with a slope indicator pattern of radar reflectors (see Paragraph 4.4.5) so that after using the pattern of radar reflectors for the approach, the pilot picks up the visual light pattern at the terminal end of the approach and uses the light pattern the last few feet and for hover and touchdown.

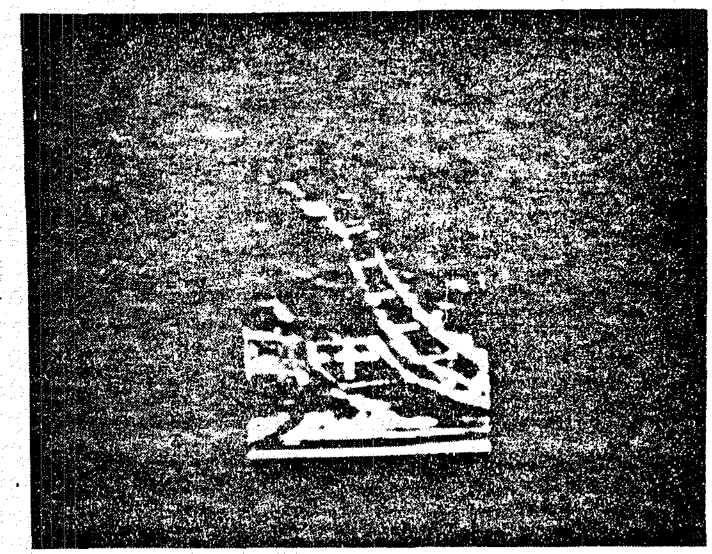
4.4.5 Microwave Passive Reflectors

The use of high resolution radar for terminal area navigation and approach introduces the possibility of enhancing the radar image with passive reflectors. By use of various shapes of small sheetmetal reflectors, the effective radar cross-section of the reflector can be made much larger than surrounding targets so the reflectors will appear as point targets on the radar display. Reflectors might be located at the corners and touchdown point on a heliport, for example, to create a distinctive pattern easily recognized by the pilot. The reflectors are low cost and require no maintenance.

Passive microwave reflectors have also been suggested as a form of glide slope indicator, Reference 61. The concept involves the use of passive reflectors designed so the reflectivity is maximum over a limited angle of a few degrees. Several reflectors are oriented at the landing site to point along the glidepath. By offsetting the alignment of certain reflectors, it is possible to have a distinctive pattern when centered on the glide slope and a different pattern for each of the misalignments of up-down, right-left of the glide slope. Figure 35, Reference 62, shows radar imagery from a rooftop experiment using a millimeter radar to scan passive corner reflectors arranged in the form of a cross. Figure 35a shows the image with all reflectors detected as when centered on the glide slope. In 35b one reflector is not being detected, which would represent an error to the left of the glide slope centerline. Errors to the right, above, and below the glide slope can be detected by orienting a reflector on the corresponding arm of the cross so that it will not be detected if there is a deviation from the glide slope in that direction.



(a) Centered on glide slope.



(b) To left of glide slope.

Figure 35. Passive reflector glide slope indicator.

4.4.6 Obstacle Detection and Avoidance.

One of the most critical problems of an all-weather helicopter flight system is the problem of avoiding obstacles. The point-to-point operation of helicopters at the low altitudes normally causes close encounters with natural and man-made obstacles. The low altitudes are not only the most efficient for helicopter operation but are necessary for separation of helicopters and fixed wing traffic. The problems of tracking low altitude helicopters with ATC radar (because of line-of-sight limitations) will require that the individual helicopter be responsible for precise path control and obstacle avoidance. This will require onboard obstacle detection and avoidance.

The objects that must be avoided include terrain in the form of mountains, hills, trees, towers, buildings, wires, ropes or cables. Detection must be made at ranges sufficient to avoid the obstacle and the detection must take place in clutter backgrounds.

There are two principal means of obstacle detection that are candidates for the ANGS: Microwave radar and Laser Radar.

4.4.6.1 Microwave Radar Obstacle Detection. The use of microwave radar for obstacle detection and avoidance is usually accomplished by using a narrow pencil beam antenna to scan the area forward of the helicopter or an elevation beam sharpening technique to dicriminate the elevation angle of targets in the antenna beam. Interferometer techniques are commonly used.

The HELMS radar, described earlier, displayed only targets above boresight from the elevation monopulse forward antenna. The antenna was elevation stabilized to point slightly below the flight path of the aircraft and was scanned ±45 degrees in azimuth and was roll stabilized. This resulted in the display of objects that protruded into the plane of the aircraft's flight path in the forward 90-degree sector. Flight test determined that all objects larger than small wires and branches could be detected and avoided. It was possible to detect the poles that supported wires but not the wires. It was also possible to detect patterns of wire supporting poles on the high resolution map display.

Since wire strike accidents often occur where wire locations are well known, it would be possible in the Advanced Navigation and Guidance System to store the position of known wires in computer memory and use symbols on the radar HSI display to indicate wire position.

Another technique that could be used is to range gate the radar on approach so that on periodic scans of the antenna the radar range would be limited to a range just short of the landing pad. By this means, background clutter would be removed and any targets protruding into the approach path would stand out.

4.4.6.2 LASER Radar Obstacle Detection. One of the most interesting developments of recent years for sensing obstacles is the Laser Radar which like a microwave radar transmits energy, which when reflected from a target is detected by a receiver. By knowing the position of the beam, the position of the target is also known. The unique feature of the laser radar is that the beam is small enough to be the approximate size of a wire so that the wire can be resolved as a distinct target.

A research effort, Reference 63, has produced a Laser Radar called LOTAWS, which has had success in detecting wires during flight test. The carbon dioxide 10.6 micron laser delivered a 340 nanosecond pulse at a pulse repetition frequency of 40 KHz. The average power was two watts. A rotating mirror scanner was used to scan the beam in the forward sector of the aircraft. The system demonstrated detection of 0.32 centimeter army field wire at typical ranges of 500m (1640 feet) and power lines at ranges of 1609m (1 mile). The research system weighed 500 pounds; it is estimated that a development system would weigh 100 to 125 pounds.

The laser radar system potentially has a dual function. It has been tested as a doppler ground speed measurement device with good success.

Since the laser operates at very high frequencies in or near the visual band, the attenuation in fog or rain is high. Figure 36, taken from Reference 64, shows that the attenuation is higher then for millimeter radar. This makes it necessary to increase the power of the laser which increases size weight and cost.

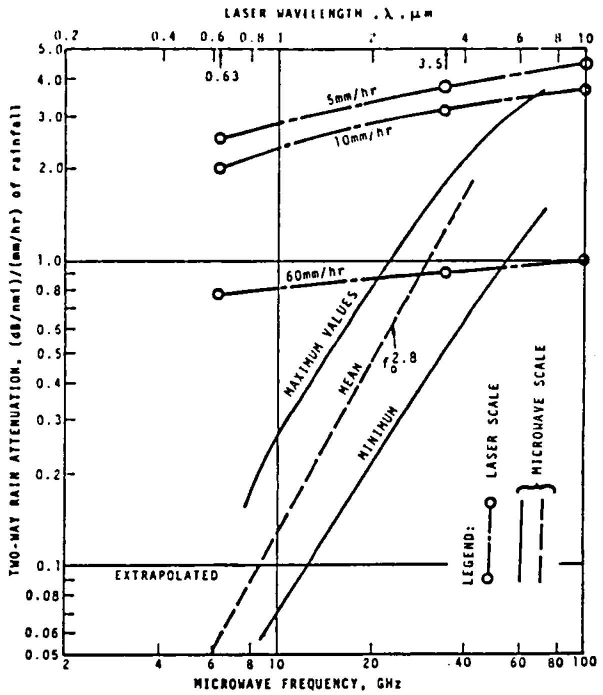


Figure 36. Microwave and laser rain attenuation.

4.4.6.3 <u>Obstacle Avoidance Trade-offs</u>. The high resolution radar at X-band frequency, for good weather penetration, is the most cost-effective means of obstacle avoidance except for wires. It is particularly attractive since it also has the potential of being an approach and collision-avoidance aid.

The laser radar has the best potential for detecting all objects including wires but is severely limited by heavy atmospheric moisture. It is also heavy and very expensive.

Research is required to improve techniques for obstacle avoidance.

4.4.7 IMAGE ENHANCEMENT AND MAP MATCHING

The requirements for precision navigation and guidance make it desirable to sense images and display detail that will allow recognition of surface features for navigation, approach, and landing. Several imaging sensors have been discussed. It would be desirable to use modern image enhancement technology to improve the images from these sensors.

The state of the art in digital computers has permitted the development of high resolution image processing by digital techniques. These image improvement processes have been widely used in space imagery and in biomedical imagery. They may possibly have application to image sensing for the zero-visibility IFR System. Three concepts will be examined: they are, image restoration, image enhancement, and map matching.

IMAGE RESTORATION

The concept of restoration is generally considered to be the reconstruction of an image toward an "Original" object by inversion of some degradation phenomena. To accomplish this inversion, there must be "a priori" information of the imaging process that causes the degregation. It could, for example, be some scanner-induced noise, some predictable motion smear, a defocused imaging system, etc., of a particular imaging process. The knowledge must be in the form of analytical or statistical models or other definable information.

The Fourier domain of the image is often used to determine and correct for badly defocused imaging systems and linear motion blurred images.

The restoration, in nearly all cases, is achieved by powerful digital computers and often not in real time in order to reduce computing power. Often the restoration is to correct some phenomena that is induced by the restrictions to sensors in space due to limited weight or complexity possible in spacecraft. For the earth-based systems under discussion, there are fewer restrictions on original design that might make restoration necessary.

IMAGE ENHANCEMENT

Image enhancement is broadly defined as an attempt to improve the appearance for human viewing or subsequent machine processing, Reference 65.

Categories of enhancement techniques used are: intensity mapping, eye modeling, edge sharpening, and pseudocolor. Intensity mapping is an effort by digital processing to reconstruct an original known grey scale. For a simple example, assume an image is reproduced of a resolution chart where it is obvious that there were only blacks and whites in the originals. An algorithm can be written for a digital computer to restructure the image with only black and whites which should eliminate noise and any grey scale information, that may have been introduced in the reproduction process, to make the image more like the original.

Edge sharpening is often implemented in the Fourier domain of an image with ramp or other monotonically increasing functions in the spatial frequency plane. The technique of subtracting out the low frequency portion of an image, thereby leaving an enhanced image that is more pleasing to the eye than the original image, is a well developed technique.

Color is often added to monochrome images for the purposes of increasing the effective visible dynamic range of the original grey scale. Two methods are used. In one, a particular grey shade is mapped to a given intensity hue, and saturation defining a color shade. The other method maps a particular spatial frequency to a particular color shade. Both techniques creat a pseudocolor that subjectively enhances the image for the viewer.

Restoration and enhancement of images have been accomplished principally with television-type scanning systems. These techniques would be applicable to television or FLIR use with ANGS. It has been shown, however, that the feasibility of approaches in fog or heavy rain with television or FLIR is questionable. The techniques could be applied to radar but there is little data on such an application.

MAP MATCHING

One of the limitations of radar, even high resolution radar, is that the displayed image does not have the same characteristics as a visual image. The spectral reflections in the microwave band do not have the same response or nearly as high resolution as in the video region. That is why a television image, if it could be sensed through the fog and rain, would be preferable to the radar image. Map matching is a technique that can make the radar image easier to recognize.

In map matching, certain features of an image (usually radar) are extracted and used to compare with common features from a map to cause the image and map to be superimposed in registration with one another on a display, so that the familiar features of the map can be used to judge position and track.

The map matching techniques involve feature extraction from the radar image that is compared with like features stored in computer memory. The features selected can be textural properties, patterns, edges or boundaries, skeletons, and related structures. Algorithms must be formulated to analyze the features. Patterns can be divided into subpatterns until the basic or primitive element is discriminated as a feature. The pattern is then analyzed by syntactic rules, Reference 66.

The map matching could use natural terrain or cultural targets, existing man-man targets, or reflectors or beacons especially placed for map matching purposes. The technique could be used to register existing maps such as airway charts, with the radar image on a common CRT that had provisions for combining the optically projected map. A computer graphic representation of the map could also be used. For example, in a terminal area, an outline of the designated corridor could be positioned to be in registration with the radar image.

The use of computer graphic techniques involves principles used in map matching and in Computer-Aided Design (CAD). The following is an example of how the technique could be used to approach an offshore oil platform. A pattern of the location of offshore platforms in an oil field would be stored in computer memory. A line drawing outline of each rig with the location of the landing platform shown would also be in memory.

When approaching the field, a map matching algorithm would compare the radar return with the pattern of rigs in memory, compensating for the change in pattern due to distance and direction. When a pattern match was achieved the radar display would be enhanced graphically. Likewise, as any particular rig was approached, the radar pattern would be matched with memory to call up a line drawing of the rig showing landing pad placement and orientation. The graphic image would be computed and displayed much like objects in CAD where scale and direction of view of a three-dimensional object can be varied on a CRT as desired. The control for determining the scale and orientation of the computed image would be the radar map matching system. The computed image, which would be superimposed directly over the radar image, would much enhance the outline of the landing pad on approach. There is a danger in such a design; however, it is no longer a purely direct-sensed display, and if the computer should error, a false image could be displayed. This possibility might lessen pilot confidence in the system.

The potential for the digital image processing and map matching techniques for ANGS is in the long range. The techniques at present are very much in the development stage and require large processors. Most of the processing is not in real time. As the techniques evolve and VLSI/VHSI circuitry is applied to civil avionics, the digital image processing, map matching, and computer enhanced displays by graphic means should become feasible.

4.4.8 COMPARISON OF TERMINAL NAVIGATION AND APPROACH SYSTEMS

The rankings of the terminal navigation and approach systems are based on their capabilities for providing precise position and velocity information to navigate to a point in space for the final approach fix and to execute a precision approach to a hover over a 30.5m (100-foot) square landing pad without external visibility. In addition to the accuracy required, considerable importance is given to pilot confidence and peace of mind such as are achieved by a pictorial type display.

The principal requirements for the terminal navigation and approach systems are:

- Should be accurate enough for zero-visibility approach.
- Should be self-contained.
- Should have good weather penetration.
- Should be low in cost.
- A direct-sensed display is desirable.
- Three-dimensional information is desirable.
- Should have good signal reliability.

Table 14 gives the subjective rating of the most promising Terminal Navigation and Approach systems for the onboard system. The values used are:

5	-	Excellent
4	-	Very good
3	-	Good
2	-	Poor
1	-	Very poor
0	-	Of no value

TABLE 14. RATINGS OF TERMINAL NAVIGATION AND APPROACH SYSTEM FOR ON-BOARD SYSTEM

		TV	FLIR	MM Radar	Differential GPS	Rotor Radar	MLS	Co-Scan
1.	Accuracy	3	3	5	3	5	4	4
2.	Self-Contained	5	5	5	2	5	0	0
3.	Weather Penetration	0	0	2	5	5	5	5
4.	Cost	4	3	2	3	2	1	2
5.	Peace-of-Mind Display (Direct Sensed)	5	5	5	0	5	0	0
6.	Three-dimensional Information	1	1	4	5	4	5	5
7.	Signal Reliability	2	2	3	3	4	4	4
		20	19	24	21	30	19	20
	Average rating	2.8	2.7	3.4	3	4.2	2.7	2.8
		Poor to good	Poor to good	Good to very good	Good	Very good to excellent	Poor to good	Poor to good

5. FEASIBILITY ANALYSIS

5.1 ALLOWABLE ERROR

The feasibility of using a particular navigator and guidance aid in the near-zero-visibility IFR systems depends upon its ability to meet the requirements of the system. The precision with which the aircraft can maintain a flight path course and a glide slope angle depends upon the navigation and guidance system error plus the Flight Technical Error (FTE) attributed to the pilot in flying the system (or to the automatic system if it is automated).

Present accuracy requirements for area navigation systems are specified in AC 90-45A, Reference 67. They are:

AIRSPACE	TSCT
En route	2.5 n.mi.
Terminal	1.5 n.mi.
Approach	0.6 n.mi.

A near-zero-visibility en route and terminal area system, however, will require greater accuracy.

The Northeast Corridor uses a ±2 n.mi. wide corridor, and Reference 23 reports that in tests with Loran-C, the statistical data indicated that ±1.0 n.mi. was never exceeded on a two-sigma, 95-percent probability basis. It seems reasonable to pick ±1 n.mi. for the en route accuracy for the analysis.

The terminal area value of AC-90-45A seems excessive for the task of navigating in an urban terminal area such as shown in Figure 6. In order to have obstacle avoidance and room for parallel opposite routes, it would seem that no more than ±0.75 n.mi. would be allowed. The approach accuracy required at the Final Approach Fix (FAF) will be determined by obstacle clearance requirements (noise control requirements and the precision required to accomplish the approach).

The system is expected to have a control system with good low-speed stability. This will permit greater precision on the glide slope than is possible for an aircraft with a minimum velocity of 60 knots. If a pictorial-type display is provided to show path and angular displacements, the pilot may be able to make corrective adjustments on the final approach that he would not be able to make at higher velocities. Assuming that the approach is 10° or higher, if the pilot intercepts the approach path at 457m (1500 feet) altitude, he will be at a range of 2597m (8522 feet) from the landing site. Assuming he enters at 60 knots and has near constant deceleration along the flight path, it will take approximately 2.8 minutes to reach a hover. This provides ample time to make corrections providing there is a horizontal display to interpret track deviation. The pilot's workload will determine his ability to make corrections. To take full advantage of the helicopter's capability for manuever and slow speed, the ability to make a spiral approach would be desirable. In restricted areas, it is likely that the major factor in setting up the FAF point and the lateral approach angle will be controlled by obstacle clearance and noise considerations.

The lateral and along-track accuracy on the glide slope must depend on the precision necessary for good aircraft controllability and the total allowable ASE and FTE.

The VHF localizer beam has a lateral variation of 5°; at 2597m (8522 feet), resulting in 227m (745 feet) lateral deviation. This will be used as a goal for the FAF lateral error. The 5 degree error will be used for lateral error on the glide slope.

The elevation deviation allowed will be determined by obstacle clearance requirements and the pilot or automatic system ability to control glide slope angle. The FAA ILS glidepath system allows an error of approximately 1.4° elevation deviation for full-scale instrument limit, Reference 68. The 1.4° allows 63.4m (209 feet) altitude deviation at the 2597m (8522 feet) FAF.

The requirements based on the above assumptions and on the limits of the 5 degree lateral and 1.4 degree vertical errors at Categories I, II, and III minimum altitude limits are shown in Table 15.

Table 15. TERMINAL AREA NAVIGATION AND APPROACH REQUIREMENTS

Terminal NAV Requirements	
Corridor Characteristics	Altitude 75.7m (250 feet) 909m (3000 feet) Straight, curved or segmented Width - .5 to 2 NM Accuracy 100 m (2σ)
Obstacle Sensing	Onboard capability
ATC	Positive control, preferably cockpit display

Approach and Landing Precision Approach	Altitude	Accuracy 2σ Lateral	Vertical
Cat I	30.5m (100 feet min.)	±9.1m	±3m
Cat II	15.2m (50 feet min.)	±4.6m	±1.4m
Cat III	0	±4.1m	±0.5m

The final phase of the zero-visibility approach, i.e., the last 61m (200 feet) before hover over the pad, is expected to be the most critical part. It will be necessary to touchdown near the center of the specified 30.5m (100-foot) landing pad. If the x, y position error is limited to ± 4.1m (13.4 feet), a large helicopter rotor (73 feet) would remain within the confines of the landing pad. The hover point in space (HPS), of 4.5m (15 feet) elevation must be achieved on approach, within the specified lateral accuracy of Table 15, which is ±4.1m (13.4 feet). This error must include the ASE and FTE.

The total allowable along-track error on the glide slope must be within limits that will permit a low workload for pilot manual control and that can also be accomplished by the automatic system.

The along-track error goal is set at ±7.6m (25 feet) beyond 61m (200 feet) range and ± 1.5m (±5 feet) from 0 to 61m (200 feet). The greatest question is what accuracy is required for the near-zero-visibility approach and landing. The use of 2σ error of ±2.5 degrees crosstrack and ±.7 degrees elevation may be unnecessarily restrictive. Assuming good slow-speed stability, the helicopter should be able to exceed that error level and still make a safe approach providing the displays can be clearly interpreted and the workload is low. The determination of the amount of error that can be tolerated is one of the tasks recommended by the study.

A sketch of the approach with plots of deviations discussed above is shown in Figure 37 and 38.

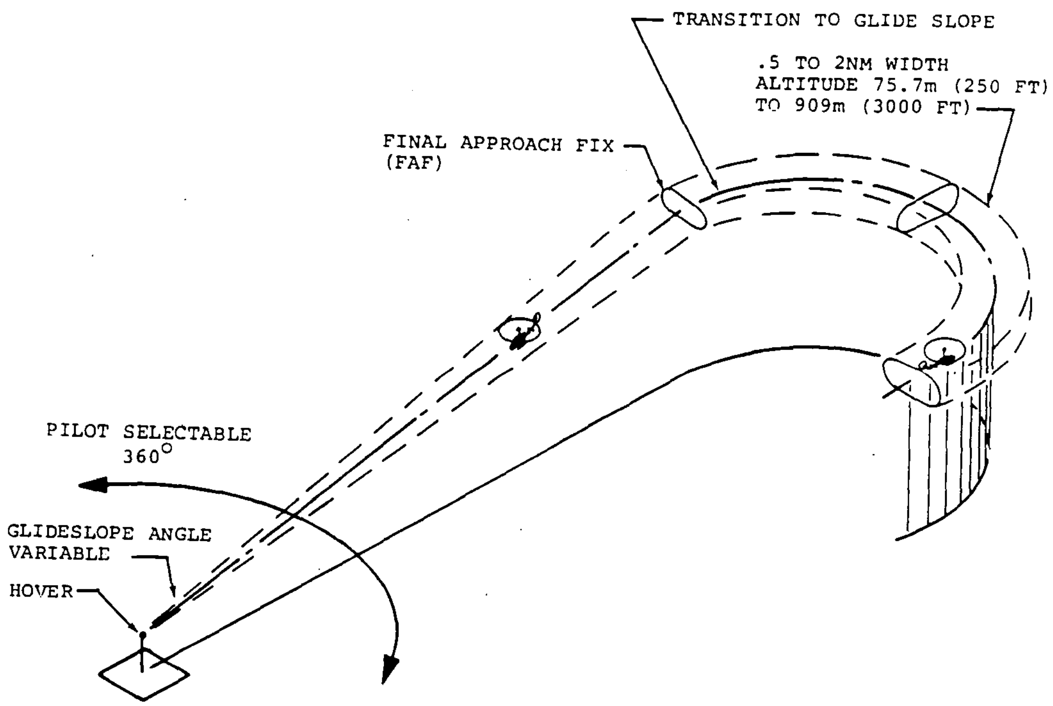


Figure 37. Sketch of final approach path.

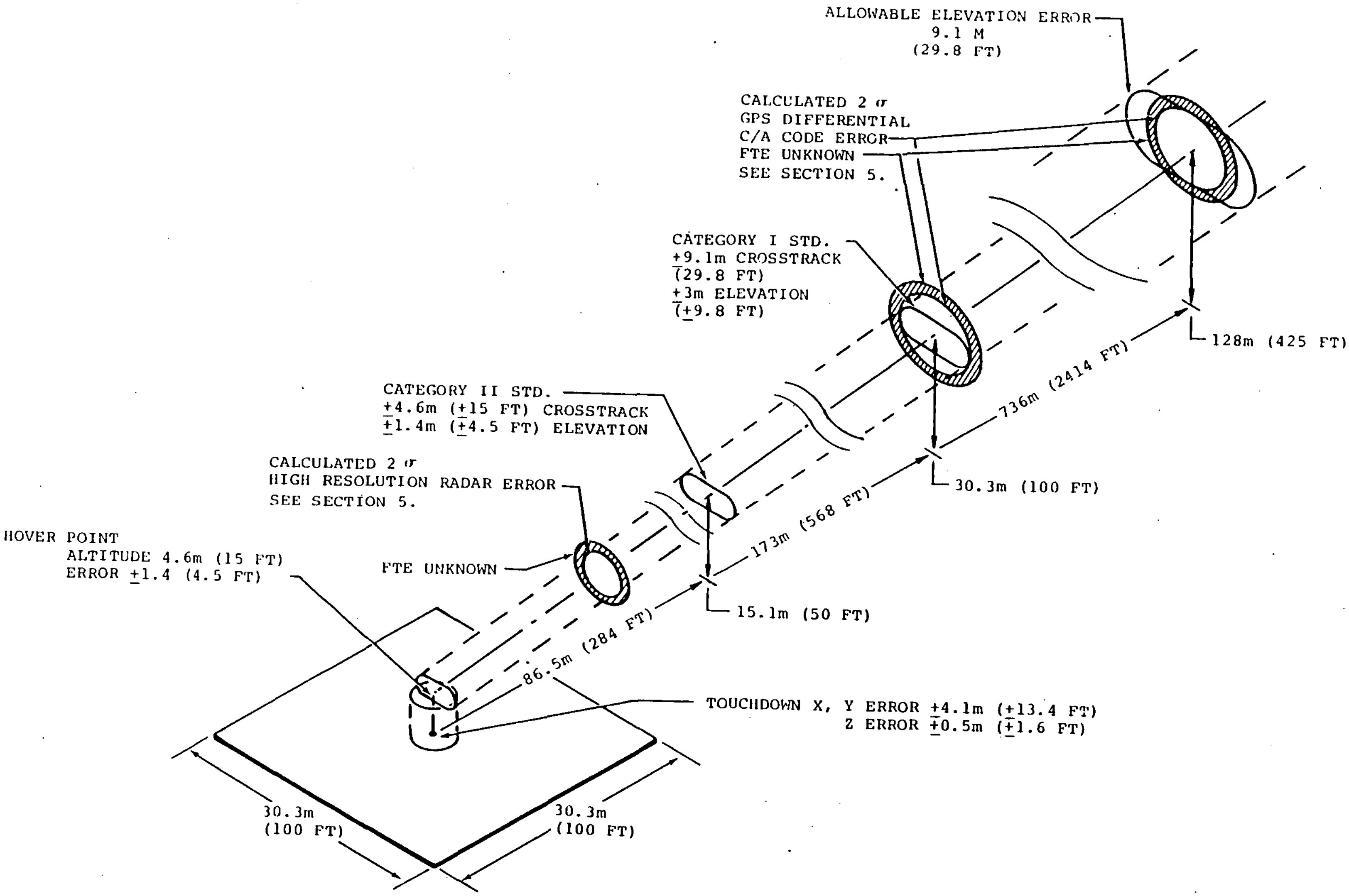


Figure 38. Sketch of final approach segment with calculated allowable error and sensor errors.

5.2 APPROACH SYSTEM FEASIBILITY

There are several combinations of area navigation, approach, and control systems that can be used for the near-zero-visibility system. The preliminary ratings have shown that Loran-C and GPS are the most promising candidate systems for the RNAV part of the mission.

Both systems have sufficient accuracy for the RNAV function and for nonprecision approach. GPS is considered to have the potential for precision approach.

The preliminary ratings of the terminal area navigation and approach systems show that High Resolution Radar and GPS are the primary candidates with MLS and co-scan having some promise for fixed sites that have heavy traffic. The most critical criterion that each system must meet is the position and velocity accuracy necessary for approach and landing.

5.2.1 GPS Terminal Navigation and Approach Feasibility

The GPS degraded C/A code accuracy, using the differential mode, is reported to be 18m single axis error (2 σ), Reference 31. It is shown in Figure 35 that the 18m error exceeds the allowable elevation error at 735m (2414 feet) from the hover point. At this point on a 10 degree glide slope, the altitude is 128m (425 feet). Using this criterion as a guide, the GPS would be satisfactory for precision approach to this visibility ceiling without exceeding the elevation error.

The calculated GPS error is within the designated crosstrack glide slope until within 205m (674 feet) of the hover point, which is at 36m (118 feet) altitude.

The precision with which the glide slope track can be maintained in elevation and crosstrack will include the ASE and the FTE. The 18m (59-foot) GPS error is the ASE (we will assume that the airborne display will include the same error as in the tested system). For whatever type readout we use, there will be FTE that must be added.

Clearly, if GPS differential mode C/A code is to be used for precision approach below 30.5m (100-foot) ceiling at 10 degrees glideslope, the elevation and crosstrack accuracy on the glide slope will have to be less than are shown in Figure 38.

For GPS to give approach guidance to a particular site, a navigation computer with the site position stored in memory is necessary. The GPS crosstrack and elevation signals must be integrated into a display that will allow the pilot to control the position on glide slope. There are many display options; a simple cross-pointer could be used, or a display as advanced as a vertical flight director with relative position and track shown on a CRT horizontal display. One of the questions is the stability of the GPS signal, particularly for derivation of velocity. Figure 39, taken from Reference 31, shows Z-set field test position errors; if the variation is typical of GPS data, a great amount of filtering will be necessary which will introduce a significant time lag in the output. The time lag would make the use of velocity for flight control inputs questionable.

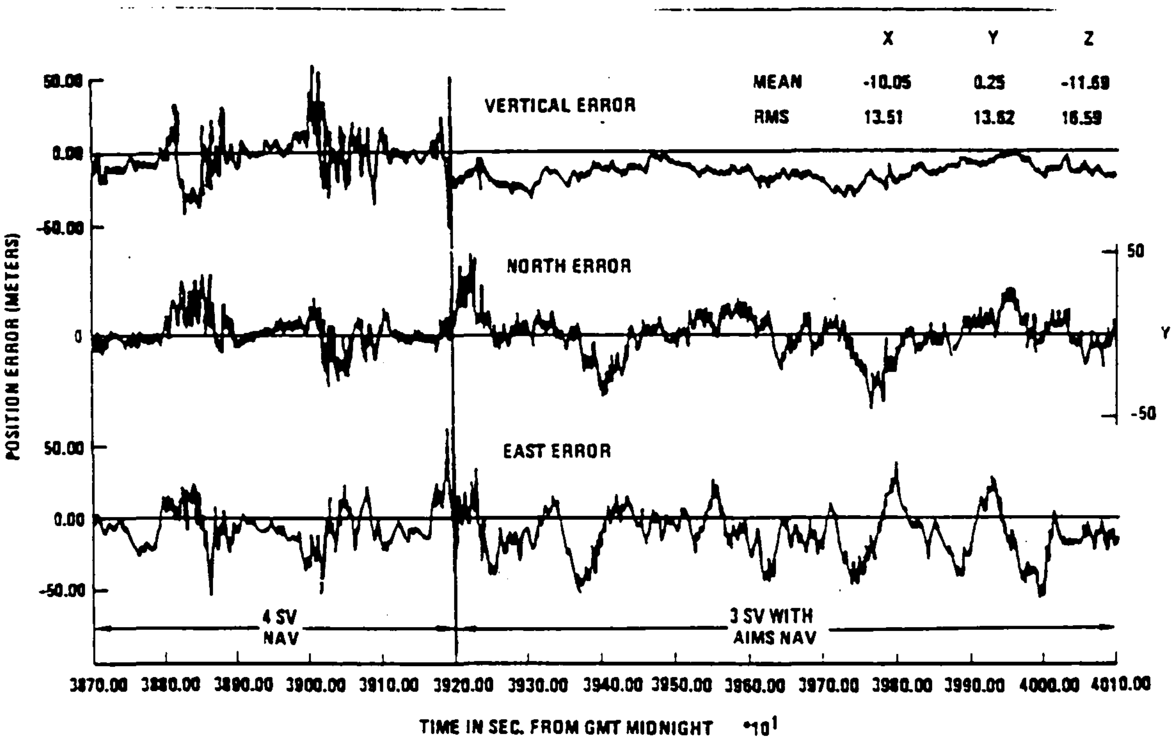


Figure 39. Z-Set field test results - position errors.

The FTE introduced by the pilot will depend upon his ability to interpret the display and the workload during manual approach. Even if a coupler and automatic control system are used, the pilot must be able to take over the manual control in case of automatic system failure.

A limitation of any display configuration for the GPS system is that it is a computed display; the pilot making an approach to low levels without visual contact must depend upon correct reception of the signal and accurate computation and display for his precise position and velocity information. Another limitation is the necessity for the ground unit for the differential mode. However, approaches could be flown to any site within the general local area of the ground receiver. There is a gradual degradation of system accuracy with increasing distance from the ground receiver (pg. 33, Ref. 30.). This can possibly be afforded for the off-shore oil industry and for sites with heavy traffic, but it is not a promising solution where great flexibility in landing sites is desirable.

5.2.2 Radar Terminal Navigation and Approach Feasibility

High resolution radar also has promise as a system for terminal navigation and approach. The radar considered for this analysis will be assumed to have the major characteristics of the HELMS system, i.e., a high-resolution 360-degree mapping mode and a forward-looking elevation monopulse antenna on the nose of the helicopter that can be scanned in azimuth and scanned or ground stabilized in elevation.

The radar is unique among the candidate systems in that it presents a direct-sensed display that is similar to a horizontal map of the area; it does not directly give map or geographical coordinates. Pilotage techniques are used in navigating with the radar; position is determined in reference to recognizable features in the radar image. The radar display can also receive inputs from the navigation computer; symbology can be created to show flight path, corridor width, etc., in correlation with the radar image. The radar can be used to update the navigation system by the insertion of checkpoint information into the navigation computer.

It has been proven in two flight test programs that high-resolution radar can be used for precision navigation in areas where recognizable targets exist, such as in the terminal area around a landing site. An active beacon located on a known position (such as a tall building) could be tracked by the radar to give precise position for input to the navigation computer. This position could then be used for automatic reporting to the ATC system.

Collision avoidance could be performed directly if all aircraft operating in the area were equipped with cooperating beacons detectable on the radar. Azimuth and bearing of all nearby traffic could be displayed. When the radar was set on a short-range scale, some means would be required to alert the pilot to threatening traffic beyond the short display range.

Obstacles in the forward area would be detected by returns from the forward antenna which is scanned in azimuth and stabilized in elevation along the plane of the flight path. Any obstacle protruding above the flight path could be shown on the mapping display. The obstacle could be displayed in a distinctive color for alerting purposes. It has been shown that this technique is effective for any object that is an obstacle to helicopter flight except medium-sized and small wires. The towers and poles on which wires are usually mounted are detectable, and the periodic nature of their placement is usually good evidence that wires exist, but detection of wires in a cluttered background is a limitation of the system and should be the subject of further research.

The initiation of approach will occur at a designated point in space where the flight path intercepts the selected approach path; e.g., if a 10-degree approach is selected and the corridor altitude is 75.7m (250 feet), the approach path will be intercepted only 430m (1419 feet) from the landing site; if the corridor altitude is 909m (3000 feet), the 10-degree approach path will be intercepted at 5164m (17,043 feet). In Figure 38, the point in space is called FAF although it does not serve exactly the same function as a standard Final Approach Fix.

The point for start of approach letdown can be indicated on the radar display by the method illustrated in Figure 23. The elevation monopulse intercept of the stabilized nose antenna is indicated on the radar display for the glide slope angle selected. The monopulse cursor intercepts the landing site at the FAF point for the selected glide slope. If the helicopter makes a correct approach, the cursor will remain on the landing site as the display scale expands with decreasing range. If deviations occur, the pilot can adjust the helicopter flight path to realign the cursor on the landing site.

Azimuth control is accomplished by keeping the azimuth cursor lined up on the intended landing spot. The first return signal from the monopulse radar is used to indicate any obstacles along the glide slope path. An obstacle extending into the glidepath can be indicated by a symbol appearing at the position of the obstacle on the radar display. The obstacle warning could be a flashing symbol, be in color, or could trigger an audio or a voice warning to attract attention.

The ability to maintain glide slope track will depend upon the radar accuracy and the FTE caused by manual or automatic control. The radar must measure azimuth and elevation angles and range rate.

5.2.2.1 Radar System Accuracy. If the azimuth beamwidth of the rotor antenna is one-half degree or less, the azimuth accuracy should be no more than 1 degree.

The display resolution and scale ratio will be the most important display features in determining ability to read the display. If the landing site is displayed at the edge of a 25 cm (10-inch) display, the ability to maintain crosstrack precision will depend upon the ability to judge azimuth position on the display. Reference 69 reports that on a cockpit display with 0.08 spacing between markings, which is equivalant to azimuth markings around a 25 cm (10-inch) CRT, that one interpolation between marks can be made. This capability would permit discrimination of 0.5 degree on the display. A conservative display reading error for azimuth control would be 1.0 degree. The total azimuth error then would be 2 degrees (2σ), (1.0 degree system error plus 1.0 degree display reading error).

The elevation monopulse accuracy will depend upon the design of the system and on the target characteristic. A conservative estimate of the elevation monopulse antenna boresight accuracy is 0.75 degree.

The precision with which elevation angle can be controlled on the final approach to hover will depend upon the accuracy of the elevation angle measurement and in the ability of the pilot to interpret the high resolution image on the display. The stabilized elevation monopulse beam should have a resolution approximately 0.5 degree, but the precision with which it can be positioned on the landing site is not known. For the 10-degree glide slope approach geometry shown in Figure 35, if the stabilized monopulse antenna line of sight along the glideslope is extended beyond the hover point, it will intercept the plane of the landing pad 10.6m (35 feet) beyond the edge of the hypothetical 30.3m (100-foot) landing pad. If the site is an elevated platform, the computer can be programmed to gradually change the antenna tilt, based on range as the helicopter approaches the platform, so the monopulse antenna will point to the center of the platform.

The pilot's ability to judge position of the landing intercept symbol should be comparable to his ability to judge azimuth symbol position discussed above. Assume, for example, that the helicopter's position on the glide slope is 30.5m (100 feet) away from touchdown and the landing site image extends over 15.2 cm (6 inches) of the CRT display. At that point on a 10-degree glide slope, the elevation angle to the near edge of the 30.5m (100-foot) square landing site is 19.3 degrees, and the elevation angle to the far edge is 6.6 degrees. Assuming 0.5-degree resolution, there will be 19.3 - 6.6/0.5 = 25.4 possible lines across the landing site image or approximately 6.3mm (0.25 inches) per line. It should be possible to interpret line position well below one line space or 0.5 degree elevation angle. Assuming reading error is 0.5 degree, then total theoretical error (adding the 0.75 degree antenna error) would be 1.25 degrees. However, there are so many unknown factors, that hardware would have to be produced and flight tests performed before the actual accuracy can be predicted with confidence.

One feature of the radar display is that when approaching the landing pad it can be determined from the shape of the image of the pad whether the helicopter is approaching from above the surface of the pad. If the helicopter were level with an elevated pad, only the front edge of the pad will be detected. and the surface would not appear on the display. If the radar is well above the display, then the forward and rear edges will appear in their correct geometric pattern and it can easily be seen that the helicopter is on the proper glidepath. This capability gives three different checks on altitude above the platform: the forward antenna intercept marker, the radar imagery itself, and the absolute altimeter. Because of the step in absolute altimeter signal at the edge of the platform, it must be treated with caution; it will be usable only when over the platform.

Although, there is insufficient data to have complete confidence in the above calculations for approach accuracy, there is encouraging flight test data. The flight test of the HELMS system, which had a similar display on a five-inch CRT, showed remarkable ability to control glide slope, see Figure 24.

The HELMS approaches were made with an unstabilized helicopter at a minimum speed of 60 knots. The proposed ANGS will use a fully stabilized helicopter with low-speed capability which should give more time to interpret displays and make control adjustments.

It is expected that the ANGS would use automatic approach control on the glide slope with the pilot monitoring progress on the displays. He would have the capability to make corrections or take over manual control at any point in the descent. It should be recognized that at present no commercial radar design has been produced that has automatic target tracking, although such military systems have been designed. Because the design of a system to lock on to a passive target is still to be accomplished, it is assumed that in initial ANGS evaluation systems the automatic approach will be designed using a digital programmer that will program an approach path in space that can be selected to coincide with the desired approach path. The onboard air data and inertial sensors will provide data for earth stabilization of the programmed approach. This technique is used in several existing U. S. Navy approach-to-hover systems. The pilot will adjust the highly damped system on the approach path by aligning the radar flight path angle and azimuth symbols to coincide with the intended landing symbol site image. For elevated or pinnacle sites, such as an oil rig platform or a tall building, a transponding beacon could be used for enhancement of the landing spot.

For a zero-visibility approach, there is no visibility decision point or MAP; the abort region is really a CDP beyond which a commitment to land must be made. This CDP for one-engine failure of a dual-engine machine will depend on helicopter type, load, pressure altitude, wind direction, and possibly other factors. For any particular machine and set of the above parameters, there will be a best single-engine climb rate. The CDP must be selected so this single-engine climb rate will clear obstacles in the abort path. The CDP should be computed and displayed to the pilot. The abort procedure can be programmed in the approach coupler so it can be initialized and performed automatically.

The flight director computer will receive inputs from the air data and inertial sensors and from the approach coupler and will compute 3-axis flight director signals. The pilot can monitor the flight director signals if the approach is automatic or can use the flight director for manual flight path control with precision corrections made from information from the radar display. The flight director and symbol-augmented radar display are redundant but complementary displays for flight path control. The flight director is a computed display and the symbol-augmented radar display is direct sensed. Pilots have a high level of confidence in the direct sensed display. If the radar system is working properly, they have a recognizable image of a landing site. If the system malfunctions, they have no image or a distorted image that is immediately recognized as in error. They do not have the same confidence in a computed display on a blind approach, feeling that the display can be in error with no apparent evidence of the error.

An advantage of the expanding scale radar display is that the closer the helicopter approaches to the landing pad, the more accurately the expanded scale display can be interpreted. The landing pad that is a small speck on the display at two miles will fill half the display at 30.5m (100 feet). As the helicopter approaches the edge of the 30.5m (100 foot) square (or diameter) landing pad, the pad will nearly fill the display. If the pad subtends 20 cm (8 inches) on the display, then each 2.54 cm (1 inch) of the display will represent 3.7m (12.5 feet). If one-eighth of an inch movement can be judged, then the pilot has the capability of judging 0.4m (1.5 feet) movement on the display. This capability should permit positioning at the hover point within the accuracy of ±4.1m (±13 feet) specified.

The helicopter will decelerate gradually along the glide slope so that the last few meters will be at a very slow velocity. The control and flight director computers will use the velocity inputs from the 360-degree low airspeed sensor and the ground speed sensor (either derived from the approach radar or from a doppler navigator). In the trade-offs, it is assumed that a doppler radar, or equivalent signal from the approach radar, is required for the ground velocity inputs.

It is necessary to have elevation, azimuth, and range control for deceleration to zero ground velocity at the hover point. With a hover altitude of 4.5m (15 feet) ± 1.5m (5 feet), the pilot will have visual contact with the landing pad if the visibility ceiling is 7.6m (25 feet). The visibility can be augmentated by surface lights at a prepared site and with an onboard landing lights at unprepared sites.

In many cases, it would be desirable to be able to perform the hover and vertical descent automatically or on instruments. Automatic hover will require a ground speed sensor with a threshold of 1/4 knot. This could possibly be obtained from the high resolution radar by tracking a specific target pulse.

Manual hover will require a well-stabilized aircraft and a radar display scale in which a low threshold of translation can be interpreted from the radar imagery. This will require display scale of only a few meters range; the display should provide for main and tail rotor obstacle clearance. The control system should be designed to accomplish an inertially stabilized hover with the pilot having a fly-through capability to control hover position based on radar ppi display interpretation. Under such conditions, it should be possible to remain within the allotted error shown in Figure 38.

The vertical descent will be made using the absolute altimeter for altitude control; ±15.2 cm (6-inch) accuracy should be possible. There is a possibility of obtaining back-up absolute altitude from the high resolution radar either by signal processing or by observation of the first return range on the display.

Among the questions to be answered are the short range performance of the radar, landing target characteristics, reflections from adjacent targets, and possible interference from other radars or microwave radiating devices.

Imaging radars typically are not designed to perform at ranges of a few feet. The problems are associated with response of T-R switches, recovery times of components, and saturation of circuits by strong returns from short ranges, Reference 70. All of these problems can be overcome by careful design. Bistatic techniques, where separate antennas are used for 'transmit' and 'receive', are sometimes used. It is necessary to have a wide range of automatic gain control during the approach. There is an inverse fourth-power relationship between the return signal and range. For very close ranges, it may be necessary to control radiated power as well as receiver gain.

There may be a problem of reflection from adjacent targets where the landing site is surrounded by buildings or structures such as a tower or an offshore oil rig. It is possible that the radiated energy could reflect off the landing platform to a metal tower or other target and be reflected back to the radar giving a false range reading. The narrow rotor antenna beam will minimize such problems and special signal processing may be used to reduce false targets from beyond the landing site.

If many helicopters should be used, each with onboard radar, there is that possibility of mutual interference. The possibility of such interference is also reduced by the narrow antenna beamwidth and fast scan. If a rotor with an antenna rotates at 300 RPM, the beam scan rate is 1800 degrees/second. If the antenna beamwidth is 0.33 degrees, then the antenna will point along one line of sight only, 1/5400 = .00018 seconds during each scan. A like radar on another helicopter will point in the exact opposite direction (so they would interfere with each other) only during the same interval but will be rotating in the opposite directions so the dwell time would be 1/2 of .00018, or .00009 second. Since there are 360 x 3, or 1080, possible pointing angles each scan, the possibility of the beams interfering with each other would be 1/1080 x 1080 or approximately 8×10^{-7} for each rotor rotation. Assuming several helicopters are in the area, the resulting interference would be only a rare, very short burst of interference. It is also possible for one helicopter radar to receive a reflected pulse off a target from another radar on the same frequency; this possibility is also diminished by the narrow fast scan beam. To reduce the probability of reflected and direct interference, the radars on the helicopters can each be tuned to a slightly different frequency.

5.2.2.2 Radar Accuracy on Approach. The high resolution radar has a theoretical accuracy that can make zero-visibility helicopter operations possible. The ASE, particularly close to the landing site, will depend on solving the short range problems of present designs and on the ability to present a high resolution, stable, nonflicker display for the pilot. The FTE, as in most other systems, will depend upon display accuracy, readability and ability to make corrective control inputs. The radar has the advantage that the positional accuracy with which objects can be presented on the display varies inversely with distance; near touchdown, the position and movement of objects relative to the helicopter can be shown on the expanded scale display with great precision.

The cross-track error is made up of the sum of the calculated 1-degree radar azimuth error, and the estimated 1-degree display reading error. Assuming additional 100 percent unspecified errors, the conservative calculated cross-track error is estimated to be ±1m (±3.4 feet) 1σ.

The calculated elevation error is made up of the sum of the 0.75-degree elevation monopulse beam error and the 1-degree display reading error which gives 1m (3.4-foot) error at the 30.3m (100-foot) range. Again assuming 100 percent unspecified errors, we get ±1m (±3.4 feet) $1\ \sigma$ elevation error.

The along-track range accuracy at short ranges will depend upon the ability to measure leading edge pulse return from the landing site target; this will depend upon the technique used to solve the short range. The theoretical along-track range accuracy of the hypothetical radar was calculated to be 7.6m (25 feet). This is insufficient accuracy to approach an elevated landing site, even at slow speed.

A method to improve range accuracy of a radar is to use a pulse compression signal processing technique, Reference 70. Military radars have been produced with compressed pulses of less than 5 nanoseconds that give a range resolution of .7m (2.5 feet). For purposes of the analysis, a conservative assumption will be made that pulse compression or leading edge tracking techniques can be used to achieve a range resolution accuracy of ± 1.5m (± 5 feet) 1 σ. Another possible technique to achieve excellent range resolution on elevated landing sites is to switch the absolute altimeter to an antenna looking forward and measure the range to the edge of the elevated site. Absolute altimeters typically can measure to very short ranges with an accuracy of ±.9m (±3 feet).

The estimated 2 σ radar errors are:

Cross-track ±2m (± 6.8 feet)

Along-track ±1.5m (± 5 feet)

Elevation ±2m (± 6.8 feet)

These errors are shown in relationship to the allowable glide slope deviations in Figure 38 at a range of 30.5m (100 feet). The amount of FTE that must be added is unknown. It is evident that the system has good potential for precision approaches, including zero-visibility conditions.

5.3 SAFETY CONSIDERATIONS

The ANG system must be designed so it can be certified for safe operation in case of system failures. The use of triple or higher levels of redundancy for calculated safe levels of performance would be cost prohibitive. A fail-safe design, with degraded "fail soft" modes of operation if certain systems fail, is used instead.

The degraded modes of operation can include: abort to an airport, going to higher visibility minimums, or an increase in pilot workload. By diversion from a restricted heliport site to an airport runaway, an ILS approach can be made at 60 knots or higher airspeed. Improvement in visibility minimums can be achieved by diverting to an alternate site where minimums are higher. The system should be designed for low pilot workloads for each part of the mission; however, experimentation may prove that in an emergency, certain mission segments could be accomplished with a higher workload. This higher workload might be caused by control failures that resulted in reduced handling qualities or degraded display modes.

Table 16 lists the redundant components in the recommended system.

TABLE 16. LEVELS OF REDUNDANCY

- Controls
  - 2 channels separated Axis. See Table 2

- Displays
  - Discrete parameter readout
  - Computed Displays
    - Flight director
      - Electromechanical
      - CRT
    - Horizontal Situation Display (HSI)
      - Electro-mechanical
      - CRT
    - Direct Sensed Displays
      - Radar PPi
        - Nav Symbol Augmentation
        - Director Symbols
        - Computed Graphics
          - Corridor limits
          - Terminal area path
          - Landing site graphics

- Navigation Systems
  - Vortac
  - Loran-C

- Approach System
  - High Resolution Radar
    - High Resolution Map (rotor blade antenna)
    - Weather Radar Map
    - Elevation Angle Measurement and Range (nose antenna)

- Altitude
    - Absolute Altimeter
    - Barometric Altimeter
    - Radar Altitude Circle

- Airspeed
    - 360 degrees Low Airspeed
    - Standard Airspeed System

- Heading Dual Systems

- Attitude Dual Systems

Table 17 gives the effects of failures in each of the components.

TABLE 17. FAILURE EFFECTS - CATEGORY III SYSTEM

Failure	Workload	Handling Qualities	Cooper Harper Rating	Landing Site	Abort Approach	Comments
No Failure	Low	5	2	Any		Full capability
1 Axis of 1 Control Channel	Low	5	2	Any		No degradation
1 Complete Control Channel	Low	5	2	Airport	Yes	Land at airport in case of 2nd control channel failure
2 Control Channels	Moderate	3	5	Airport	Yes	Maintain adequate forward speed - run on landing
Area Nav	Moderate	5	2	Any		Use dead reckoning, radar and Vortac for Nav
Approach Coupler	Moderate	4	4	Any		Use backup radar symbols on approach
One Engine	High	5	2	Airport	Yes	Require one engine gradient on abort path
Radar System	Moderate	5	3	Airport	Yes	ILS run on landing
Absolute Altimeter	Moderate	5	2	Any		Use baro altimeter and radar altitude circle
Low Airspeed	Moderate	4	4	Any		Use radar ground speed near hover
Flight Director	Moderate	4	4	Any		Use basic instruments and radar symbols
Obstacle Sensing	Low	5	2	Airport	Yes	Known clearance
				Any	No	Must know site is clear of obstacles

<u>Handling Qualities</u>

Excellent 5
Good 4
Adequate 3
Poor 2
Unacceptable 1

Assumptions
All operatons in zero visibility
Redundant power supplies
Ability to make zero-visibility run on landing at runway having either full control system or full radar display

5.4 RECOMMENDED SYSTEMS

5.4.1 Category III Zero-Visibility System. The major components of the recommended system for full zero-operational capability are shown in Table 18.

TABLE 18. CATEGORY III MAJOR SYSTEM COMPONENTS

Component	Function	Principal Use
Dual Mode Radar		
Rotor-Mounted Antenna	High resolution mapping (short range)	Term area nav Landing site Ident Ground obstacle detec.
Active Beacon	Enhance targets in clutter	Collision avoidance
Forward Antenna	Low resolution mapping (long range)	Weather Detection Long range Nav
Elevation Monopulse	Elevation angle measurement	Approach Control Obstacle Sensing
Ground Speed Computation	Ground velocity	Flt Control input
Cathode Ray Tube	Display	Radar display. Navigation Symbols. Approach Control symbols
Loran-C	2-D Position	Area Navigation Compute and Display bearing distance, etc. Interface with radar display
Dual Control System	Provide stability for low speed IFR operation	Low speed final approach and landing
Approach Computer and Coupler	Programmed approach	Reduce pilot workload
Flight Director, HSI	Provide command display for approach	Reduce pilot workload
Low Airspeed Sensor	360 degrees airspeed	Control System input
Dual Inertial Sensors	Body axis position	Control System input
Laser Radar	Detect obstacles	Wire detection
Radar Altimeter	Absolute altitude	

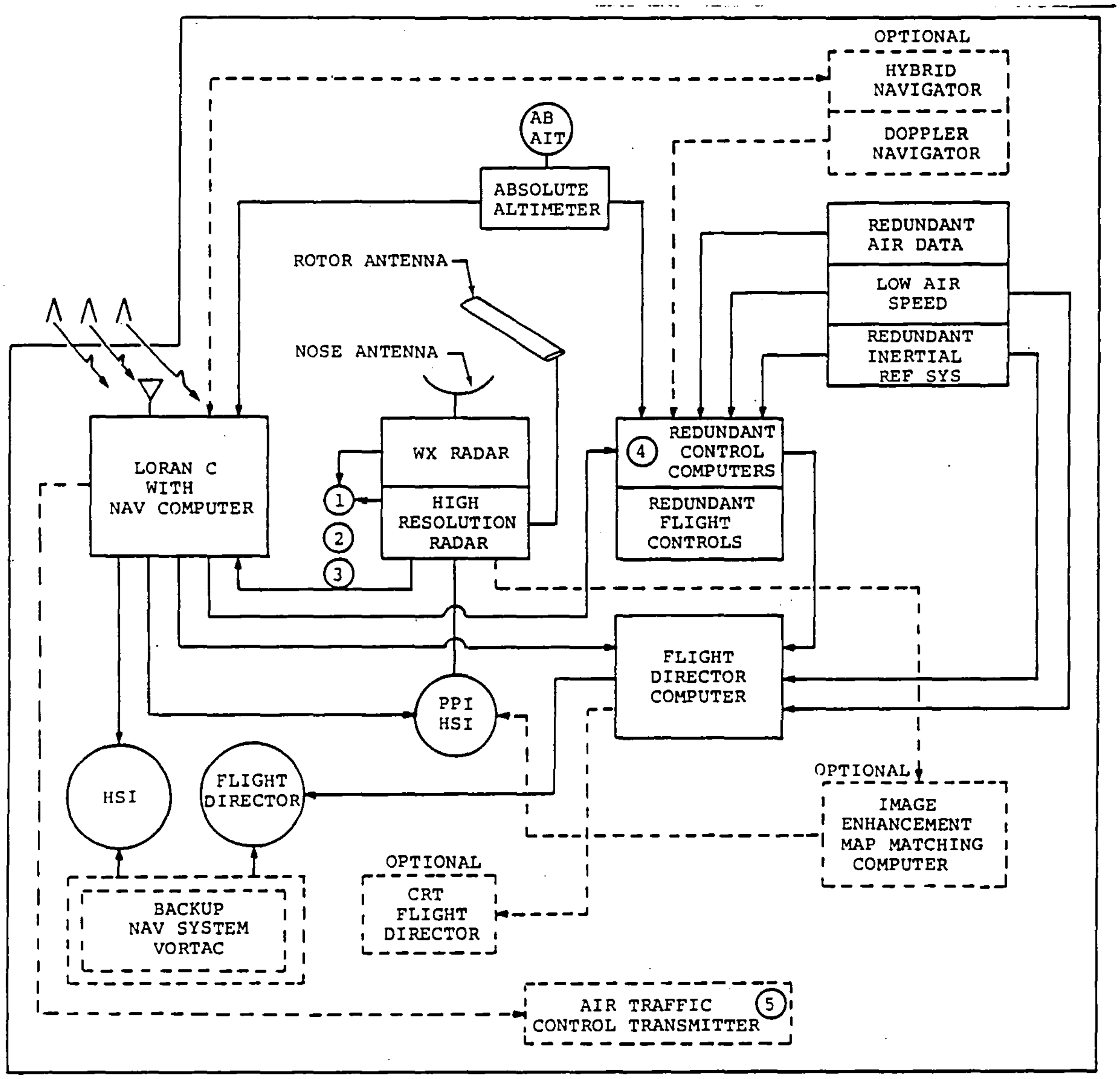
The block diagram of the system is shown in Figure 40. The block diagram shows several options for addition to the system that can be used to improve the accuracy of the system at additional cost. The cost effectiveness for the optional components will have to be determined.

5.4.2 Category II 30.4m (100-foot) Minimum Ceiling System. The major components of a system for Catagory II visibility conditions are shown in Table 19. A Block diagram of the system is shown in Figure 41.

TABLE 19. CATEGORY II MAJOR SYSTEM COMPONENTS

Component	Function	Principal Use
GPS, Z Set, C/A Code	3-D position	Area Navigation (Compute and display bearing distance, etc. Interface with Wx radar display)
Differential Mode Ground Set	3-D precision position	Area Navigation 3-D Approach Control
Dual Control System	Provide stability for low speed IFR operation	Low speed for ap-approach and landing
Approach Computer and Coupler	Programmed approach	Reduce pilot work-load
Flight Direction, HSI	Provide command display for approach	Reduce pilot work-load
Low Airspeed Sensor	360 degrees airspeed	Control system
Laser Radar	Detect obstacles	Wire detection
Radar Altimeter	Absolute altitude	

Many different variations of the two basic systems can be devised. Civil helicopters are quite often operated in a local area performing a specific task. An example is the offshore oil industry where a fleet of helicopters may operate to offshore rigs in a regional area such as the Gulf of Mexico or the North Sea. This encourages the formulation of special systems possibly operating under special rules and regulations for special missions.



(1) OBSTACLE DETECTION (NOT WIRES).

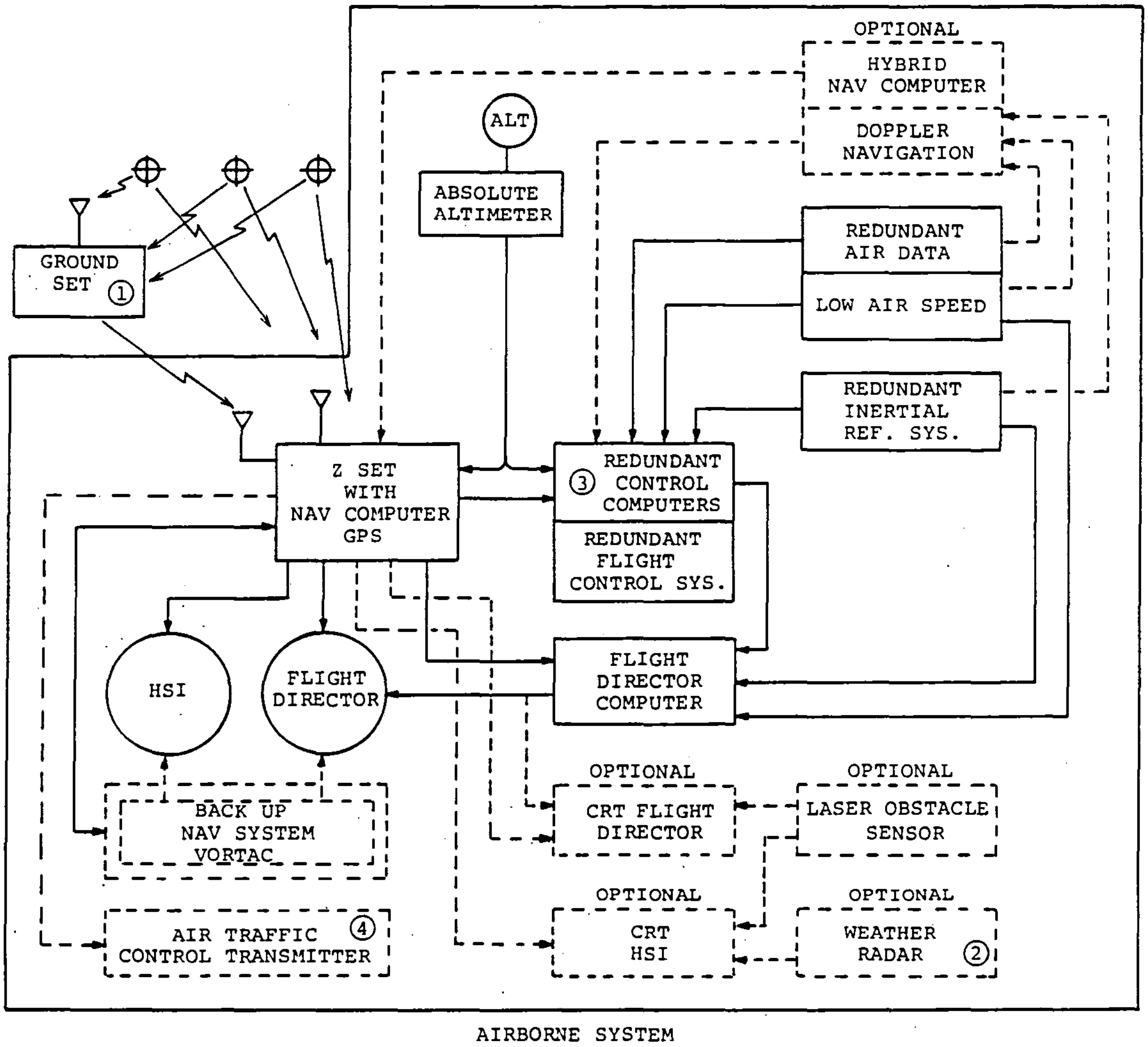
(2) COLLISION AVOIDANCE WITH COOPERATING BEACONS.

(3) CHECK POINT ENTER.

(4) INCLUDES APPROACH COMPUTER/COUPLER.

(5) PROBABLE LINK WITH RELAY TO ATC.

Figure 40. Advanced Navigation and Guidance System B (high resolution radar primary).



① DATA LINK, PSEUDOLITE OR TRANSLATER TYPE.

② HSI CRT CAN BE WX RADAR PPI.

③ INCLUDES APPROACH COMPUTER/COUPLER.

④ PROBABLE LINK WITH RELAY TO ATC.

Figure 41. Advanced Navigation and Guidance System A (GPS primary).

One example of possible special application would be to use the repeatable accuracy of Loran-C at a site or in an area where excellent repeatability is obtained. If it is known that the area is clear of obstacles and strong heliport lights are available, it may be possible to use Loran-C and weather radar for precision approaches in minimums as low as 30.4m (100 feet). Special regulations would have to authorize such service only in the specific area or possibly to specific sites. A control system with sufficiently improved helicopter stability to permit lower speed instrument flight than is now possible would greatly improve such a system.

Lower minimums might be accomplished with weather radar approach if the beamwidth could be sharpened. The use of interferometer or monopulse techniques could possibly be used so the center of the azimuth beam could be displayed for a more accurate directional approach than is possible with the present system. On-water targets, such as ships and oil rigs, could be skin-tracked with improved accuracy; over land, where many targets and clutter exist, a beacon would be required. By use of the sharpened weather radar beam and a beacon, approaches could be made with improved precision to heliports and other restricted sites. Beacons could be used to direct helicopters to emergency sites such as highway accidents. One of the major problems in lowering minimums with such a system is how to avoid obstacles.

Helicopter instrument systems that operate in ceiling limitations of approximately 30.5m (100 feet) may benefit from the use of a FLIR or Low Light Level Television system. If operation is performed at night and lights at the landing site are not possible, then the FLIR or LLTV would assist in recognition of the landing site. Both systems are severely attentuated by moisture, but with the limited visibility, they could enhance details of the landing site allowing improved precision and obstacle detection on the final few meters of the approach.

For large helicopters with sufficient load-carrying and revenue-earning capability, a system with improved redundancy could be used. Such a system could use the Dual Mode Radar, GPS, Doppler radar or inertial navigation, hybrid navigation, and sophisticated multifunction displays, all integrated with multipule computers and a multiplex buss. Equipments for potential improvements in navigation and guidance systems for small, medium, and large helicopters are summarized below.

Small Helicopters

Loran-C	Use good repeatability at certain locations
Weather Radar	Improved resolution by beam sharpening
Improved Controls	Make possible slower speed instrument flight

Medium Helicopters

-Dual mode radar as primary system - 1st recommended system.

-GPS as primary system - 2nd recommended system

Large Helicopters

-Dual Mode Radar
-GPS
-Doppler or inertial navigator
-Hybrid navigator
-Triple redundant control system
-Multifunction displays
-Multiplex buss system for system interface

It should be recognized that various combinations of the above system can be used in any helicopter depending on mission and cost effectiviness.

5.5 OPERATIONAL LIMITATIONS

The Dual Mode Radar based system recommended as number one for the ANGS is designed to minimize the operational limitations of helicopters by making precision approaches in Catagory III conditions possible. If the system can be achieved, it will be the first operational system that can perform in all visibility conditions. The principal operational limitation will be reduction in load due to the approximate 150-pound weight of the basic radar system. One hundred and fifty pounds added weight is a significant factor for the the smaller helicopters and will have to be considered in the effectiveness tradeoffs for the system. The increased revenue from operating all-weather may be reduced by loss of load-carrying capability or loss of range.

As an example of the reduction in range, Reference 71 reports on the reduction in range for a twin-engine 9544-pound gross weight helicopter at sea level, standard day to be 15 n.mi. for a weight increase of 150 pounds.

The GPS-based system has slightly less weight but must use a ground set and has a ceiling limitation of 15.2m (50 feet) to 30.5m (100 feet) depending on ultimate accuracy achieved. The ceiling (and range visibility) limitations introduce the questions of weather reporting and aborts due to weather discussed earlier. The predominate factor is safety; with such low visibility limitations, it places a large burden on pilots and ground personnel to determine when conditions require an abort.

The routine operation in fog, clouds, rain, and snow increase the possiblity of encounters with icing whenever temperature are below freezing. In northern latitudes where mountains exist, the helicopter can encounter icing even in the summer months. Deicing provisions are considered a requirement for all advanced IFR systems that can encounter freezing conditions.

The dependence on electronic systems for precision approach without external visibility requires excellent reliability. Among the potential threats to the system are man-made interference or natural EMI such as lightning. Special attention will have to be given in the design to EMI/EMC protection. All equipments and connectors that are susceptible must be filtered and shielded, and in certain critical areas it may be necessary to use fiber-optic interconnects. Attention may also need to be given to landing sites to assure that ground equipment in the area is nonradiating.

5.6 REQUIRED TECHNICAL DEVELOPMENTS

5.6.1 System Developments

The above analysis has shown that production hardware is not presently available to meet all of the requirements of an onboard zero-visibility helicopter IFR system. However, all the segments of zero-visibility flight have been accomplished on an experimental basis. There is a good probability that hardware can be developed, using the proven techniques, for a practical Catagory III system.

The principal areas of technology development directly related to the navigation and guidance system are:

- High Resolution Radar development and evaluation
- GPS airborne system development and evaluation
- Simulation of the final approach and landing with emphasis on control stability and display symbology.

Technology developments indirectly related but important to the Navigation and Guidance System are:

- Investigation of FAA requirements for certification of zero-visibility IFR system.
- Obstacle detection with emphasis on a reasonable cost wire detector.
- Low cost deicing
- System integration with emphasis on common digital buss and interface structure so that individually developed components can be interfaced in a total system.

5.6.2 <u>Radar Development</u>

Two principal techniques have promise for the high resolution radar:

- Use of a long X-band array antenna, self-scanned by the main rotor, for 360-degree high resolution image.
- Use of mast mounted pencil beam mm band radar for 360-degree high-resolution image.

5.6.2.1 <u>X-Band Radar Development</u>. The X-band radar investigation should include the following items:

- Determine optimum technique for practical main rotor mounted X-band antenna adaptable, with minor modifications, for any rotor design.
- Fabricate test antenna and perform pattern tests.
- Determine techniques for short range (61m (200-foot) range to hover) performance of radar.
- Determine technique for accurate velocity readout from radar.

- Determine display symbology for the approach including the final 61m (200 feet). Include display of various ground reflector patterns.

- Fabricate flight test hardware for interface with weather radar using common display.

- Evaluate dual mode radar with emphasis on final approach and landing including small pinnacle sites.

5.6.2.2 Millimeter Band Radar Development. The principal effort for mm radar is to determine the feasibility for use in heavy fog and rain.

- Evaluate existing mm wave hardware in severe weather conditions (including heavy rain) to determine capability to perform the zero-visibility mission.

- Determine feasibility of rotor mount and scan method to achieve 360-degree scan coverage for terminal navigation.

- If weather penetration is successful, fabricate and flight evaluate system with emphasis on terminal approach and landing.

5.6.3 GPS Development

1. The development of GPS airborne systems for helicopter should emphasize the low-cost Z set and the hardware and software for use of the differential C/A code.

2. Display interface for landing approach with GPS should be developed and make use of Flight Director and HSI displays. Particular attention should be given to display of predicted accuracy so the pilot can judge the safe limits of approach.

3. A flight test evaluation should be performed using the Z set, C/A code differential mode, and approach displays.

5.6.4 Simulation of Approach using Radar and GPS Displays

The most critical phase of the mission for zero-visibility operation is the final precision approach to a hover, over a point on the small landing pad. It is recommended that a pilot-in-the-loop simulation be conducted to determine the best techniques and displays for the task. It will be necessary to develop the control laws (for a particular helicopter), simulate the displays to be used, and collect data during simulated approaches. The simulation should be conducted with simulated radar and GPS displays.

The objective of the simulation should be to determine the level of automatic control that is necessary to perform the tasks with each display concept. It is desirable to be able to perform the task with as unsophisticated a control system as possible. If, for example, a pilot could perform a complete blind approach using the radar display and manual control, with only stability augmentation, then it might be possible to certify the system without redundant automatic control systems. The experimenters should be able to vary stability to check the effect on workload.

5.6.4.1 Simulation with Radar Display.

- Select helicopter and develop control laws for use in stability augmentation system, automatic control, and programmed approach program.

- Develop radar display simulator with capability for simulating dynamic imagery on approach with emphasis on final 61m (200 feet). Include approach control symbology and any other symbols, such as abort path symbology, that may be used.

- Configure instrument panel with flight director and other instruments required for the final approach simulation. Include several candidate display systems for evaluation.

- Perform pilot-in-the-loop simulation with emphasis on zero-visibility approach for the final 61.0m (200 feet) to a hover.

The fidelity of simulation should be accurate enough so that the combined airborne equipment and flight technical errors will be realistic. Determine the display scales required, ability to hover on radar display, elevation accuracy possible, abort capability, and other requirements necessary to accomplish the final approach and hover task.

The measures taken should be: accuracy of path, hover and touchdown control, pilot workload, and time and ability to recover from blunders and abnormal situations. The displays and control algorithms should have the flexibility to vary parameters over a range to determine optimum design.

5.6.4.2 Simulation with GPS. The GPS simulation will be similar to the above described radar simulation with the following exceptions.

- Develop GPS display simulator that will use vertical and horizontal displays suitable for approach with GPS. Techniques should be developed to convert the 3-D position signal into a glidepath to a landing site position stored in memory.

- Perform pilot-in-the-loop simulation with emphasis on how close an approach can be made to the platform with the combined airborne equipment and Flight Technical Errors.

5.7 SYSTEM COSTS

One of the most important considerations for an Advanced Navigation and Guidance system is its cost feasibility; does the increased operating time which the system permits produce the additional revenue necessary to make a profit on the system? There are other considerations, of course, such as improved safety and convenience but the financial trade-off is very important.

The operators who responded to the survey indicated a willingness to pay an average of seven percent of aircraft cost for improved IFR capability. There was also a direct correlation between the amount they were willing to pay and the minimum ceiling and visibility. The estimated costs of the proposed systems are compared below with average small, medium and large helicopter costs.

The estimated prices for the helicopters and avionics are in 1981 dollars. The estimated helicopter prices, supplied by the Bell Helicopter Textron (BHT) Market Research Department have been taken from various helicopter publications. The prices used reflect best estimates for delivered average equipped IFR configurations.

The estimated prices for avionics are avionics manufacturer list prices for production quantities of several hundred systems. These prices do not consider installation costs associated with normal manufacturing of special-type certificate installations. The prices have been obtained from vendors where possible, and for items not yet developed the costs have been estimated by comparison with system similar in complexity.

5.7.1 Light Helicopters

The helicopters selected as being representative of IFR-equipped light helicopters were the Bell 206L-1, the Aerospatiale AS355E, and the Agusta A-109. The average selling price of these helicopters in 1981 dollars is estimated to be $775,000. Seven percent is $54,250.

5.7.2 Medium Helicopters

The helicopters selected as being representative of medium IFR equipped helicopters were the Bell 412, the Bell 222, the Sikorsky S76 and the Aerospatiale SA365N. The average selling price of these helicopters in 1981 dollars is estimated to be $1,655.000. Seven percent is $115,850.

5.7.3 Large Helicopters

The large helicopters selected were the Vertol 234, the Bell 214ST and the Aerospatiale Super Puma. The estimated average selling price of these helicopters in 1981 dollars is $5,796,000. Seven percent is $405,766.

The additional seven percent of aircraft cost that operators would pay for improved IFR which is the cost goal is:

Light Helicopters	$54,250
Medium Helicopters	$115,000
Large Helicopters	$405,766

The estimated system costs for the recommended high resolution radar primary system are discussed below.

5.7.4 Radar Costs

Add Monopulse Capability to Weather Radar	$ 30,000
Add High Resolution Capability to Weather Radar	30,000
Add Rotor Antenna	25,000
Basic Weather Radar	50,000
Total Multifunction Radar Costs	$135,000
Control System & Approach Coupler Computers	$ 30,000
Low Airspeed Sensor	10,000
Dual Inertial Attitude Heading Reference Systems	70,000

Improved Displays	10,000
Dual Radar Altimeters	20,000
Air Traffic Control Transmitter	10,000
Loran-C Navigation	5,000
Radar Primary Total System	$290,000

This system has potential capability for zero-visibility operation with the limitation of inability to detect wires.

For additional capability in precision navigation and advanced displays, the following items can be added.

Doppler Navigation	$ 30,000
Hybrid Navigation Computer	10,000
Image Enhancement & Map Matching Computer	25,000
CRT Flight Director	15,000
Total Optional Equipment	$ 80,000
Basic System	290,000
Total Optional System	$370,000
Laser Obstacle Sensor (Wire Detector)	$100,000
Total Maximum System	$470,000

The estimated costs for the GPS primary system for 30.5m (100-foot) minimum ceiling are:

*	GPS	$ 10,000
**	Weather Radar	50,000
	Control System and Approach Coupler Computers	30,000
	Low Airspeed Sensor	10,000
	Dual Inertial Altitude and Heading Reference system	70,000
	Improved Displays	10,000
	Dual Radar Altimeters	20,000
	Air Traffic Control Transmitter	10,000
	GPS Primary System Total	$210,000

* Price does not include approximately $20,000 per landing site for GPS Ground Unit.

** Weather radar can be optional in this system but is expected to be included in most systems.

Additional options can be:

Doppler Navigation	$ 30,000
Hybrid Navigation Computer	10,000
CRT Flight Director	15,000
	$ 55,000
Basic GPS System	210,000
	$265,000
Laser Obstacle Sensor (Wire Detector)	100,000
Total Max GPS System	$365,000

A third system recommended for 30.5m (100-foot) ceiling and 400m (1/4 mile) visibility minimum is the use of monopulse beam sharpening on the weather radar and the use of powerful lights on the landing site. This configuration would only be suitable where such lights are feasible such as a permanent installation with heavy traffic such as an off-shore platform.

Add Monopulse Capability to Weather Radar	$ 30,000
Weather Radar	50,000
	$ 80,000

A reasonable configuration would be the GPS Z set added to the monopulse radar system which would total $90,000 for a system excluding the cost of the landing site lights and GPS ground set for the differential mode.

5.7.5 Cost Summary

The $290,000 estimated cost of the Radar Primary Zero-Visibility system falls between the goal of $115,000 for medium helicopters and $405,766 for large helicopters. Lack of wire detection capability is a shortcoming of this system. When the laser wire detector is added, the $390,000 system cost approximately equals the cost goal for large helicopters. Added options to make an optimum system can total $470,000.

The GPS primary system estimate of $210,000 also exceeds the medium helicopter cost goal. The only listed system which meets the medium helicopter cost goal is the monopulse weather radar configuration using bright landing lights in an attempt to lower the ceiling to 30.5m (100 feet) ceiling and 400m (1/4 mile) range visibility.

These estimates do not look encouraging for economic feasibility of the recommended systems. There are possible solutions, however.

- One major cost improvement would to be improve control display design so that in the event of automatic control failure a safe zero-visibility landing could be accomplished manually using the radar and advanced displays. This can only be determined through experimentation by simulation and flight test, but if possible would remove the requirement for control redundancy.

- A reduction in cost may be made with major application of VLSI/VHSI circuitry although this is several years in the future.

- A third possibility is innovation in concept and design of systems. The above estimates are based on known techniques. Often when a new goal , such as zero-visibility flight is set, innovative concepts will be developed.

- There is a reason to expect that when hardware is made available to the operators they will develop new operational techniques that may permit simplification of the system.

6. CONCLUSIONS

The results of the operators' survey show that a significant number of helicopter operators wish to extend their IFR operation to lower limits. The average IFR lower limits picked by the operators were 30.5m (100 feet) visibility and 0.4km (1/4 mile) visibility.

Examination shows that weather variability and lack of measurement facilities will make it difficult to determine when visibility limits are 30.5m (100 feet) and below, at ground level and elevated sites. This will be especially true at remote sites. If 30.5m (100 feet) is set as the minimum, the operational conditions will most likely be 30.5m (100 feet) ± 15.2m (50 feet).

It is concluded that the goal of an advanced guidance and navigation system should be to provide zero-visibility landing capability for rotorcraft all-weather operations. Increased productivity and utility will result from reduced cancellations and diversions, and safety will be enhanced under low visibility landing conditions.

Most of the technology for a zero-visibility system has been evaluated in experimental form but much simulation, design, and system integration and evaluation work must be accomplished to prove feasibility, particularly in the terminal approach and landing phase.

Areas of system development have been addressed and include:

- <u>Sensor Development</u>

  High Resolution Radar, at X band using a rotor-mounted antenna, appears to be the most promising candidate for the approach phase of the mission.

  GPS has excellent promise for area navigation and some promise as an approach aid, but there is concern over the deliberate degradation of the signal in national emergencies.

  Loran-C is the most cost-effective area navigation system.

- <u>Stability and Control</u>

  A control system is required to improve stability and handling qualities for slow-speed, steep-angle approach in near-zero visibility.

· Simulation

A pilot-in-the-loop flight simulation should be conducted to investigate zero-visibility approach to a landing pad. Simulation of the radar and GPS approach controls should be included.

· Near Term Techniques for Lowering Minimums

Lowering of ceiling to 30.5 (100 feet) in the near-term should be possible by beam-sharpening techniques on weather radar and use of high power landing lights on the site and, if necessary, improving stability and control.

· Wire Detection

Research should be accelerated on finding a moderate cost obstacle- and wire-detection system.

· Deicing

A moderate cost deicing system is a major requirement.

· Field Evaluation

A zero-visibility IFR flight test system should be fabricated and after feasibility evaluation should be evaluated in the field by operators.

· Certification Requirements

Early in the program, the requirements for FAA Certification of a zero-visibility system should be investigated.

APPENDIX A

MARKETING SUPPORT INCLEMENT METEROLOGICAL CONDITIONS ANALYSIS

This Appendix contains analyses and supporting information from questionnaires submitted to a controlled sampling of operators to provide part of the foundation for the overall response to the contract.

Specific goals of this analysis were to ascertain the extent of rotorcraft operations in Instrument Meterological Conditions (IMC), the desire of rotorcraft operators to operate to lower IFR limits, and to establish a range for aircraft cost increases that could be justified for this improved operational capability.

To achieve these goals, a comprehensive questionnaire was developed and distributed to approximately two hundred helicopter operators in the U. S., Canada, and around the North Sea. The results of this questionnaire form the basis for these analyses.

A computer software package, Statistical Analysis System (SAS), provided the statistical tools necessary for the extensive data manipulation and analyses required in this study. A copy of the questionnaire is included.

IFR

QUESTIONNAIRE FOR CORPORATE OFFICER AND CHIEF PILOT

NAME
(CORP. OFFICER) ______

POSITION ______

ORGANIZATION ______

______

ADDRESS ______

______

TELEPHONE ______

CORP OFFICER SECTION

1. Do you now operate rotary-wing aircraft IFR?
Yes ____ No ____

2. How many helicopters do you have equipped for IFR operation?
Large (Above 12,500 GW) ____
Medium (8,000–12,500 GW) ____
Small (Below 8,000 GW) ____

3. What percent of your missions involve some flight in instrument meteorological conditions? Large ____ Medium ____ Small ____ Overall ____

4. How many total hours per year do you estimate you operate in instrument meteorological conditions? Large ____ Medium ____ Small ____ Overall ____

5. Please select the missions normally performed by your company or organization and estimate the percentages of each that are affected by weather on a yearly average.

	NON IFR EQUIPPED	IFR EQUIPPED	
TYPE MISSION	Not scheduled or cancelled due to WX less than VFR	Completed IFR	Not scheduled or cancelled due to WX less than IFR
Offshore Petroleum	____ %	____ %	____ %
Corporate/VIP	____ %	____ %	____ %
Logging, Forestry Mgmt.	____ %	____ %	____ %
Police-Local	____ %	____ %	____ %
Police-Federal	____ a	____ %	____ %
Rescue/Ambulance	____ %	____ %	____ %
Survey and Mapping	____ %	____ %	____ %
Media	____ %	____ %	____ %
Spray, Agriculture	____ %	____ %	____ %
Air Taxi/ Scheduled	____ %	____	____ a
Other	____ %	____ %	____ %

1

6. How many pilots does your company employ?

____

7. How many of your pilots are IFR rated?

____

8. Approximately how much IFR time does each pilot log actually in instrument meteorological conditions each month?

____

____

9. Would your operations benefit if improvements in Rotary Wing IFR Systems would permit flights into high density and remote sites under visibility conditions lower than those presently used.? Assume regulator agency approval was granted.

____

High Benefit — **No Benefit**

1 2 3 4 5 6

10. What weather minimum for landing would you desire? (If more than one selected, please indicate 1 for 1st choice, etc.)

Ceiling	**Visibility (miles)**	
500 ft?	1	________
200 ft?	1/2	________
100 ft?	1/4	________
50 ft?	1/8	________
0 ft	0	________
Other?	Specify	

____

____

____

11. As a percent of aircraft cost, how much would you pay to achieve the lower minimums desired in question 10?

Large Helicopter Additional % of Cost	**Medium Helicopter** Additional % of Cost	**Small Helicopter** Additional % of Cost
________	________	________

2

12. What percentage increase in total operation revenue would you envision as a result of lowered minimums desired in question 10?

100 ft	____ %
50 ft	____ %
0 ft	____ %

13. Please rank the type missions that would most benefit from the lowered minimums. *(Use 1 for mission most benefiting)*

	Rank
Offshore Petroleum	________
Corporate/VIP	________
Logging, Forestry Mgmt.	________
Police-Local	________
Police-Federal	________
Rescue/Ambulance	________
Survey and Mapping	________
Media	________
Spray, Agriculture	________
Air Taxi/Scheduled	________
Other	________

14. Would lowered IFR operating minimums result in improved life saving benefits such as for ambulance and search and rescue missions? ____

____

15. Do you know of missions where a helicopter would be substituted for airplanes, ground vehicles or boats if all-weather operation could be assured? ________________________

____

____

16. Do you have comments regarding aspects of your IFR/IMC operations not mentioned in this questionnaire?

____

____

____

____

____

____

17. To aid the study, would you be willing to discuss Rotary Wing IFR/IMC operation in more detail at your convenience? ________________________

____

3

PILOT SECTION

1 What are present regulatory visibility limits for IFR flight for the landing sites in which you operate IMC? ______

2 Are IFR operations specific to any particular missions (specify)? ______

3 How often are missions not scheduled or cancelled due to weather? State as a percentage of all missions flown. ______

4 How many of your flights have approved weather reporting service or forecasting service available at destination? ______

5 Indicate approximately, by percentage, the type of weather conditions resulting in IMC.
- Rain ______
- Snow ______
- Blowing Snow ______
- Smoke ______
- Fog ______
- Haze ______
- Smog ______
- Low Clouds ______
- Blowing Dust ______

6 Give us an index of the adequacy of weather prediction Excellent ______ Adequate ______ Poor ______

7 In what percent of all missions are icing conditions experienced? ______ % IMC missions? ______ %

8. Does the adequacy of your weather prediction affect the number of flights which are cancelled? ______

9 What type of enroute navigation do you presently use?

VOR/DME ______ OMEGA ______
LORANC ______ Other ______
RNAV ______

Which do you prefer and why? ______

4

10. Are the current terminal area landing aids adequate for your requirements? If not, state what landing aid characteristics would best meet your requirements. ______

11. What percentage of your IFR flights originate or arrive at an airport ______ % At a heliport in a congested area? ______ % At a heliport in a remote area? ______ % Are Air Route Traffic Control methods, equipment and procedures appropriate to rotorcraft operations enroute? ______ In terminal control areas? ______ At heliports in congested areas? ______ At heliports in remote areas? ______

COMMENTS: ______

Thank you for your participation.

5

DOCUMENTATION OF STATISTICAL ANALYSIS

SUMMARY OF APPROACH

The requirement for a comprehensive IFR operations questionnaire and its analysis grew from the award to Bell Helicopter Textron of NASA Contract NAS2-10743 (RA) for Investigation of Advanced Navigation and Guidance System Concepts for All-Weather Rotorcraft Operation. A part of this study included a determination "of the extent to which IFR operations are being used currently, and to what extent they will be required in the future by various types of operators in various geographical areas."

BHT Marketing Support provided assistance in the review, formatting, administering, and analysis of the navigation and guidance questionnaire required under the NASA contract and attempted to assure an appropriate sampling of rotary-wing operators was taken. Sampling information was derived from AIA Operators' Directory, FAA records, and from the BHT-owned marketing data file. Efforts were also made to stratify the sample for such population characteristics as mission, aircraft size, geographic conditions, etc.

Marketing Support goals in assisting with overall NASA funded IFR study included but were not limited to determining:

1. The extent of operations in instrument meteorological conditions

2. The desire for operations to lower IFR minimums

3. The cost increase that could be justified for improved operational capability

The IFR questionnaire, in its final form consisted of 29 questions covering a range of interrelated topics from IFR fleet size and number of pilots to the adequacy of terminal area landing aids. The questionnaire was mailed to some 200 operators in the United States and Canada in two mailings of 100 in order to improve response rates and to assure operator statistical validity of the sample, approximately 50 of the initial nonrespondents were selected as potential telephone interviews. Twenty of these individuals were telephoned and asked to participate in the survey via phone. Their responses were included in the overall survey. A total of 67 responses were received.

The overall response rate was 32 percent with 35 percent of the U.S. operators participating. This rate is an expected response to surveys of this type where a 30-40 percent rate can be anticipated and 50 percent response is considered excellent. The listings below show response summary data from each of Bell's Marketing Divisions.

Divisions	% Response by Division	Geographic Area % of Survey
Pacific	25.0	21.3
Mountain	32.0	12.1
Central	50.0	12.6
Great Lakes	9.1	5.3
Eastern	37.5	19.3
Southern	17.6	3.2
Eastern Canada	17.4	11.1
Western Canada	23.5	8.2
International	100.0	1.9
		100.0

Analysis of the IFR questionnaire responses was performed using a computer software package, Statistical Analysis System (SAS). This package provided the statistical tools necessary for the extensive data manipulation and analyses required in this study. A copy of the questionnaire is included here and a question-by-question summary of responses may be found in Paragraph 2.2.

2.2 QUESTIONNAIRE RESPONSE SUMMARY

1. Slightly less than half of all respondents (46 percent) presently operate rotary-wing aircraft in IFR roles.

   The true population proportion of all operators in IFR roles can be expected to fall in the interval below with 95 percent confidence.

   27.6% to 64.5%

2. For companies that operate helicopters in IFR roles the mix of aircraft owned leans toward heavier helicopters.

Average Number of Helicopters
By Size for Each Operator

	Operate IFR	Do Not Operate IFR
Large	6	0
Medium	4	1
Small	2	2

Helicopter sizes were defined as follows:

Large (above 12,500 pounds gross weight)
Medium (8,000-12,500 pounds gross weight)
Small (below 8,000 pounds gross weight)

3. For companies that operate helicopters in IFR roles, the percentage of missions that involve some flight in instrument meteorological conditions by helicopter size class is given below.

Helicopter Size	IFR OPERATORS Percent IMC Missions
Large	27
Medium	25
Small	-
Overall	28

Sample sizes recounting percentage of IFR missions for companies who do not operate helicopters in IFR roles were too small to yield statistically valid information as was the small helicopter size class for IFR operators above.

4. Companies that operate IFR helicopters estimate their overall IMC flight time at 880 hours per year versus 32 hours per year for non-IFR operators.

5. Respondents indicated missions normally performed by their companies in helicopters not equipped for IFR in the following order of frequency. Percentages of each mission not scheduled or cancelled due to weather are also shown in parenthesis (%).

Corporate VIP (7)
Survey Mapping (6)
Other (7)
Petroleum Offshore (9)
Media (3)
Scheduled Air Taxi (7)
Rescue Ambulance (16)
Logging, Forestry Mgt. (13)
Agriculture Spraying

Missions normally performed by IFR-equipped helicopters were clearly only the two below, with

Petroleum Offshore (56), Corporate VIP (44)

percentages of missions completed shown in parenthesis.

Missions not scheduled or cancelled due to weather less than IFR minimums are shown in parenthesis.

Petroleum Offshore (7%), Corporate VIP (9%)

6. Respondents who operate IFR helicopters report employing an average of 85 pilots.

   Range for respondents was from 3 to 820 pilots.

   A 95 percent confidence interval for the population average number of pilots is between 26 and 144.

   Respondents who do not operate IFR helicopters report employing an average 15 pilots.

   Range for respondents was from 2 to 200 pilots.

   A 95 percent confidence interval for the population average number of pilots not operating IFR is between 8 and 22.

7. The IFR operating survey subgroup employed an average 37 IFR-rated pilots.

   Range from 2 to 200 pilots.

   95 percent confidence interval - 18 to 56 pilots.

   For non-IFR operators, the average number of IFR pilots is 6.

   Range - from 0 to 46 pilots.

   95 percent confidence interval - 3 to 9 pilots.

   A comparison of the ratio of IFR pilots to total pilots reported in Question 6, shows that IFR operations do not significantly increase the number of IFR pilots employed.

Companies Which Operate IFR		Companies Which Do Not Operate IFR
Avg Pilots	85	15
Avg IFR Pilots	37	6
Percent IFR Pilots	43.5	40

8. IFR pilots working for a company operating IFR can anticipate an average 10.3 hours/month of actual instrument time.

   A 95 percent confidence interval - 7 to 14 hours.

   IFR pilots working for a non-IFR operator can anticipate a negligible amount of actual instrument flight time.

9. Companies that do not operate IFR helicopters perceived relatively high benefit from improvements in rotary-wing IFR systems that would permit flights into high density and remote sites under conditions lower than currently used minimums.

   The distribution was bimodal with average benefit rating of 2.5 (high benefit through low benefit were determined in the range 1 through 6).

   21 percent of IFR operators perceived relatively low benefit from improvements permitting expanded flight envelopes. If these operators are ignored, benefit rating for improved operational capability averages 2 in the range of 1 to 6.

   For companies that do not operate IFR helicopters, perceived benefits from improvements in rotary-wing IFR systems permitting extended IMC flight regimens were considerably lower. Again the distribution was bimodal with benefit rating averaging 5.4 in the range 1 to 6, if the 25 percent system proponents are discounted.

10. Weather minimums desired for landing tend to be lower for companies that presently operate IFR helicopters, although the first choice for both IFR operators and nonoperators was for 100-foot ceilings and 1/4-mile visibility.

		Operating Minimums Desirability	
Ceiling	Visibility	IFR Operator	VFR Operator
152.4m (500 ft)	1600m (1 mi)	5	4
61.0m (200 ft)	800m (1/2 mi)	4	2
30.5m (100 ft)	400m (1/4 mi)	1	1
15.2m (50 ft)	200m (1/8 mi)	2	3
0	0	3	5

11. Companies that do not operate IFR helicopters would be willing to pay 2 percent more to achieve lower minimums in medium helicopters than IFR operators, who are the predominant operators of mediums, would be willing to pay.

Small helicopter cost increases as measured by amount appear more acceptable to IFR operators than for non-IFR operators.

Percent of aircraft cost operators would be willing to pay to achieve lower minimums.

	Additional % of Cost	
Helicopter Size	IFR Operator	IFR Nonoperator
Large	7	4
Medium	7*	9
Small	8	7*

*Approaching statistically acceptable sample sizes

12. IFR operators perceive total operating revenues would increase significantly more as a result of lowered minimums than do non-IFR operators.

	Additional Revenue %	
Minimum Ceiling	IFR Operator	IFR Nonoperator
30.5m (100 ft)	7*	2*
15.2m (50 ft)	4	4
0	7	3

*Approaching statistically acceptable sample sizes

13. Both IFR helicopter operators and nonoperators perceive the same missions would most benefit from lowered minimums.

Missions Ranked by Importance*

IFR Operators	IFR Nonoperators	Overall
Offshore Petro.	Offshore Petro.	Offshore Petro.
Corporate VIP	Corporate VIP	Corporate VIP
Air Taxi Scheduled	Air Taxi Scheduled	Rescue Ambulance
	Rescue Ambulance	Air Taxi Scheduled

* Only missions with at least eight responses were shown.

14. Over two-thirds of all respondents felt lowered IFR operating minimums would result in improved life savings benefits.

15. This question provided partial information of limited value to the survey results and has been omitted. Respondents do know of missions where helicopters could be substituted for airplanes but were noncommittal as to which ones.

16. Of all respondents, 27 percent offered comments on additional IFR/IMC areas not covered by the questionnaire. These responses which could be categorized into four specific helicopter related areas, are shown in priority order below.

Comment Categories	Percent of Respondents
A. Approach Facilities and Equipment	20%
B. Regulatory Agency Inflexibility	29%
C. Icing Certification and Equipment	24%
D. En route Control Systems	18%

The specific comments are reproduced in Addendum 1 to this Appendix.

17. There is a high degree of willingness to discuss rotary-wing IFR/IMC operations in more detail on the part of respondents, with 94 percent of respondents to this question indicating interest.

18. Both IFR and non-IFR operators indicated the present regulatory weather minimums for sites into which they operate average approximately 300-foot ceilings and one-half mile visibility.

The most common responses for ceiling heights and visibilities are shown below for all respondents.

Ceiling Height	%	Visibility	%
Other	14	400m (1/4 mi)	34
61.0m (200 ft)	43	800m (1/2 mi)	34
122m (400 ft)	24	1200m (3/4 mi)	3
152.4m (500 ft)	19	1600m (1 mi)	28

19. Respondents feel IFR operations are not specific to any particular mission aside from petroleum offshore.

20. Missions are not scheduled or cancelled due to weather more often by IFR operators than by non-IFR operators.

	Cancellations % of All Missions Flown
IFR Operator	11
Non-IFR Operator	7
Overall	9

21. IFR operators indicated a significantly higher number of destinations with approved weather reporting service than did non-IFR operators.

	Percent of Destinations With Approved Weather Reporting
IFR Operators	66
Non-IFR Operators	47
Overall	55

22. For all respondents, four conditions of weather seemed to be responsible for virtually all IMC. These are listed below in order of significance.

Weather Condition	Percent IMC Caused
Fog	38
Low Clouds	25
Snow	16
Rain	15
Other	6

For missions in weather conditions such as in blowing snow, smoke, haze, smog, or blowing dust there was insufficient response rates for considerations.

23. Generally, both IFR operators and nonoperators feel that present weather prediction capabilities are adequate to poor. No responses of excellent were received.

	Operator Weather Prediction Perceptions - Percent		
	Excellent	Adequate	Poor
IFR Operator	-	52	47
Non-IFR Operator	-	78	22
Overall	-	66	34

IFR operators are much more critical of present weather predictions than nonoperators.

24. IFR operators and non-IFR operators experience practically no difference in the percentage of all missions in which icing conditions occur or in the percentage of IMC missions in which icing conditions occur.

	Avg Percent Experiencing Icing	
	All Missions	IMC Missions
IFR Operator	6.8	10.4
Non-IFR Operator	6.7	11.6
Overall	6.8	11.0

23. For all respondents, the adequacy of weather predictions does affect the number of flights that are cancelled.

	% Flights Cancelled Because Of Inadequate Weather Predictions	
	Yes	No
IFR Operator	63	37
Non-IFR Operator	63	37
Overall	63	37

26. For all respondents, en route navigation systems are used in the order of frequency shown below. VOR/DME and RNAV were clearly set apart from the remaining systems as the most frequently used.

VOR/DME	LORAN-C
RNAV	OTHER
	OMEGA

IFR operators indicated strong preference for LORAN-C while non-IFR operators selected VOR/DME and to a lesser extent LORAN-C.

Of all respondents, 43 percent expressed some en route navigation systems preference. LORAN-C was chosen by 48 percent of these individuals because of the three general categories below.

Accuracy/Relaibility
Only System Available
System Flexibility (lower altitude)

VOR/DME was chosen by 29 percent of these individuals because of the two general categories below.

Accuracy
All that's needed for VFR

RNAV was chosen by 11 percent of these individuals for a variety of reasons.

A reproduction of specific comments can be found in Addendum 1 to this Appendix.

27. Most respondents feel their current terminal area landing aids are adequate for their requirements.

	Terminal Area Percent Aids Adequate	
	Yes	NO
Overall	82	18
IFR Operator	79	21
Non-IFR Operator	86	14

28. For all respondents, flight originations or terminations for various facility types are shown in the table below.

IFR operators show a higher propensity to use airports than nonoperators, while non-IFR operators are most likely to use heliports in congested areas. Both seem to operate to heliports in remote areas with equal frequency.

Percentage of IFR flights originating or terminating at:

Respondent	Airport	Congested Area Heliport	Remote Area Heliport
Overall	38	22	40
IFR Operator	40	20	40
Non-IFR Operator	32	28	40

Air Traffic Control method, equipment, and procedures appropriateness to rotorcraft operations in select environments are given in the table below.

Yes response to ATC methods equipment and procedures appropriateness for rotorcraft operations:

Respondent	En route	Terminal Control Areas	Congested Area Heliports	Remote Area Heliports
Overall	58	59	17	38
IFR Operator	68	65	24	47
Non-IFR Operator	17	33	0	0

All operators feel ATC is generally weak while landing at heliports, but generally acceptable while flying.

29. General comments have been reproduced in Addendum 1 to this Appendix.

The comments seemed to fall into or make inference to any or all of four general categories (prioritized below beginning with most important).

1. Respondents indicated a lack of adequate equipment and navigational aids.

    a. Respondents expressed a need for remote or mobile remote landing aids.

2. Types of mission involvement.

    a. Respondents operations were primarily related to offshore oil.

    b. Respondent indicated no IFR operational involvement.

3. Regulatory agency inactivity.

    a. Respondents feel regulatory agencies were resistant to changes in rotory-wing regulations.

    b. Respondents expressed a need for rotary-wing only regulations.

    c. Respondents expressed a need for rotary-wing only approach minimums.

4. Respondents comments were related to other areas; common communications, anti-ice protection; weather reporting standards, etc.

ADDENDUM 1
APPENDIX A

QUESTIONNAIRE COMMENTS

Question 16 Comments

(A) = Approach Facilities and Equipment
(B) = Regulatory Agency Inflexibility
(C) = Icing Certification and Equipment
(D) = En route Control Systems

(A) 1. Fully coupled approaches to CAT. I, II, III required to be compatible with fixed-wing.

(B) 2. FAA overly strict on mins., as present avionics would safely allow much lower mins.

(A) 3. Need mobile approach aids.

(C) 4. Need cert. to fly in icing conditions.

(C) 5. Don't forget anti-ice/deice capabilities on helicopters.

(C) 6. What about icing at high MEAS in Pacific N.W.

(A) 7. Approach facilities development needed for remote area and other heliports.

(A) 8. Police emergency flights would be greatly assisted by IFR improvements.

(D) 9. Specialized helicopter ARTC needed to be most effective.

(B) 10. FAA is big holdback.

(C) 11. Need anti-ice protection.

(B) 12. Expect much difficulty with FAA in San Diego area.

(A) 13. Explore advanced Nav Systems, FLIR, Low Lite TV, Computer Imagery, etc.

(D) 14. ATC lacking in Gulf.

(D) 15. Big problem is practical IFR routing in LAX Basin.

(B) 16. Easier to go VFR due to Hi IFR mins in mountains. Regs ignore unique R/W capabilities.

(B) 17. Canadian Reg Agency Res. Fuel and Alts requirements most irritating.

<u>Question 26 - Comments</u>

1=VOR/DME 2=LORAN-C 3=RNAV 4=OMEGA 5=OTHER

<u>Preference</u>

2 1. RNAV useless after breaking out for going SVFR to heliport.

3 2. RNAV offers most complete coverage.

1 3. VOR/DME accurate.

2 4. Lower altitudes - unlimited routes.

1 5. VOR needed for accuracy, Ontrac III needed for range.

2 6. It's the only thing offshore.

5 7. None that we have is adequate.

2 8. LORAN-C accuracy.

2 9. LORAN-C accuracy at low altitudes.

5 10. ADF preferred because type of facility available.

3 11. RNAV nature of flights are point to point.

3 12. RNAV direct routing.

1 13. Least costly.

2 14. LORAN-C only thing available in Gulf area.

1 15. VOR/DME most practical.

2 16. LORAN-C allows flexible routing and precise navigation.

3 17. RNAV ease of operation and cost.

1 18. VOR/DME most useful; LORAN-C not reliable in Alaska.

3 19. RNAV accuracy.

5 20. GNS-500 is the best I've seen.

2 21. LORAN-C most accurate most reliable.

1 22. All that's needed for VFR.

1 23. Convenience.

2 24. LORAN-C better accuracy.

2 25. LORAN-C accuracy and reliability.

1 26. VOR/DME most accurate.

2 27. Nothing else available for price that will do the job.

2 28. Offshore favors ADF, LORAN-C, OMEGA.

1 29. VOR/DME best for our local needs.

2 30. LORAN-C due to flexibility and reliability.

2 31. LORAN-C provides range, distance, and ground speed info.

2 32. LORAN-C desirable for sites where VOR/DME reception too poor for reliable RNAV reception.

5 33. Decca most accurate and reliable.

3 34. RNAV; Radar.

<u>Question 29 Comments</u>

1. Current approach minimums are for fixed-wing with possible exception of new TERPS. Would like to see rotorcraft-only Regs which recognize the safety and capability of helicopters in IMC. Most of us can crawl along in (bad weather) operating VFR <u>legally</u> when IFR is

impossible. This is a stupid situation and I feel one that causes accidents. In making our decision to equip aircraft for VFR only, we realize our current IFR minimums are above those required for helicopter VFR. Why file IFR and then cancel when weather lowers and proceed VFR. No sense spending the money. We would really like to see the situation changed (unfortunately, regulatory agencies are the holdback).

2. When adequate equipment nav aids are available, we expect to develop our share of the IFR market, not necessarily offshore.

3. My scope of operation is only offshore oil exploration.

4. All our flights are heliport to remote areas with no landing aids. We operate VFR using present company minimums of 400-500 feet and one-mile visibility.

5. IFR is needed for instrument training which is a sizeable chunk of our business.

6. We are very interested in the lower (0-0) minimums that we think will be possible with the MLS.

7. A sharp distinction can be drawn between en route IFR operations--which need not necessarily be IMC operations -- and IFR/IMC expirations culminating in an instrument approach; it is in the latter area that there is room for improved facilities although I doubt whether (North Sea) offshore operations will ever see a decision height below 50 feet.

   Advances in the reporting of actual weather conditions would be necessary. At present, most offshore reports are compiled by a radio operator with little or no training in weather reporting. In the past, this has led to problems when using minima of 200 ft. and 1/2 mile and I am sure automatic weather stations would be needed.

8. Radar coverage offshore needs expanding. We have no way, at present, to make precision approaches to remote helipads.

9. We do not presently operate helicopters IFR although we anticipate going into this in the near future primarily for offshore and en route ferrying.

10. We do radiation mapping and detection. The only IFR we encounter is on a cross country to a research project, and then only when trapped.

11. We do not operate IFR/IMC.

12. Due to lack of IFR facilities for remote landing areas in our (geographic region), IFR is not practical at this time.

13. A visit would be required to understand the environment in which we operate -- Labrador Coast and Northwest Territories.

14. Much work needs to be done (on helicopter IFR/IMC operations).

15. IFR in the winter is very difficult to plan because of the lack of anti-ice protection.

16. All our helicopter pilots are instrument rated. We have IFR equipped helicopters. However, IFR procedures off-shore are inadequate and unsafe.

17. The industry needs specialized routes and procedures and reduced equipment requirements to make helicopter IFR practical.

18. A lot of work needs to be accomplished (to establish) a common form of communications between (rotorcraft operating for different) companies for the good of all and increased safety.

19. We do not have an IMC operations need at this time.

20. We do not operate IFR and don't have IFR equipment.

21. We are involved heavily with the transportation of crews to construction projects. These can last for several years. A mobile remote landing aid would increase our capability and thus our productivity.

22. We do not operate IFR.

23. (We have) no IFR flights. Weather is not a factor in our operations area (Tampa, Florida).

24. We (a public utility) recently received our (military

surplus) helicopter and had flight director and commercial avionics installed. No SAS or autopilot was installed and no STC was obtained. We are, however, following the guidelines of SFAR 25-2/3 as closely as possible to the requirements of commercial operators (and hope to shortly have) our flight crews qualified and our IFR helicopter program implemented.

25. ARTC methods equipment and procedures are appropriate to rotorcraft operation en route and in terminal control areas given the current capabilities (of helicopters are not fully utilized). Development of discrete routing separate from fixed-wing traffic has not yet been tried (in Alberta). However, RNAV based routes have been tried in Southern Ontario for the Ontario Government Ambulance Service. This was well handled by Toronto area ATC in allowing direct routing to hospitals in the Toronto core area. Published approaches at these hospitals is the next appropriate step.

ADDENDUM 2
APPENDIX A

IMC/IFR SAMPLE

- * Respondent
- ** Telephone Survey
- *** Telephone Respondent
- # Address Incorrect (Returned to Sender)
- \- Nonrespondent

- Advocate Airways, Inc.
Plymouth, MA

- Aerospatiale Helicopter Corp.
Grand Prairie, TX

- Ag Helicopters, Inc.
Ft. Collins, CO

* Air Logistics
Lafayette, LA

* Air Services International
Helicopter Division
Scottsdale, AZ

** Air West Helicopters
Ft. Collins, CO

* Alaska Helicopters, Inc.
Anchorage, AK

- Alpine Helicopters, Ltd.
Calgary, Alberta, Canada

** Anchorage Helicopter
Service Inc.
Anchorage, AK

- Apex Helicopters
North Battleford
Saskatchewan, Canada

- Appalachian Flying Service
Blountville, TN

* Associated Helicopters, Ltd.
Edmonton, Alberta, Canada

** Atlantic Aviation Corp.
Wilmington, DE

** Bow Helicopters, Ltd.
Calgary, Alberta,
Canada

- Briles & Wing Heli-
copters
Santa Monica, CA

- Buffalo Airways, Ltd.
Fort Smith, Northwest
Territories, Canada

- Canwest Aviation, Ltd.
Calgary, Alberta,
Canada

** U.S. Dept. of Energy
Bonneville Power
Administration
Portland, OR

*** Carson Helicopters, Inc.
Perkasie, PA

- Cascade Helicopters,
Inc.
Cashmere, WA

* Central Helicopters,
Inc.
Bozeman, MT

- Chesapeake & Potomac
Airways, Inc.
Baltimore, MD

*** L.A.P.D.
Air Support Division
Helicopter Section
Glendale, CA

- City of Chicago
Dept. of Purchases,
Contracts & Supplies
Chicago, IL

- Coast Operations of Canada
Ltd.
Ottawa, Ontario, Canada

- Collins General Aviation
Division
Rockwell International
Cedar Rapids, IA

*** Columbia Helicopters, Inc.
Aurora, OR

** Condor Helicopters &
Aviation
Ventura, CA

** Crescent Airways
West Hollywood, FL

* Crescent Airways
West Hollywood, FL

** Dept. of Transportation
Flight Services Branch
Ottawa, Ontario, Canada

* Akland Helicopter Co.
Talkeenta, AK

* Okanagan Helicopters, Ltd.
Richmond, British Columbia,
Canada

- Dot Helicopter, Inc.
Corpus Christi, TX

*** Evergreen Helicopters, Inc.
Corpus Christi, TX

* Chevron U.S.A.
New Orleans, LA

** Chicago Fire Dept.
Helicopter Unit
Chicago, IL

*** Duncan Aviation, Inc.
Lincoln, NE

* ERA Helicopters, Inc.
Anchorage, AK

- Edwards & Associates,
Inc.
Blountville, TN

** Erickson Air-Crane Co.
Central Point, OR

* Executive Helicopters,
Inc.
Atlanta, GA

** Exxon Corporation
Aviation Dept.
Houston, TX

- Exxon Corporation
Oil Center Station
Lafayette, LA

- Fetsko Aviation Sales
& Transportation
Media, PA

- Frontier Helicopters,
Ltd.
Watson Lake, Yukon
Canada

* Golden State Helicopters
San Francisco, CA

- Grand Canyon Helicopters
Grand Canyon AZ

Helicopters Associates
Phoeniz, AZ

* Evergreen Helicopters, Inc.
McMinnville, OR

** Imperial Helicopters, Inc.
South St. Paul, MN

\- Indiana State Police
Indianapolis, IN

\- Interair Services Inc.
Clearwater, FL

\- Jacksonville Helicopter Service
Jacksonville, FL

** Jelco Incorporated
Salt Lake City, UT

** JNO McCall Coal Co., Inc.
Baltimore, MD

** Mack Trucks, Inc.
Allentown, PA

Joy Manufacturing Co.
Franklin, PA

\- L & J Equipment Company
Madisontown, PA

\- Les Helicopters Laverendrye
Saint-Clet, Quebec, Canada

** Heli Voyageur, Ltd.
Val D'Or, Quebec, Canada

\- Canadian Helicopters, Ltd.
Dorval, Quebec, Canada

* Liftair International, Ltd
Calgary, Alberta, Canada

\- Shirley Helicopters
Edmonton, Alberta, Canada

\- Livingston Copters, Inc.
Juneau, AK

\- Highland Helicopters,
Richmond, British Columbia, Canada

* Houston Helicopters, Inc.
Pearland, TX

\- Midwest Airlines, Ltd.
Helicopter Division
Winnipeg, Manitoba
Canada

\- Idaho Helicopters Inc.
Boise, ID

** Nahanni Helicopters, Ltd.
Delta, British Columbia,
Canada

* Aerial Measurement Operation
Las Vegas

\- Ocean Technology, Ltd.
Anchorage, AK

** Tundra Copters, Inc.
Fairbanks, AK

\- Ominiflight Helicopters
Janesville, WI

* Petroleum Helicopters
Lafayette, LA

*** Pacific Crown Aviation
Spokane, WA

\- Pacific Helicopters, Inc.
Starup, WA

\- Decair Helicopters, Inc.
Spring Valley, NY

*** Reeder Spraying, Inc.
Twin Falls, ID

- Maryland State Police
  Pikesville, MD

- Rotor-Aire
  Madison, WI

* Heliflight Systems, Inc.
  Houston, TX

* Houston Police
  Helicopter Division
  Houston, TX

- Sea Airmotive, Inc.
  Anchorage, AK

- Huisson Aviation, Ltd.
  Timmins, Ontario, Canada

** Canadian Coast Guard
  Fleet Systems
  Ottawa, Ontario, Canada

- Skytel Aviation, Inc.
  Fort Lauderdale, FL

Aviation Medical Services
  Houston, TX

*** Orlando Helicopter Airways
  Orlando, FL

- Southern California Edison
  Aircraft Operations
  Chino, CA

* Louisiana State Police
  Baton Rouge, LA

* Suncoast Helicopters, Inc.
  Tampa, FL

- Temsco Helicopters, Inc.
  Ketchikan, AK

* Tennessee Valley Authority
  Chattanooga, TN

* Rocky Mountain Heli-
  copters
  Provo, UT

* Parker Aviation Corp.
  Worcester, MA

- Ronson Aviation, Inc.
  Trenton, NJ

*** Toronto Helicopters, Ltd.
  Markham, Ontario, Canada

- Wayfarer Ketch Corp.
  White Plains, NY

** Eagle Air, Inc.
  Sitka, AK

** International Air
  Transport
  Anchorage, AK

** Kenai Air Alaska, Inc.
  Kenai, AK

** Air Crane, Inc.
  Tucson, AZ

* Astrocopters, Ltd.
  Oakland, CA

- Moore Aviation, Inc.
  Tulare, CA

- Rogers Helicopters, Inc.
  Clovis, CA

* Rotor Aids, Inc.
  Ventura, Ca

** Utility Helicopters, Inc.
  Long Beach, CA

- Flight For Life
  St. Anthony Hospital
  System
  Denver, CO

*	Textron, Inc. Aircraft Department Warwick, RI	#	Global Transportation & Logistics, Inc.
-	Seminole Flying Service Haines City, FL	-	Clark Jet Service Wallingford, CT
-	Kenai Air Hawaii Honolulu, HI	-	Carib Aviation & Marine Consultants Miami, FL
-	Maui Helicopters Kihei, HI	-	El Aero Services Elko, NV
**	Boise Cascade Corp. Aviation Division Boise, ID	-	Lear Aira Reno, NV
-	Chicago Helicopter Airways Chicago, IL	-	Top Flight Helicopter Leasing Co. Barrington, NH
-	Roto Whirl, Inc. Wabash, IN	*	Ronson Aviation, Inc. Trenton, NJ
-	Trafficopters, Inc. Indianapolis, IN	#	United Helicopter, Inc. Pleasantville, NJ
**	Kentucky Helicopters Carlisle, KY	#	A.I.R. Co., Inc. Staten Island, NY
-	Faust International Baton Rouge, LA	***	Island Helicopter Corp. Garden City, NY
***	Offshore Logistics, Inc. Lafayette, LA	-	Robards Helicopter, Inc. Danville, NY
-	Northeast Helicopters Bucksport, ME	-	Imperial Helicopters, Inc. Charlotte, NC
*	Fostaire Helicopters St. Louis, MO	-	Inland Helicopters Grants Pass, OR
***	St. Louis Helicopters Airways, Inc. Maryland Heights, MO	#	Copter, Inc. Philadelphia, PA
*	Mountain West Helicopters Kalispell, MT	*	Fleet Helicopter Corp. Zion Hills, PA
**	Panhandle Aviation, Inc. Lincoln, NE	***	Keystone Helicopter Corp. West Chester, PA

- Hoskings Helicopters, Inc.
  Bountiful, UT

- Fire Master Helicopters, Inc.
  Everett, WA

North American Helicopter Service, Inc.
  Seattle, WA

- Trans-Alaska Constructors
  Seattle, WA

** Weyerhauser Company
  Gig Harbor, WA

- Vecellio & Grogan Aviation Division
  South Charleston, WV

- Hawkins & Powers Aviation
  Greybull, WY

- Kenting Helicopters Division of Kenting Aircraft Ltd.
  Calgary, Alberta, Canada

- Alpine Helicopters, Ltd.
  Kelowna, British Columbia, Canada

- United Helicopters, Ltd.
  Calgary, Alberta, Canada

- Quasar Aviation, Ltd.
  Richmond, British Columbia, Canada

- Viking Helicopters, Ltd.
  Ottawa, Ontario, Canada

* Sealand Helicopters
  St. Johns, Newfoundland, Canada

* Universal Helicopters, Ltd.
  St. Johns, Newfoundland, Canada

- South Carolins Helicopters
  Saluda, SC

Executive Helicopters, Inc.
  Houston, TX

** Offshore Helicopters, Inc.
  Sabine, TX

- Ontario Helicopter Services
  Lakefield, Ontario, Canada

- Ontario Hydro-Helicopter Section
  Missauga, Ontario, Canada

* Ranger Lake Helicopters
  Maine, Ontario, Canada

- Universal Helicopters
  Carp, Ontario, Canada

Helicopters Olympiques, Ltd.
  Montreal, Quebec, Canada

- Helicraft, Ltd.
  St. Hubert, Quebec, Canada

- Helicopters Canada, Inc.
  Chiboughaman, Quebec, Canada

- Heli-Quebec, Ltd.
  Pte. Claire, Quebec, Canada

Northern Wings Helicopter
  Dorval, Quebec, Canada

Olympic Helicopters, Ltd.
  Montreal, Quebec, Canada

- Trans-Canada Helicopters
  LesCedres, Quebec, Canada

- E. H. Darby Aviation
  Sheffield, AL

- Harbert Construction Corp.
  Birmingham, AL

** International Supply Corp.
   Scottsdale, AZ

- Circle Air Parts
  Burbank, CA

Fluor Corporation
  Los Angeles, CA

* Rockwell International Corp.
  El Segundo, CA

** United Technologies Corp.
   East Hartford, CT

- Dupont Corp.
  Wilmington, DE

- Lacy Steel, Inc.
  Ewa Beach, HI

- McDonald's Corp.
  Oakbrook, IL

- Interstate Coal Co., Inc.
  London, KY

* Continental Oil Company
  CAGC Division
  Lake Charles, LA

* Mobil Oil Corp.
  Morgan City, LA

- Prudential Ins. Co. of America
  Executive Air Fleet
  Helicopter Service
  Teterboro, NJ

- Jos. E. Seagram & Sons
  White Plains, NY

* Athasbaske Airways, Ltd.
  Prince Albert,
  Saskatchewan, Canada

- Trans North Turbo Air, Ltd.
  Whitehorse, Yukon,
  Canada

* Thomson Industries, Inc.
  Port Washington, NY

- Ohio Coal & Construction Corp.
  Wintersville, OH

- Portland General Electric Co.
  Portland, OR

- Consolidated Coal Co.
  Continental Oil Co.
  West Mifflin, PA

- Boeing Vertol Company
  Philadelphia, PA

- Al Hamilton Construction Co.
  Woodland, PA

*** Tenneco, Inc.
    Aviation Department
    Houston, TX

** Boise Interagency Fire Center
   Bureau of Land Management
   Boise, ID

* New York City Police Department
  Aviation Unit
  Brooklyn, NY

*** Texas Department of Public Safety
    Aircraft Division
    Austin, TX

* British Airways Helicopters
United Kingdom

* British Caledonian
United Kingdom

* British National Oil Co.
United Kingdom

*** Suffolk County Police
Department
New York

*** New York State Police

*** City of Dallas Police
Department
Helicopter Division
Dallas, TX

* KLM Helicopters
The Netherlands

* Nassau County Police
Department
New York

*** Pennsylvania State
Police

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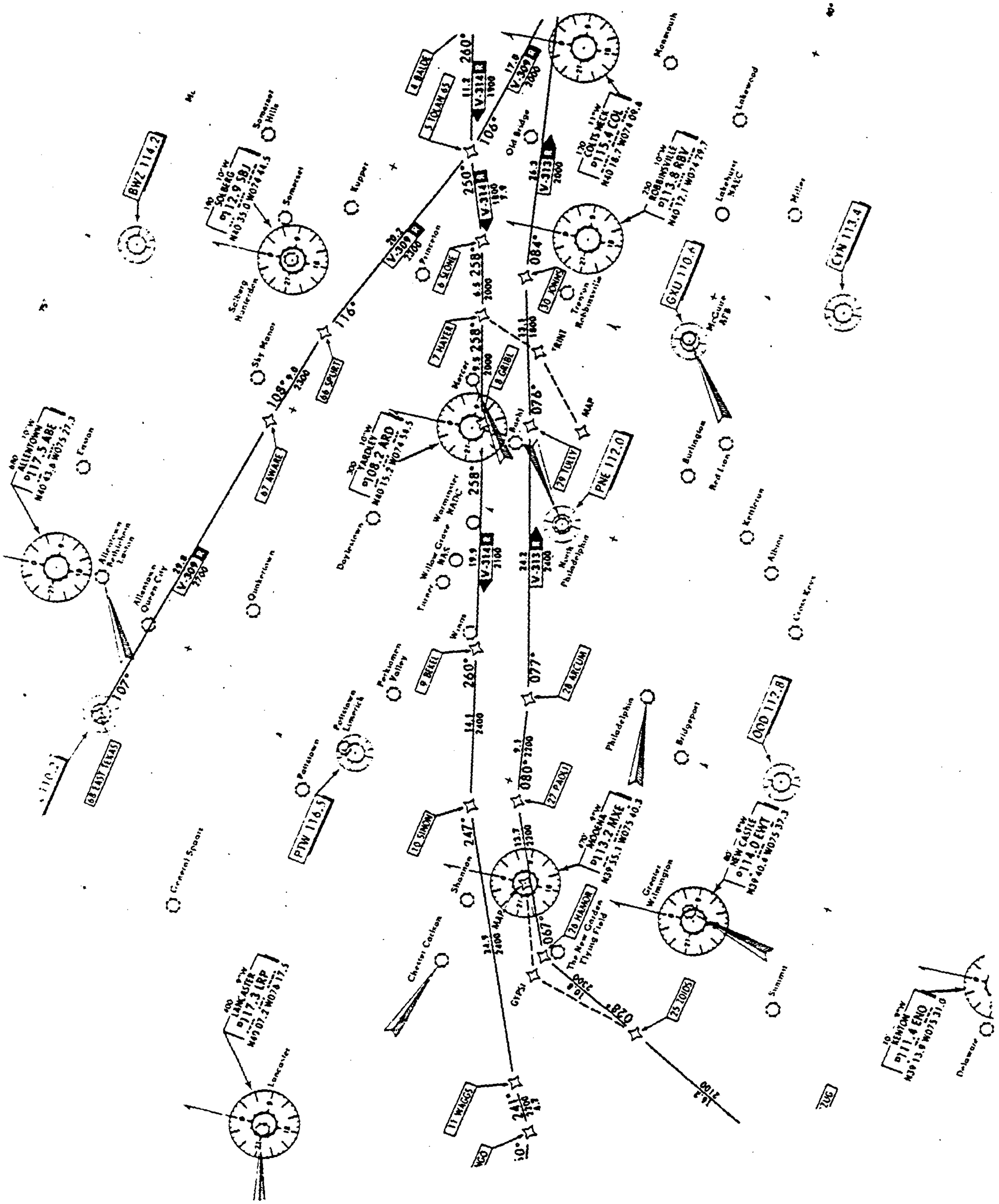
ABBREVIATIONS AND ACRONYMS

ANGS	Advanced Navigation and Guidance System
ASE	Airborne System Error
ATC	Air Traffic Control
CDP	Critical Decision Point
CDTI	Cockpit Display of Traffic Information
CEP	Circular Error Probability
CTOL	Conventional Takeoff and Landing
DME	Distance Measuring Equipment
DSAL	Decelerating Steep Approach and Landing
FAA	Federal Aviation Agency
FAF	Final Approach Fix
FDC	Flight Director Computer
FLIR	Forward Landing Infrared
FTE	Flight Technical Error
GDOP	Geometric Dilution of Precision
GPS	Global Positioning System
HAI	Helicopter Association International
HELMS	Helicopter Multifunction System
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
IAP	Initial Approach Point
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILM	Independent Landing Monitor
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
LLTV	Low Light Level Television
LOFF	Loran-C Flight Following
LOS	Line of Sight
MADGE	Microwave Aircraft Digital Guidance Equipment
MAP	Missed Approach Point
MLS	Microwave Landing System
MPSBLS	Man Portable Scanning Beam Landing System
NEC	Northeast Corridor
PAR	Precision Approach Radar
PIS	Point in Space
PPI	Plan Position Indicator
RLG	Ring Laser Gyro
RNAV	Area Navigation
ROC	Required Obstacle Clearance
RSRE	Royal Signals and Radar Establishment
TACAN	Tactical Air Navigation
TERPS	U. S. Standard for Terminal Procedure
TSCT	Total System Crosstrack Error
UHF	Ultra High Frequency

VFR	Visual Flight Rules
VHF	Very High Frequency
VHSI	Very High Speed Integration
VLF	Very Low Frequency
VLSI	Very Large Scale Integration
VOR	VHF Omnidirectional Range

APPENDIX B

Examples of the route structure of the Northeast Corridor referred to in Section 4 are shown in Appendix B along with a typical N.E. Corridor approach plate to Logan International Airport, Boston, Mass.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Lancaster
Allentown
Trenton
Robbinsville
Burlington
Red Lion
Pottstown
Doylestown
Mercer
Old Bridge
Monmouth
Lakewood
Lakehurst
Summit
Delaware

Victor airway 313R Washington, D C to Bridgeport
(This airway continued from Northeast Helicopter Corridor Routes (Washington, D C to New York) chart)

NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
32	ROLER	JFK	115 9	00	061 0°/20 0	11W	N405104 8/W732631 1
33	MAUDE	RVH	117 2	01	284 0°/19 8	13W	N405401 4/W732052 1
34	FLOPP	RVH	117 2	01	331 8°/13 0	13W	N410330 3/W730604 8
35	IGORR	RVH	117 2	01	359 8°/20 2	13W	N411324 1/W730052 5

Victor airway 315R, New York to Boston

NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
51	AMUSE	DPK	111 2	01	315 0°/19 5	12W	N405805 7/W733950 1
52	HIPAN	DPK	111 2	01	335 0°/16 8	12W	N410054 9/W733136 2
53	ORALE	DPK	111 2	01	007 5°/18 3	12W	N410545 4/W732008 7
54	IGORR	RVH	117 2	01	359 8°/20 2	13W	N411324 1/W730052 5
55	DROUN	MAD	110 4	02	024 9°/2 9	13W	N412139 9/W724045 9
56	DANEY	PVD	115 6	01	297 0°/21 9	14W	N414819 5/W715420 4
57	MEEOW	BOS	112 7	00	245 4°/20 4	15W	N420825 3/W712045 9

Victor airway 316R, Boston to New York

NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
41	ROGEE	BOS	112 7	00	231 8°/21.1	15W	N420432 4/W711636 1
42	MOURO	PVD	115 6	01	296 9°/16 0	14W	N414659 8/W714639 3
43	CLINT	MAD	110 4	02	124 0°/4.2	13W	N411719 0/W723621 4
44	MUSIK	RVH	117 2	01	019 0°/14 5	13W	N410809 3/W725245 3
45	FLOPP	RVH	117 2	01	331 8°/13 0	13W	N410330 3/W730604 8
46	CLEMM	DPK	111.2	01	031.4°/14 9	12W	N410133.7/W731142.5

MAR 30-79 Special Tailored **NORTHEAST HELICOPTER CORRIDOR ROUTES**
(NEW YORK CITY TO BOSTON)

Victor Airway 309R, Allentown to New York

NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
68	EAST TEXAS	ABE	117 5	07	240 2°/13 6	10W	N403451 2/W754103 6
67	AWARE	SBJ	112 9	02	265 0°/14 0	10W	N403119 6/W750215 6
66	SPURT	SBJ	112 9	02	238 0°/7.3	10W	N403005 0/W745038 4
65	TOLAN	SBJ	112 9	02	135 0°/18.0	10W	N402437 0/W742513 6
64	BANKA	COL	115 4	01	061.0°/6 5	11W	N402252 3/W740305 7

Victor Airway 313R, Washington, D C to Bridgeport

NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
21	BERNY	BAL	115 1	01	151 5°/12 2	08W	N390026 0/W763023 0
22	MOISH	BAL	115 1	01	130 0°/17.7	08W	N390050 5/W762026 1
23	RUSEY	BAL	115 1	01	083 0°/22 8	08W	N391606 3/W761120 2
24	ABZUG	ENO	111 4	00	308 0°/24 6	09W	N392546 5/W755844 6
25	ZOIDS	EWT	114 0	01	283 0°/11 2	09W	N394107 6/W755147 5
26	HAMOR	EWT	114 0	01	333 0°/13 4	09W	N395120 3/W754718 0
27	PAOLI	EWT	114 0	01	021 5°/18 6	09W	N395831 9/W753205 0
28	ARCUM	ARD	108 2	03	246 0°/24 5	10W	N400126 0/W752055 0
29	TULLY	ARD	108 2	03	166 0°/5 0	10W	N401037 4/W745149 5
30	JONNS	RBV	113 8	03	317.0°/6 2	10W	N401552 1/W743611 6
31	BANKA	COL	115 4	01	061.0°/6 5	11W	N402252 3/W740305 7

(This airway continued on Northeast Helicopter Corridor Routes (New York to Boston) chart)

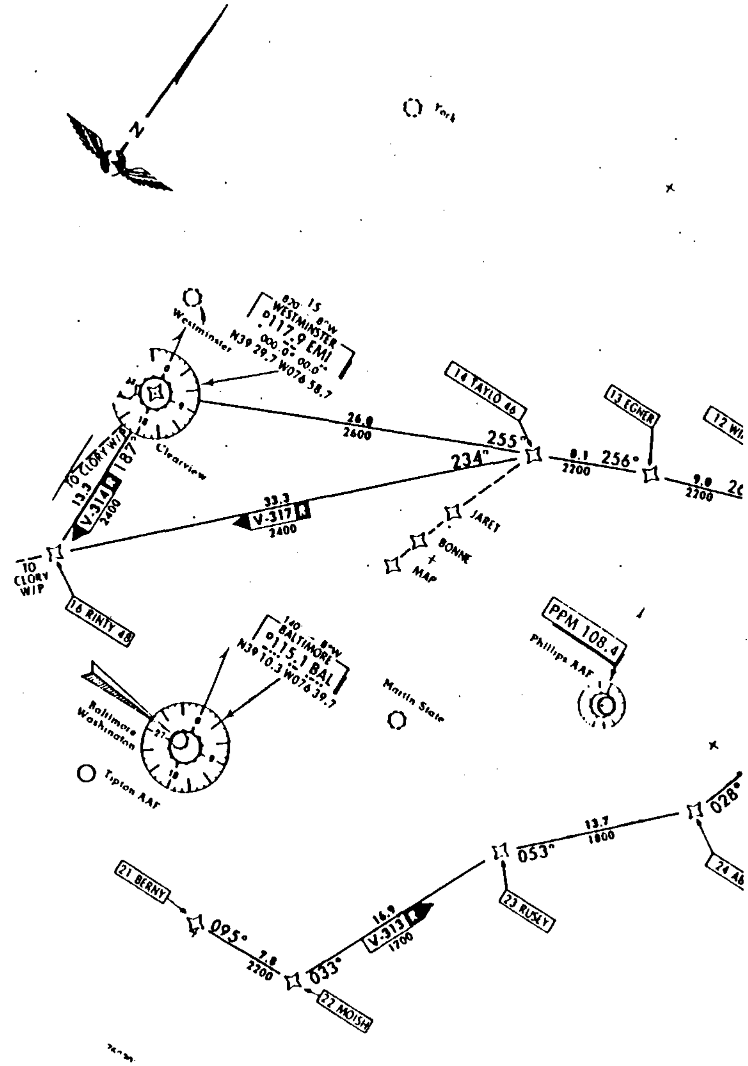
Victor Airway 314R, New York to Washington, D C

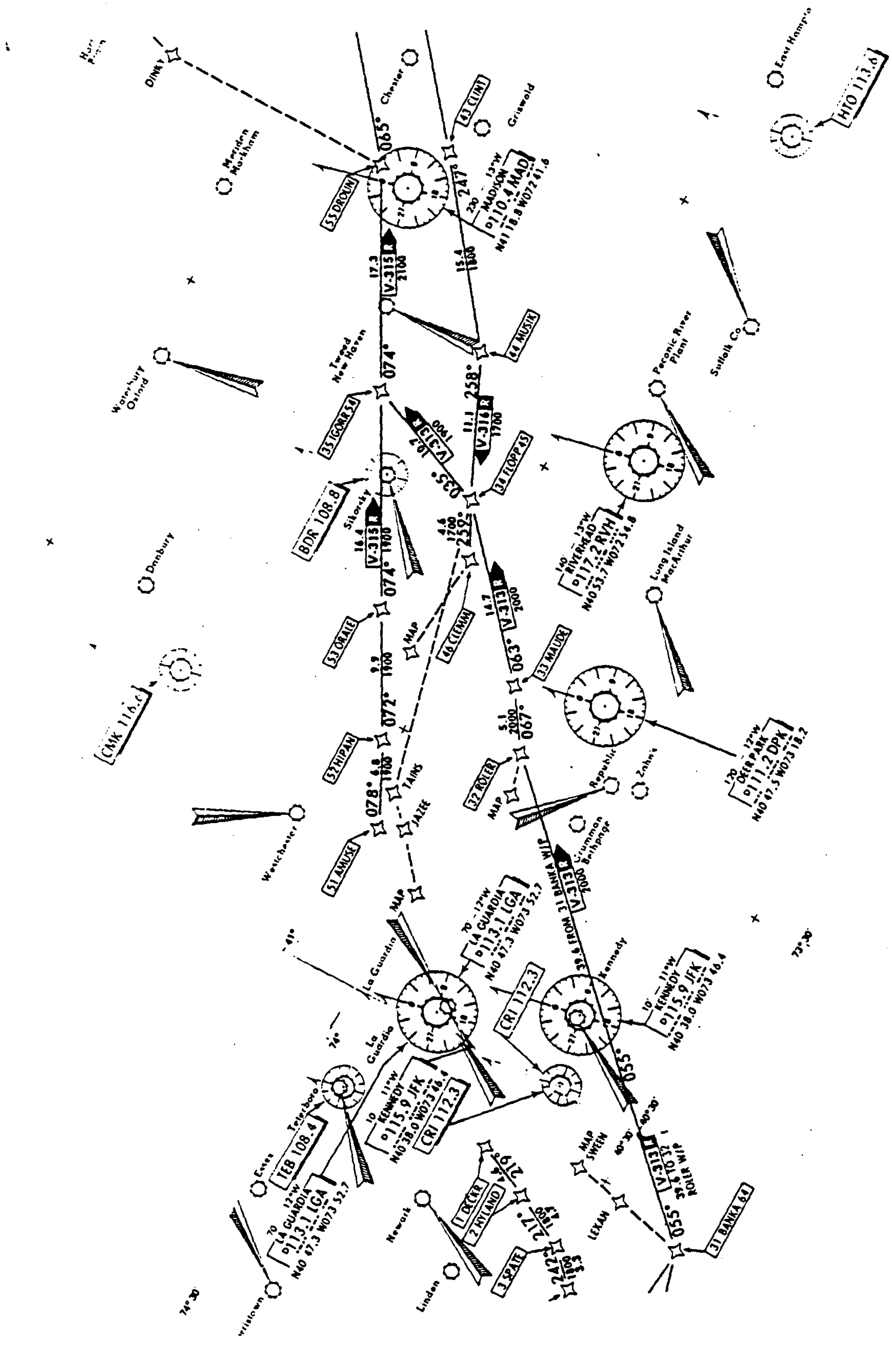
NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
1	DECKR	LGA	113 1	01	235 3°/11 2	12W	N403907 0/W740243 0
2	HYLAN	CRI	112 3	00	269 5°/9 2	11W	N403500 0/W740530 0
3	SPATE	CRI	112 3	00	252 7°/12 6	11W	N403045 4/W740813 6
4	BALDE	COL	115 4	01	002 5°/10 1	11W	N402841 4/W741134 0
5	TOLAN	SBJ	112 9	02	135 0°/18 0	10W	N402437 0/W742513 6
6	SLONE	SBJ	112 9	02	161 0°/16 4	10W	N402036 8/W743407 8
7	HAYER	ARD	108 2	03	083 0°/10 0	10W	N401806 6/W744158 8
8	GRIBL	ARD	108 2	03	144 0°/1 0	10W	N401430 0/W745332 3
9	BEKEL	ARD	108 2	03	255 5°/19 5	10W	N400703 8/W751736 5
10	SINON	MXE	113 2	05	039 5°/8 3	09W	N400213 4/W753447 2
11	WAGGS	MXE	113 2	05	259 0°/18 0	09W	N394852 3/W760213 3
12	WINGO	LRP	117 3	04	168 0°/22 7	09W	N394550 5/W760656 7
13	EGNER	LRP	117 3	04	190 0°/24 2	09W	N394258 6/W761802 5
14	TAYLO	EMI	117 9	08	075 0°/26 0	08W	N393947 6/W762744 3
15	WESTMINSTER	EMI	117 9	08	000 0°/00 0	08W	N392941 7/W765843 8
16	RINTY	EMI	117 9	08	187 0°/13 3	08W	N391623 1/W765825 9

Victor Airway 317R, Alternate New York to DCA

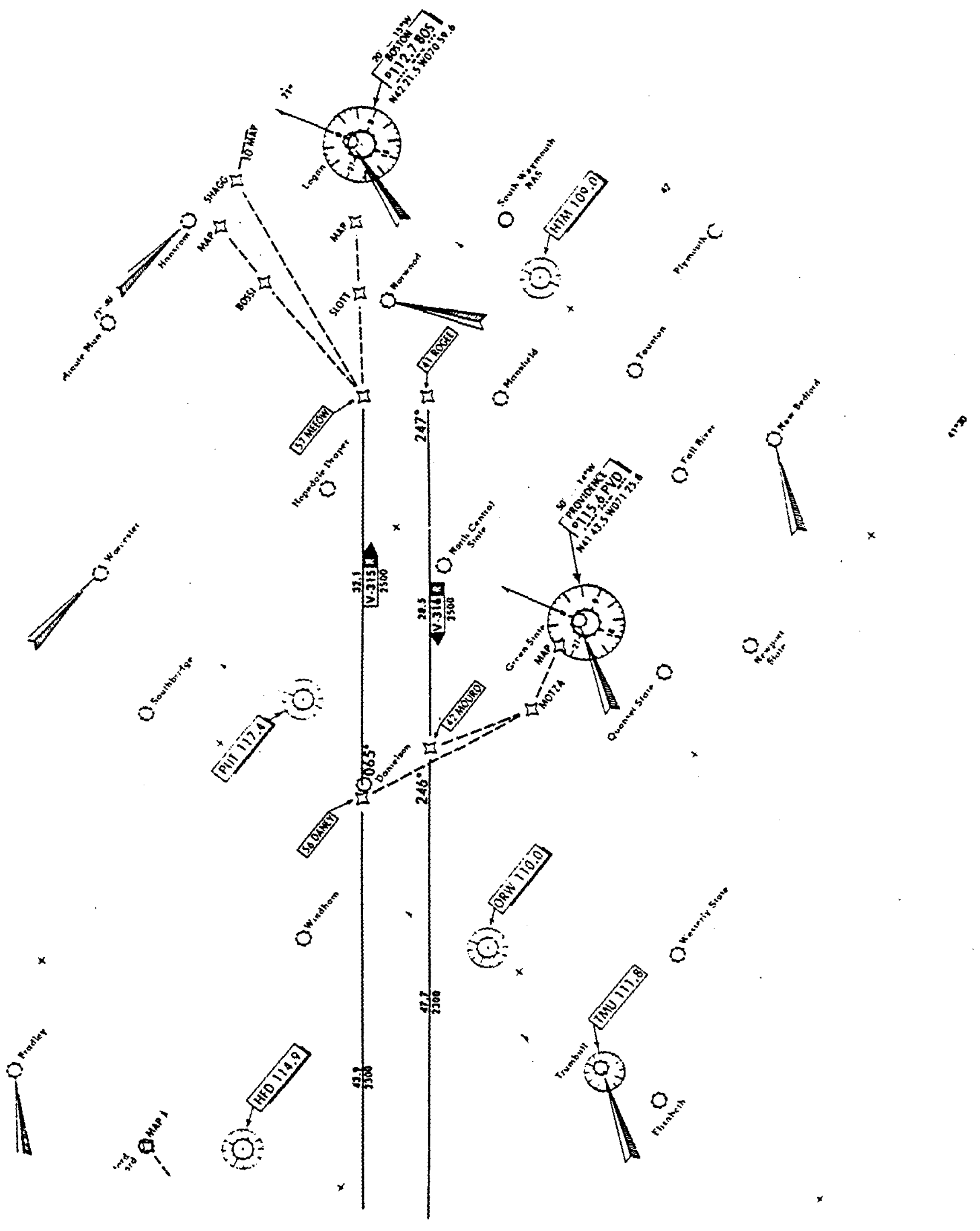
NO	NAME	IDENT	FREQ	ELEV	BEARING/DME DIST	VAR	LAT/LONG
46	TAYLO	EMI	117 9	08	075 0°/26 0	08W	N393947 6/W762744 3
48	RINTY	EMI	117 9	08	187 0°/13 3	08W	N391623 1/W765825 9

MAR 30 79 Special Tailored **NORTHEAST HELICOPTER CORRIDOR ROUTES**
(WASHINGTON D.C. TO NEW YORK CITY)





DINNY
Chester
43 CLINT
Griswold
East Hampton
HTO 113.6
Meriden Markham
55 DROUN
065°
247°
MADISON
110.4 MAD
N41 18.8 W072 41.6
17.3
V-315
2100
15.4
1800
Tweed New Haven
074°
64 MUSIK
Suffolk Co.
Peconic River Plant
Waterbury Oxford
35 GORR 54
258°
V-316
1700
V-313
1900
34 FLOPP 45
RIVERHEAD
117.2 RVH
N40 53.7 W072 38.8
BDR 108.8
Sikorsky
16.4
V-315
1900
074°
Danbury
Long Island MacArthur
53 ORALE
MAP
46 CLEMM
14.7
V-313
2000
063°
33 MAUDE
CMK 116.6
9.9
1900
072°
52 HIPAN
6.8
1900
078°
TAINS
JAZEE
32 ROLLER
5.1
2000
067°
DEER PARK
111.2 DPK
N40 47.5 W073 18.2
Republic
Zahns
Westchester
51 AMUSE
Grumman Bethpage
V-313
2000
39.6 FROM 31 BANKA W/P
LA GUARDIA
113.1 LGA
N40 47.3 W073 52.7
La Guardia
CRI 112.3
Kennedy
KENNEDY
115.9 JFK
N40 38.0 W073 46.4
055°
Teterboro
TEB 108.4
Essex
V-313
39.6 TO 32 ROLLER W/P
MAP
SWEEN
LEXAN
31 BANKA 64
Newark
1 DCKR
2 HYLAND
3 SPATE
Linden
219°
217°
242°
Morristown
74°30
73°30


BOSTON
PROVIDENCE
Logan
Hanscom
SHAGG
BOSSI
SLOTT
MAP
Norwood
South Weymouth NAS
HTM 109.0
Plymouth
Mansfield
Taunton
New Bedford
Fall River
57 MEEOW
41 ROGEE
247°
Hopedale Draper
North Central State
Worcester
V-315
V-314
2300
Green State
MOTZA
Newport State
Quonset State
Southbridge
PUT 117.4
42 MOURO
063°
Danielson
246°
56 DANNY
ORW 110.0
Windham
Westerly State
TMU 111.8
Trumbull
Elizabeth
Brainard
HFD 114.9
MAP

NE Corridor Approach (Special) NOV 17-78 (19-7)

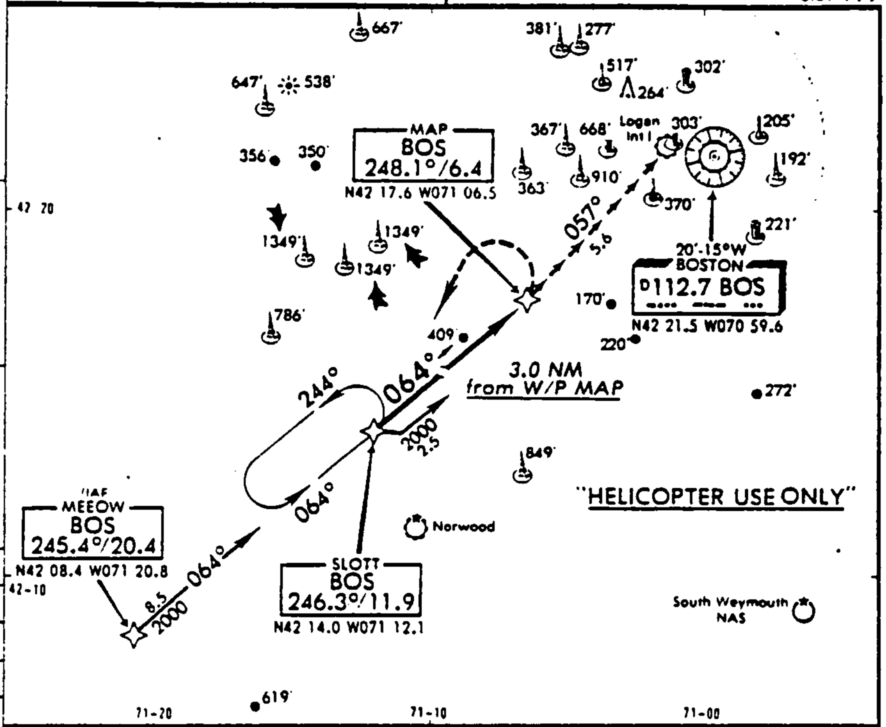
BOSTON, MASS.
POINT-IN-SPACE
COPTER RNAV-064°

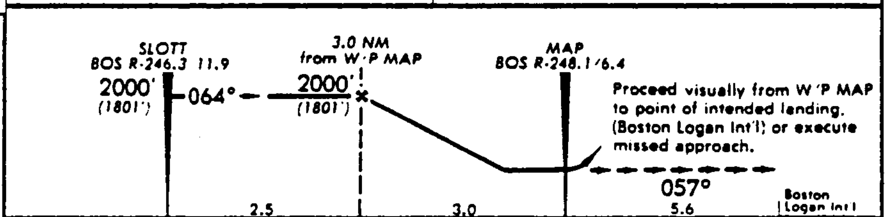
VOR 112.7 BOS

Class VORTAC

Elev 199'

Use Boston, Logan Int'l altimeter setting.





MISSED APPROACH: Climbing LEFT turn to 2000' direct to W/P SLOTT and hold.

	LANDING H-064	TAKE-OFF	ALTERNATE
	MDA 800' (601')		
A	3/4	NA	NA

Gnd speed-Kts	70	90	100	120	140	160
GS Setting 3.77°	472	607	675	810	945	1079

CHANGES: New procedure.

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NASA CR-166274		

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16. Abstract

This study investigates the requirements for all-weather operations for rotary wing aircraft, and the technical and cost feasibility of several advanced systems.

The results of a survey of IFR operations by commercial operators are presented.

Candidate systems were examined for capability to meet the requirements of a mission model constructed to represent the modes of flight normally encountered in low visibility conditions.

Recommendations are made for development of high resolution radar, simulation of the control display system for steep approaches, and for development of an obstacle sensing system for detecting wires. A cost feasibility analysis is included.

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