IN-05
151337
P.84

DOT/FAA/DS-88/2
DOT/FAA/PS-88/8
NASA CR 177483

"Zero/Zero" Rotorcraft Certification Issues

Advanced System
Design Service
Washington, D.C. 20591

Volume II
Plenary Session Presentations

(NASA-CR-177483-Vol-2) ZERO/ZERO ROTORCRAFT CERTIFICATION ISSUES. VOLUME 2: PLENARY SESSION PRESENTATIONS Final Report (Systems Control Technology) 84 p CSCL 01C N88-25454
Unclas
G3/05 0151337

Richard J. Adams

Systems Control Technology, Inc.
1611 N. Kent Street, Suite 910
Arlington, VA 22209

July 1988

Final Report

This Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation

Federal Aviation Administration

NASA

National Aeronautics and Space Administration

Ames Research Center
Moffett Field, California 94035

Technical Report Documentation Page

1. Report No. NASA CR 177483, Vol.II DOT/FAA/PS-88/8, Vol.II DOT/FAA/DS-88/2, Vol.II	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle "Zero/Zero" Rotorcraft Certification Issues Volume I Executive Summary Volume II Plenary Session Presentations Volume III Working Group Results		5. Report Date July 1988 6. Performing Organization Code
7. Author (s) Richard J. Adams		8. Performing Organization Report No.
9. Performing Organization Name and Address Systems Control Technology, Inc. 1611 North Kent Street, Suite 910 Arlington, Virginia 22209		10. Work Unit No. (TRAIS) 11. Contract or Grant No. NAS2-12478
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591		13. Type Report and Period Covered Final Report 14. Sponsoring Agency Code ADS-220

15. Supplementary Notes

In a recent reorganization the FAA Rotorcraft R&D Program BRANCH, APS-450, has become the Rotorcraft Technology Branch, ADS-220

16. Abstract

This report analyzes the "Zero/Zero" Rotorcraft Certification Issues from the perspectives of manufacturers, operators, researchers and the FAA. The basic premise behind this analysis is that "zero/zero", or at least extremely low visibility, rotorcraft operations are feasable today from both a technological and an operational standpoint. The questions and issues that need to be resolved are: What certification requirements do we need to ensure safety? Can we develop procedures which capitalize on the performance and maneuvering capabilities unique to rotorcraft? Will extremely low visibility operations be economically feasable?

Volume I of this report provides an overview of the Certification Issues Forum held in Phoenix, Arizona in August of 1987. It presents a consensus of 48 experts from the government, manufacturer, and research communities on 50 specific Certification Issues. The topics of Operational Requirements, Procedures, Air-worthiness and Engineering Capabilities are discussed.

Volume II presents the operator perspectives (system needs), applicable technology and "zero/zero" concepts developed in the first 12 months of research of this project.

Volume III provides the issue-by-issue deliberations of the experts involved in the Working Groups assigned to deal with them in the Issues Forum.

17. Key Words		18. Distribution Statement
Rotorcraft Helicopter Low Visibility Approaches Low Speed Approaches	Advanced Approaches Steep Approaches Heliports	This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	90	

Form DOT F 1700.7 (8-72) Reproduction of this document is authorized

TABLE OF CONTENTS

This page intentionally left blank.

"ZERO/ZERO" SYSTEM REQUIREMENTS

- AN OPERATOR'S PERSPECTIVE -

BY

MR. FRANK L. JENSEN, JR.

PRESIDENT

HELICOPTER ASSOCIATION INTERNATIONAL

AUGUST 1987

1.0 "ZERO/ZERO" SYSTEM REQUIREMENTS - AN OPERATOR'S PERSPECTIVE

HAI represents the operational component of the civil helicopter industry. Our regular membership comprises three kinds of operators:

- Commercial - primarily Part 135 "fly for hire"
- Corporate - primarily Part 91 corporate or personal use
- Public Service - government operations at federal, state or local level

HAI has about 450 operating companies among our regular members, and together they operate about 3,500 helicopters.

What use is made of these helicopters, and how much priority is placed by operators on: 1) Instrument flying in general, and 2) a true zero/zero capability?

Before I attempt to follow up on those rhetorical questions, I would like to ask for a show of hands: How many helicopter pilots do we have in the room? Please raise your hands.

Thank you. I count about 30, out of a total of about 50.

Now, how many of the helicopter pilots present are reasonably current on instruments? Again, please raise your hands. Thanks again, about 15 of us in the room are more or less safe on the gauges.

Certainly each person in the room views the helicopter from a different perspective - based on what exposure he or she has had with helicopters.

To help establish a common frame of reference, I'll show you a matrix which lists the major types of helicopter operations as shown in the Helicopter Annual - I'll read them for those who can't see the small print.

Agriculture
Air Carrier - Part 127
Air Taxi - Charter Part 135
Bank Paper Transfer
Commuter Air Carrier/Schedule
Construction
Corporate - Part 91
Electronic News Gathering
EMS/Air Ambulance
Executive Transport
Exploration
External Cargo
Fire Control/Support
Government Contracting Agency
Government Agency
Herding Stock & Wildlife
Law Enforcement
Logging
Offshore
Patrol/Power, Pipeline, Buried Cable
Photography
Pollution detection/monitoring
Private Owner
Sightseeing
Skiing
Traffic Watch

PRECEDING PAGE BLANK NOT FILMED

I hope that its obvious that I am leading up to a point - most helicopter operations are conducted VFR. Most helicopter operators could not care less about IFR operation, and zero/zero could go into the category of "pie in the sky."

However, for those operations which require reliability of scheduling, or which must be flown in rain or shine we must make our best effort for IFR.

Some Examples:

- Anywhere there is a need for higher priority movement of parts and people by helicopter off shore, for maintenance. When the operator misses a crew change, two things happen - both bad: 1) morale goes down, and 2) costs go up.

- High-density metro areas with a heliport complex (hub and spoke) as these become operational.

- Future helicopters/tilt-rotor/advanced technology with true CAT A performance, in metro areas, or in limited remote sites, without airports, but in need of air transport.

- Also, just about every pilot, from time to time, finds himself in a situation where a full panel - plus some nav or approach aids - plus the knowledge and skill to use them - would be most welcome. We've all been there.

What are some of the current roadblocks to more productive helicopter IFR operations? Not necessarily in order of priority:

- Lack of helicopter routes on IFR charts, and lack of published IFR approaches to serve existing helicopter IFR operations.

- Lack of IFR let-down to VFR - for use in remote areas during marginal VFR - for EMS, SAR and executive travel - using RNAV, LORAN C and maybe GPS.

- Lack of cost-benefit analyses showing the efficiency of full IFR capabilities for helicopters.

- Lack of adequate IFR training regimens including wider use of helicopter simulators to sharpen skills.

- Lack of public helicopter IFR routes.

- Lack of properly located, public-use heliports.

To use the popular phrase - we need a full-blown helicopter IFR infrastructure.

Let's face it - there isn't any point in helicopters flying just airport to airport - whether VFR or zero/zero. We just cannot compete with fixed wing on a cost-per-seat-mile basis.

We all have a tendency to focus on the exotic - and I'm not saying that is all bad. Beneath the T-shirt of every low-time single-engine VFR helicopter pilot, there beats the heart of a hopeful future captain of a tilt-rotor or an EH101 - a Walter Mitty making a fantasized curved MLS approach, with a 45 degree slope, touching down at zero/zero in the heart of Manhattan or London. (In the case of Cessna 172 pilots, its VFR into Red Square).

But none of us - regulators or operators - engineers or air traffic controllers - can assume away the nitty gritty basic needs which I have outlined.

Remember the famous quotation of the bag lady on 14th and Pennsylvania: "The only thing that kept me from graduating from college was high school".

In summary, zero/zero IFR capability - as a part of a total system - could help us to attain the full potential of the helicopter/future rotorcraft, but not without public heliports, public helicopter routes, and published helicopter approaches. In short, we must get a system into place from which to build. Believe me, HAI wants zero/zero.

Meanwhile, lets not forget the task which helicopters do best - Helicopters...Above All... Save Lives!

TECHNOLOGY "IN-HAND" FOR A ZERO/ZERO IFR CAPABILITY

BY

MR. JOHN ZUGSCHWERT

EXECUTIVE DIRECTOR

AMERICAN HELICOPTER SOCIETY

AUGUST 1987

PRECEDING PAGE BLANK NOT FILMED

2.0 TECHNOLOGY "IN-HAND" FOR A ZERO/ZERO IFR CAPABILITY

The FAA has recently recognized the low airspeed control capabilities of helicopters. Because of this, helicopters are normally granted weather approach minimums below those of fixed wing aircraft. Few fixed wing aircraft can fly at airspeeds below sixty knots. The FAA has certified Sikorsky S-76 helicopter approaches to forty knots. While this is a step in the right direction, it still keeps the helicopters in a fixed wing environment where forward speed is mandated to keep the aircraft in the air. A helicopter can hover, remaining in the air at zero airspeed. This is one of its greatest capabilities, and was the advantage over the autogyro which could land and take off on a few feet but could not sustain zero airspeed flight. What difference does this make? It is the determinant for the size of the landing sites (airport runway, helipad, etc.) and the distance criterion from obstacles such as buildings along the flight path and adjacent to the landing site. Slowing airspeed approach and aircraft control to a hover will determine whether downtown heliports can become a reality under all weather conditions.

As in the past, military specifications and designs have set the stage for the next generation civil helicopter. The power requirements for third and fourth generation helicopters have increased. They must demostrate the ability to climb at 500 feet per minute at 95 percent rated power at 4,000 foot density altitude and 95 degrees Fahrenheit.

Operationally, these helicopters were required to spend a large percentage of flight time at a hover, doing "pop and bob" (up and down) maneuvers in a hover at 50 to 100 feet. Precision hover devices such as the High Energy Rotor system were developed, allowing safe autorotation from the above and higher altitudes while in the "dead man's curve" at a hover at zero airspeeds.

With the ability to safely execute an autorotation in a high hover (especially with multi-engined aircraft) and possessing excess power, the "dead man's curve" disappears. The ability for full zero/zero helicopter IFR operations became a reality.

Many may challenge that the "dead man's curve" has not disappeared. In fact, it has not in many first (reciprocating engine powered) and second generation helicopters operating with full or excessive loads. But it has disappeared for the third and fourth generation aircraft such as the Black Hawk, Apache, CH-47D and AHIP. Even many second generation aircraft spend many hours at high hover (several hundred feet on many occasions) such as the sonar dipping anti-submarine warfare helicopters and CH-53, CH-54, BV-107 and CH-7 helicopters which operate in logging operations, installation of power lines, and in construction.

I can recall, while in the MI-17 and MI-26 at the 1979 Paris Air Show, being introduced to a precision hover device. On the instrument panel, both aircraft had a round instrument with two needles, one hinged from the left side and the other from the top (much like the normal OMNI indicator) which allowed one to hover over a spot on the terrain at altitude by keeping the needles centered.

Because of the advances being made today and those which will be made tomorrow, we are safely executing the maneuvers which make the zero/zero capability a reality.

The ability to automatically hover at altitude exists in the Apache and AHIP. The computer can automatically move the aircraft from a 500 foot hover to a 50 foot hover over the same spot. The US and the USSR have been doing this manually for years. I do not believe there is an electronic/avionics company which will not be able to install the automatic hover/approach and departure system in third and fourth generation aircraft. They can also install emergency procedures for autorotation at various altitudes/conditions on a pre-programmed basis, perhaps better than pilots. This is not for all aircraft. Many smaller and older helicopters could never qualify for these capabilities. But it is not correct to penalize those capable now. Certainly this capability would be a "must" for taking full advantage of the abilities of the tilt rotor and X-wing aircraft.

So, why is someone not correcting this situation? The FAA is the regulatory agency which will approve or disapprove this system. Their position has been to show them what you have and they will tell you if it is acceptable.

In this era of streamlined budgets, it is difficult to find anyone interested in investing the funds necessary on the probability it will take years of qualifications and modifications for approval through the bureaucracy and the competitive scene which follows. (Remember the PLASI, LASSI, CLASSI situation when industry followed this route.)

What the industry would like is for the regulatory agency to write specifications for a system and competively fund its development. One can be sure there would be many anxious bidders and an excellent product could be developed at minimal risk.

The FAA has a charter for the development and advancement of civil air capabilities. The FAA, I imagine, has to question where it will get the funds to support a program of this nature. The answer is to fight for the funds in the budget cycle. I am sure one would find industry willing to support and help in the fight.

Perhaps there may be a middle ground where the FAA could establish a jointly agreed criterion with funding shared between government and industry. This would keep less sincere bidders out of the program.

I believe it is safe to say the helicopters of today can execute zero/zero all weather approaches and departures from relatively small downtown heliports safely and efficiently. I believe it is also safe to say, within the FAA and the industry, there exists the capability to write the specifications for executing this program. This was evident by the enthusiastic support and objective, non-confrontational participation in the Zero/Zero Forum.

The arrival of the tilt rotor in the early 1990s will demand a system of this type to maximize its capabilities. We have agency responsibility and industry interest. We have the likelihood for successful funding with support from government and industry.

What are we waiting for?

CERTIFICATION OF HELICOPTER "ZERO/ZERO" OPERATION -- CONCEPTS AND RESEARCH RESULTS

BY

RICHARD J. ADAMS
VICE PRESIDENT
ADVANCED AVIATION CONCEPTS, INC.

AND

DAVID L. GREEN
PRESIDENT
STARMARK CORPORATION.

AND

JOHN L. THOMPSON
OPERATIONS ANALYST
SYSTEMS CONTROL TECHNOLOGY, INC.

AUGUST 1987

PRECEDING PAGE BLANK NOT FILMED

INTRODUCTION AND WEATHER ANALYSIS

BY

RICHARD J. ADAMS

AUGUST 1987

AGENDA

- INTRO & BACKGROUND
- PROJECT SUMMARY
- Wx PHENOMENA & "ZERO/ZERO" PROBLEM
- APPLYING TODAY'S CONCEPTS, PROCEDURES AIRSPACE, ETC.
- NEW CONCEPTS, STATUS, UNRESOLVED PROBLEMS, ETC.

SURVEY OF COMMERCIAL OPERATORS:

- 200 SURVEYED
- 50% OPERATE IFR
- 25% OF MISSIONS
- 900 HOURS/YR/OPERATOR
- PRIMARY OIL & CORPORATE

WEATHER PHENOMENA AND

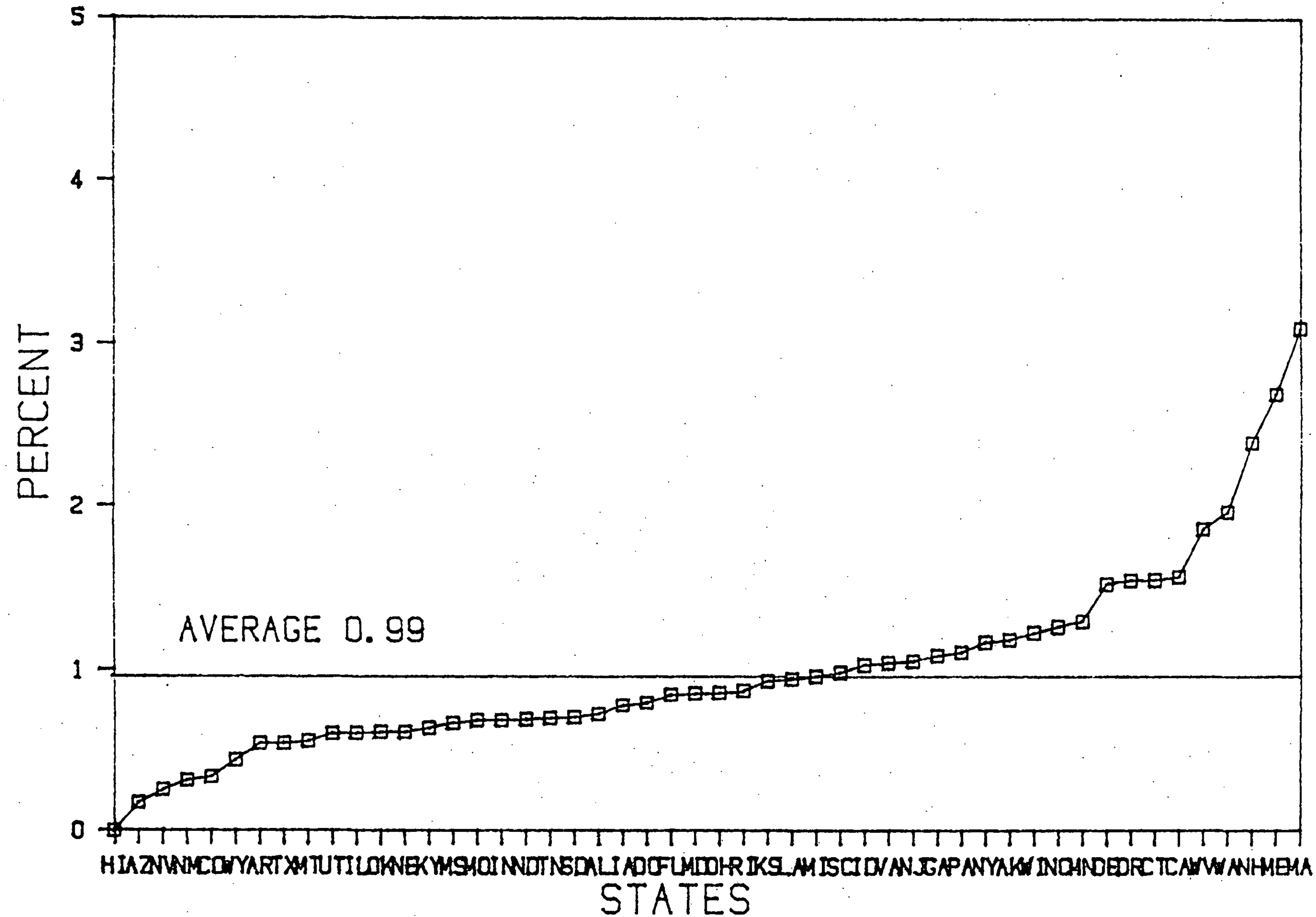
THE "ZERO/ZERO" PROBLEM

- PREDOMINANT IMC IS FOG
- FOLLOWED BY LOW CLOUDS, SNOW, AND RAIN
- ONLY 7% ICING

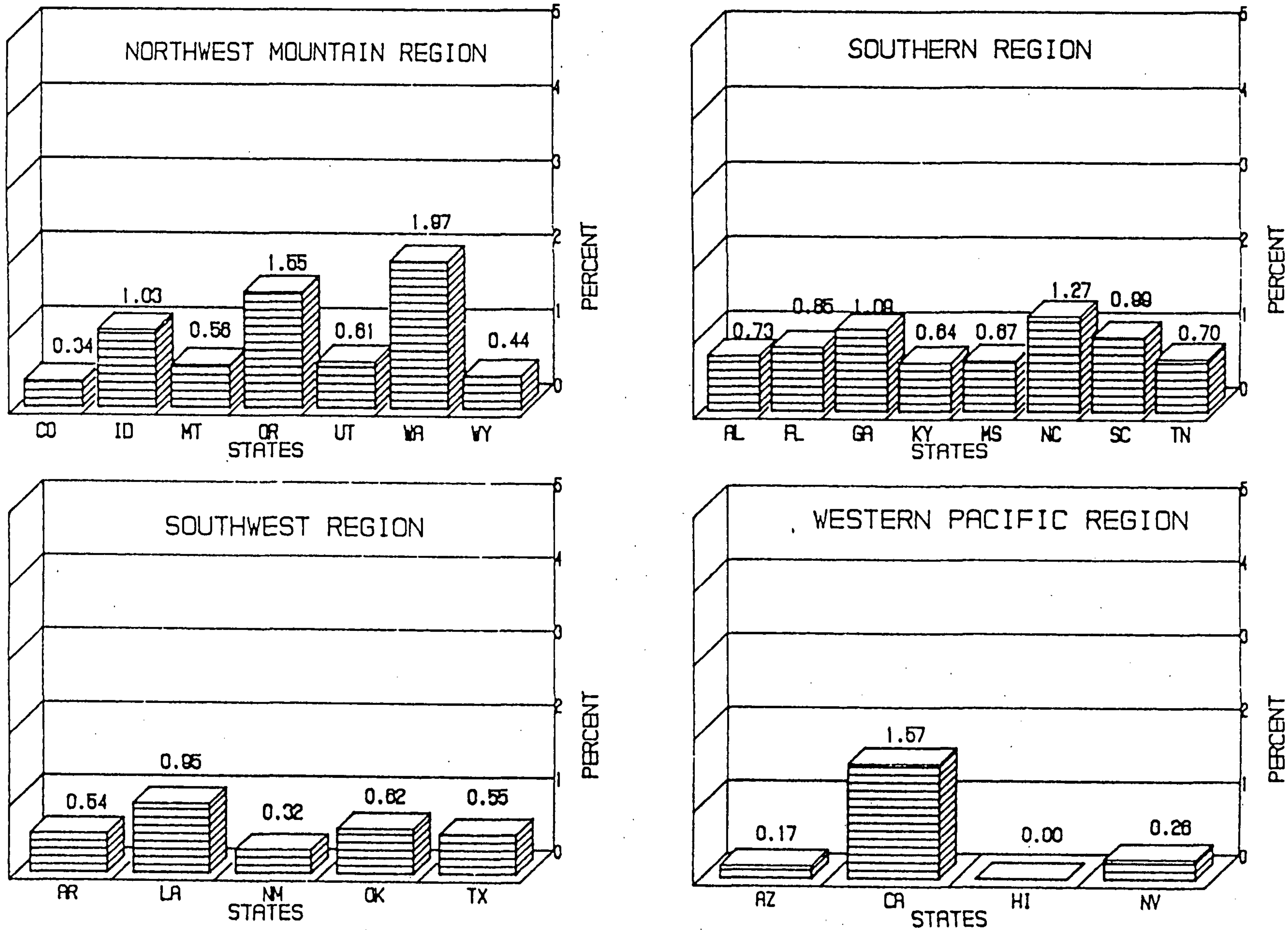
MINIMUMS

- TODAY: 300' & 1/2 NM
- DESIRED: 100' & 1/4 NM

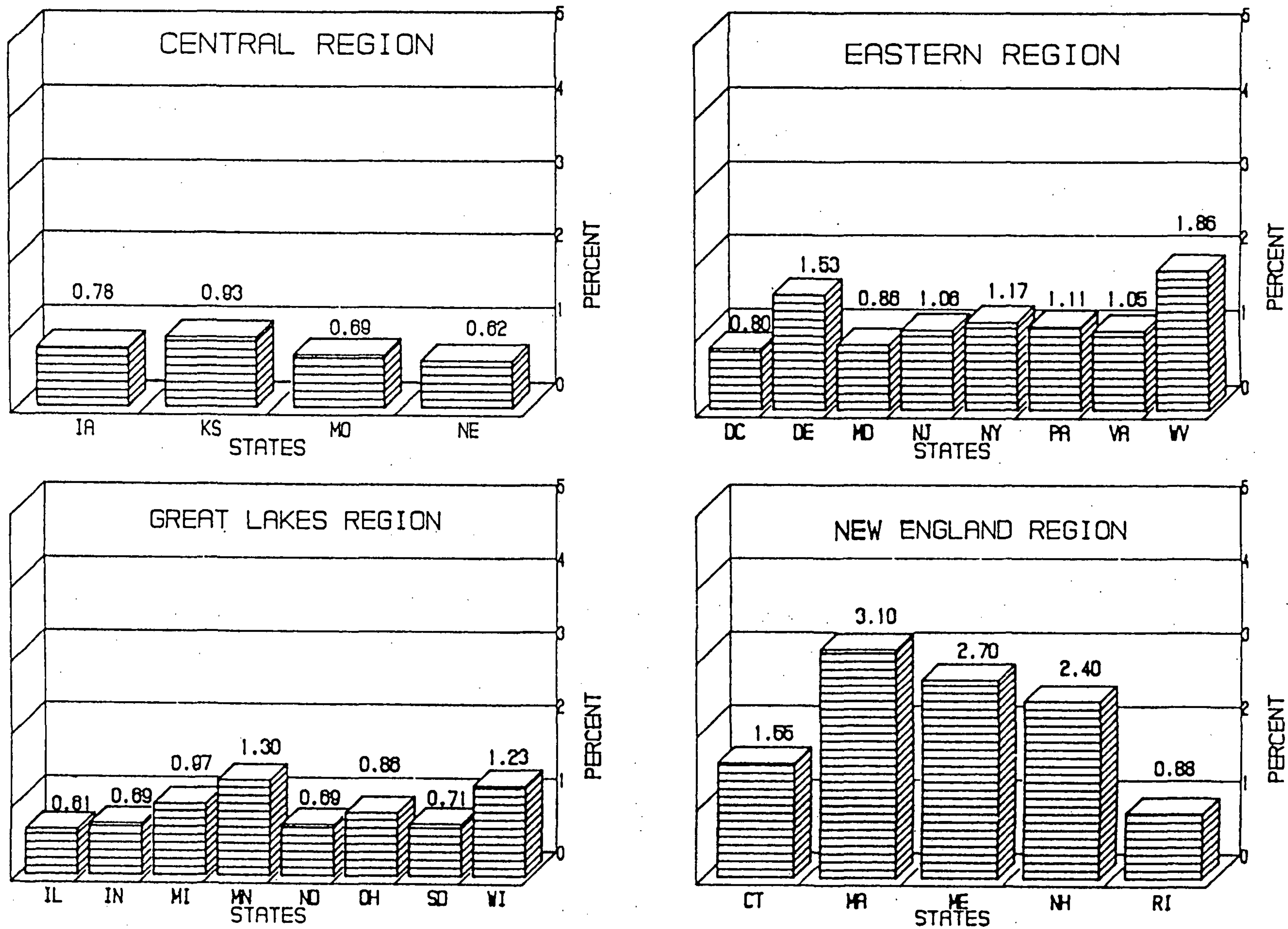
PORTION OF YEAR C<=200′ OR V<=1/2MI



PORTION OF YEAR C<=200' OR V<=1/2MI



PORTION OF YEAR C<=200' OR V<=1/2MI



SUMMARY : C<=200' OR V<=1/2 NM

2-3% : MA, ME, NH = 3

1-2% = 15 STATES

0-1% = 31 STATES

OBSCURATION PHENOMENA

NOT "ZERO/ZERO"

ELV - EXTREME LOW VISIBILITY

EGO - EXTREME GROUND OBSCURATION

ELVIRA - EXTREME LOW VISIBILITY ROTORCRAFT APPROACH

OPERATIONAL REQUIREMENTS

1. FLY THE ROTORCRAFT TO A POINT ON A GLIDESLOPE AT A SPEED WHICH WILL PERMIT THE USE OF A MODEST DECELERATING FLARE MANEUVER TO A HOVER
2. INITIATE A DECELERATING FLARE
3. AVOID DESCENDING BELOW THE SAFE ALTITUDE SPECIFIED FOR THE SPECIFIC LANDING SITE/ROTORCRAFT IN CASE
4. CONCLUDE THE DECELERATION AT THE SPECIFIED TARGET POINT
5. ESTABLISH VISUAL CONTACT (EITHER BY DIRECT VIEWING OR BY AN ELECTRONICALLY AIDED VIEWING SYSTEM)
6. DETERMINE THAT THE LANDING AREA IS CLEAR

OPERATIONAL REQUIREMENTS(CONT'D)

7. MANEUVER THE ROTORCRAFT, IF REQUIRED, TO ESTABLISH A PRELANDING HOVER
8. ESTABLISH VISUAL REFERENCES WHICH ARE SUITABLE TO PERFORM A VERTICAL DESCENT TO A FINAL TOUCH DOWN (EITHER MANUALLY OR SEMI AUTOMATICALLY)
9. LAND
10. EXECUTE A MISSED APPROACH (3 ALTERNATIVES)
    - A. INITIATE A VERTICAL CLIMB
    - B. ACCELERATE TO TRANSLATIONAL LIFT AND ESTABLISH CLIMB ANGLE NECESSARY TO STAY WITHIN OBSTACLE FREE AIRSPACE
    - C. EXECUTE 3 DEG/SEC PEDAL TURN (RIGHT OR LEFT) DEPENDING ON ROTORCRAFT AND PILOT VISIBILITY AND IF NO VISUAL CONTACT PERFORM A. OR B. AS APPROPRIATE

PROJECT SUMMARY
AND
DEFINITIONS

BY

JOHN L. THOMPSON

AUGUST 1987

PROJECT SUMMARY

&

DEFINITIONS

CERTIFICATION ISSUES

- OPERATIONAL REQUIREMENTS
- PROCEDURAL CHANGES
- ENGINEERING CAPABILITIES

STATEMENT OF WORK SUMMARY

FOUR TASKS:

1. DEFINE CERTIFICATION ISSUES
2. IDENTIFY CERTIFICATION SHORTFALLS
3. RESOLVE SHORTFALLS (EQUIPMENT, PROCEDURE, ETC)
4. DEVELOP A WORKPLAN FOR IMPROVED CERTIFICATION STANDARDS

STATUS

- HAVE COMPLETED COMPREHENSIVE LITERATURE SEARCH
  - RESEARCH DATE BACK TO 1968
  - 154 DOCUMENTS IDENTIFIED
- PLAYERS INCLUDE
  - FAA APS
  - FAA TC
  - NASA ARC
  - NASA LRC
  - FAA SW REGION
  - FAA AVN
  - DOD
  - MANUFACTURERS
  - OPERATORS

CAPABILITIES FOR ZERO/ZERO ARE HERE TODAY

1. AIRCRAFT (HH-65A, S-76B)

2. AVIONICS (COLLINS, SPERRY SYSTEMS)

3. PILOTS (USCG, USN EXPERIENCE)

WHAT DOES
HELICOPTER ZERO/ZERO MEAN?

1. IT IS NOT "ALL WEATHER"

2. IT IS NOT "CONTINUED DESCENT/DECELERATION TO TOUCHDOWN" WITHOUT ANY VISUAL CONTACT

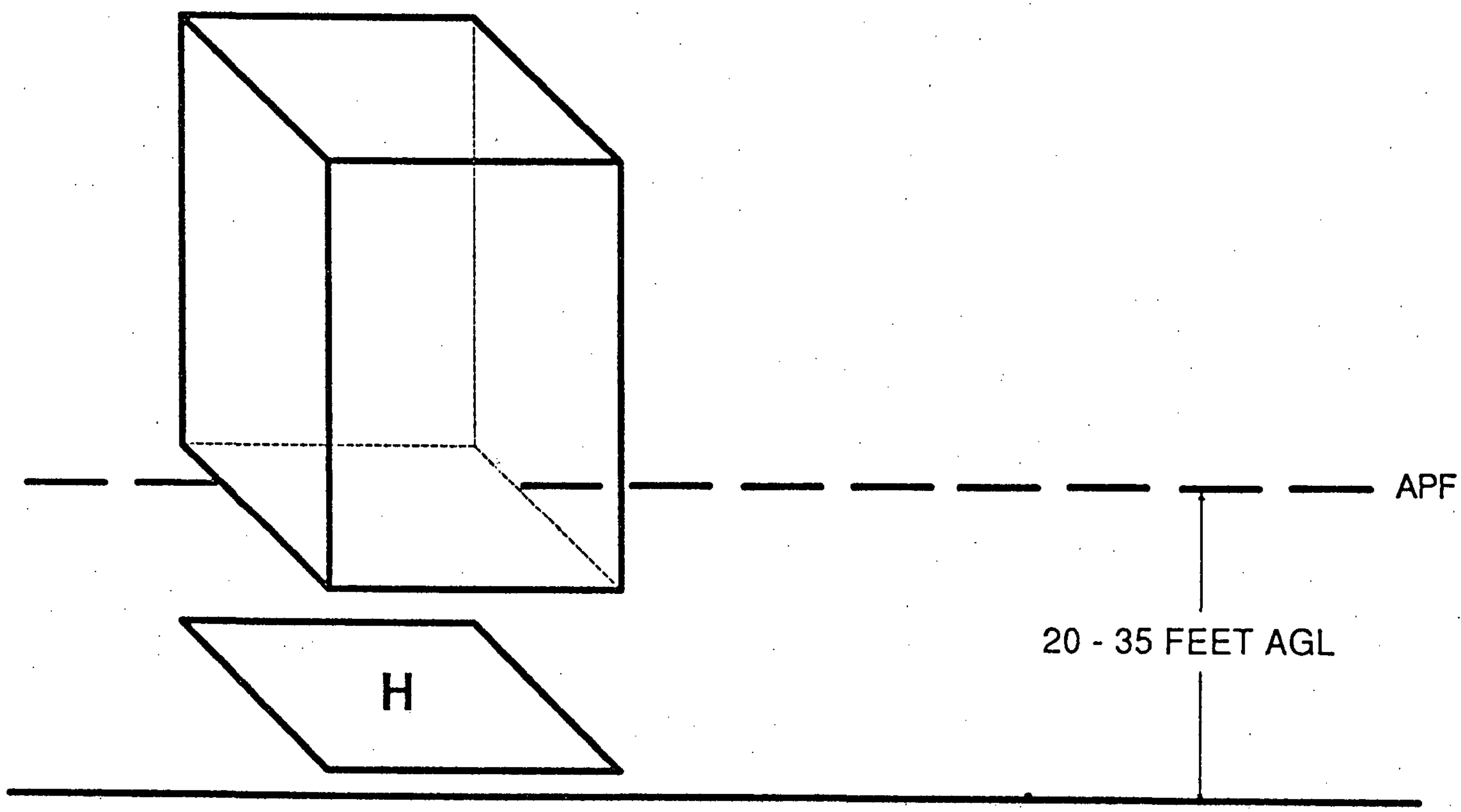
3. IT IS: A CONTROLLED DESCENT/DECELERATION IN PROTECTED AIRSPACE WITH PRECISION GUIDANCE TO A "TARGET POINT"

TARGET POINT: THAT POINT AT WHICH SPECIFIC COMBINATIONS OF AIRSPEED, DECELERATION, PITCH RATE AND HELICOPTER SYSTEM CAPABILITIES ALLOW A CONTINUED SAFE APPROACH TO A LANDING UNDER "DELAYED VISUAL CONTACT" METEOROLOGICAL CONDITIONS

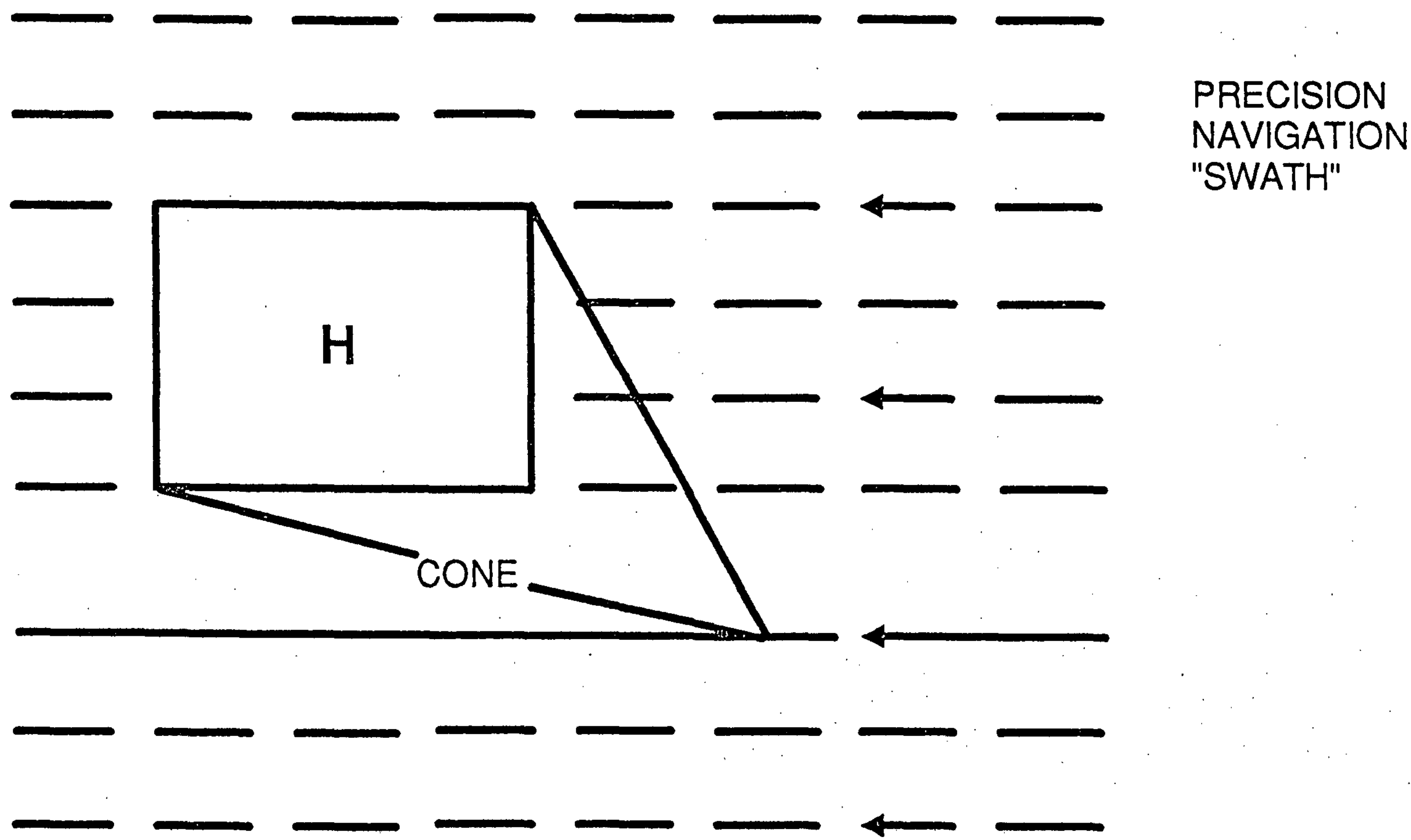
DEFINITION OF TERMS

DELAYED VISUAL CONTACT (DVC) APPROACH = A PRECISION APPROACH TO A "HOVER VOLUME"

HOVER VOLUME = PROTECTED VOLUME OF AIRSPACE WITHIN WICH A VARIETY OF DVC APPROACHES MAY BE EXECUTED.



OFFSET "VISUAL" APPROACH (OVA)



TOP VIEW

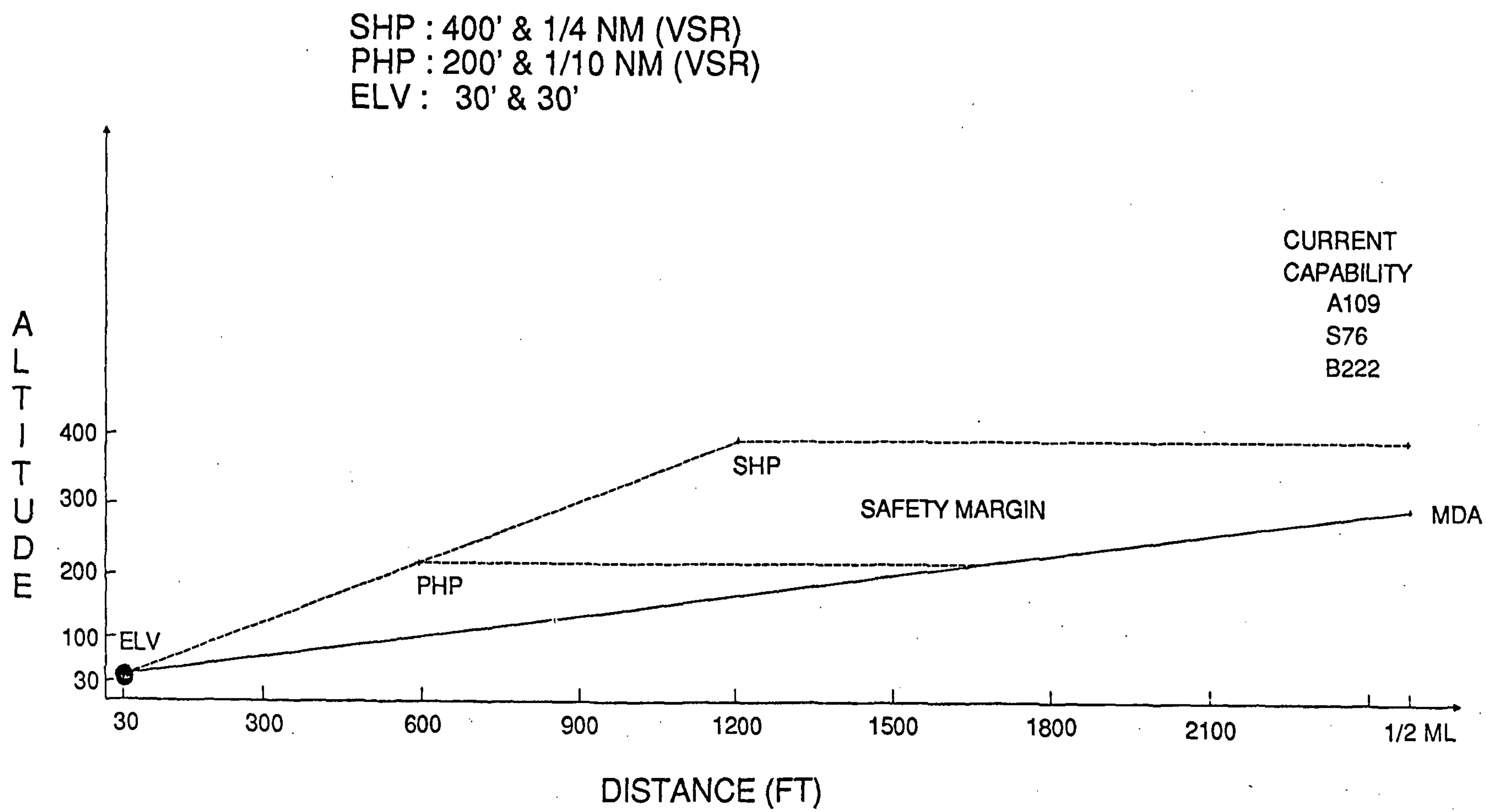
TARGET POINT VARIES WITH DEGREE OF AUTOMATION

1. MDA = MINIMUM DESCENT ALTITUDE FOR MANUALLY FLOWN DVC APPROACH (20-30 KTS GROUND SPEED IN TRIM, NO PITCH RATE, NO ACCEL RATE)

2. SHP = SHORT HOVER POINT (AUTOMATIC LEVEL OFF REQUIRED, CONSTANT DECELERATION (6 KTS/SEC) TO HOVER

3. PHP = PRECISION HOVER POINT (FULLY COUPLED, CONSTANT DECELERATION APPROACH TO AUTO HOVER)

NOTE: 2 & 3 REQUIRE "UNATTENDED PERSISTENCY"


SHP : 400' & 1/4 NM (VSR)
PHP : 200' & 1/10 NM (VSR)
ELV : 30' & 30'
CURRENT
CAPABILITY
A109
S76
B222
ALTITUDE
400
300
200
100
30
ELV
PHP
SHP
SAFETY MARGIN
MDA
30
300
600
900
1200
1500
1800
2100
1/2 ML
DISTANCE (FT)

EXTREME LOW VISIBILITY APPROACH CONCEPTS

BY

DAVID L. GREEN

AUGUST 1987

The following definitions are provided to assist in describing the zero/zero operational approach concept:

CDP - Critical Decision Point: Minimum speed, aircraft certified for zero/zero.

AVC - Augmented Visual Contact: All equipment is operable and obstacle clearance and navigation to the landing site are assured via unaided eye or augmented visual means.

SVR - Slant Visual Range of the unaided eye or augmented visual contact.

VCP - Visual Contact Point: Criteria for visual (contact) landing are met, or missed approach is initiated.

CVR - Contact Visual Range: Visual range of the unaided eye.

Flare Line - at the Flare Line the pilot will initiate a deceleration flare to arrive at a ground speed of 0 to 10 knots.

Basically a precision approach can be flown to a 200 foot ceiling and 2200' foot slant range depending on glideslope anlge. Generally, it is assumed that to achieve lower minima at a heliport the helicopter must decelerate to range rates below 40 knots. Additionally, the heliport must be aquired visually (either aided or unaided) to continue the approach beyond the visual contact point minimums. If visual contact is not achieved a missed approach is initiated.

Two "classes" of operators are envisioned:

Category H1 Operators - These operators must meet requirements established for the AVC. The CDP is about 2200 feet from touchdown point for an approach speed of 40 knots.

Category H2 Operators - These operators will fly an established speed schedule (not to exceed values) with at least the following slant visual range "gates":

2200 Feet	40 Knots
1200 Feet	30 Knots
800 Feet	20 Knots
400 Feet	0-10 Knots

If visual or electronically aided visual contact is not made at the AVC point, a missed approach is initiated. Similarily, if visual references suitable for landing are not established at the VCP point, a missed approach is performed.

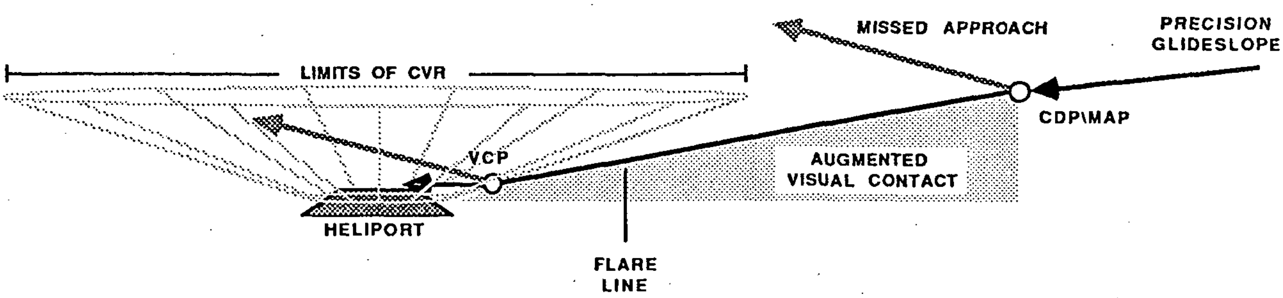


Figure 1 Zero/Zero Approach Concept

The precise location of the AVC and VCP require additional analysis for various helicopter and electro-optical system combinations. Ultimately, TERPs flight tests are required to establish precise minima, practical airspace requirements and minimum equipment for the operation.

APPLYING TODAY'S CONCEPTS

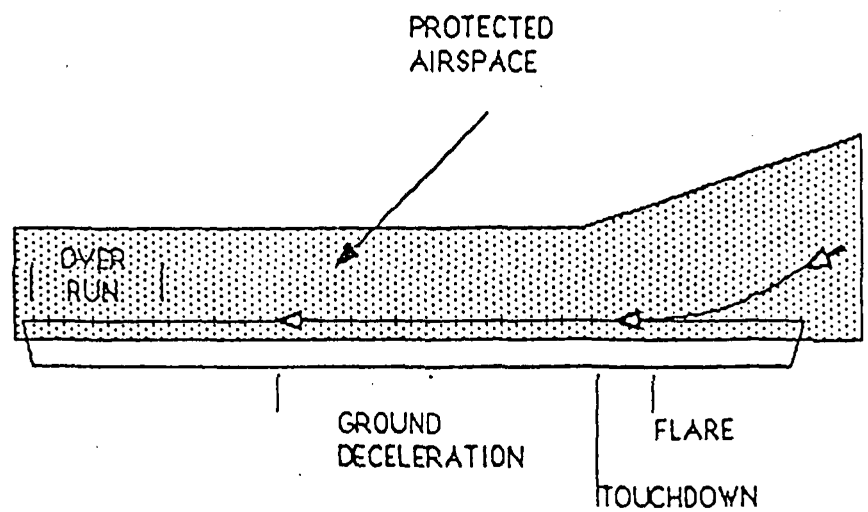
PROCEDURES,

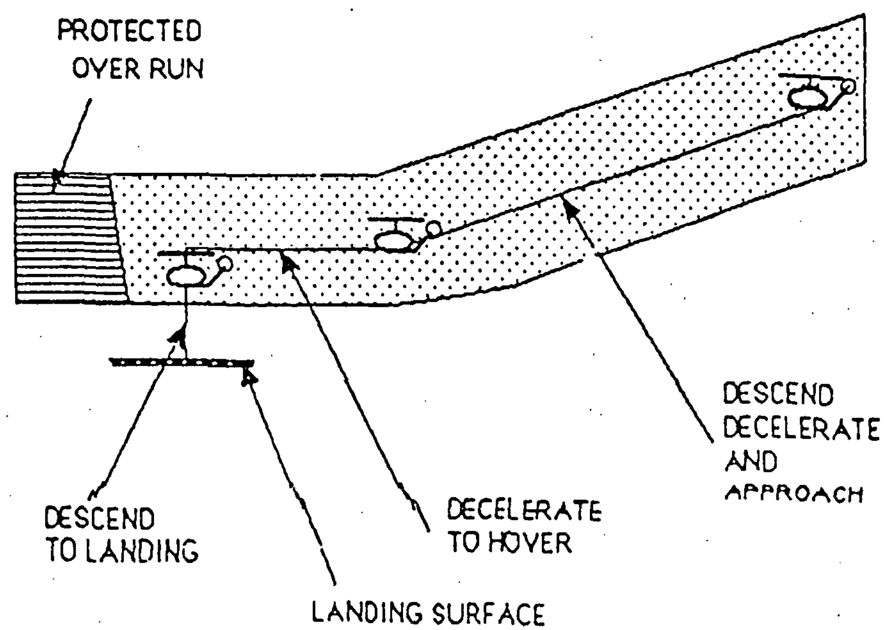
AIRSPACE CRITERIA

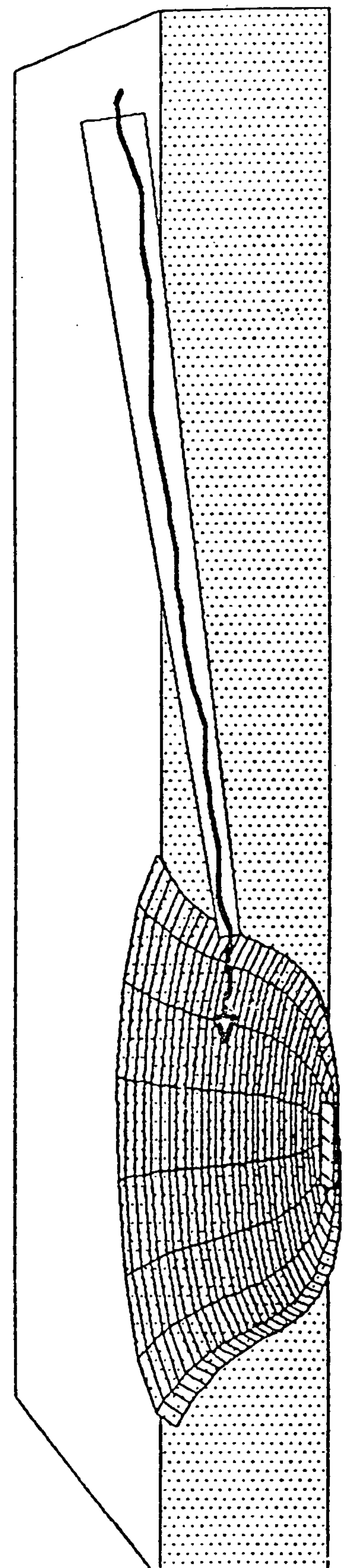
1. HOW DO TODAY'S PROCEDURES/AIRSPACE CONCEPTS APPLY TO OUR OBJECTIVES?

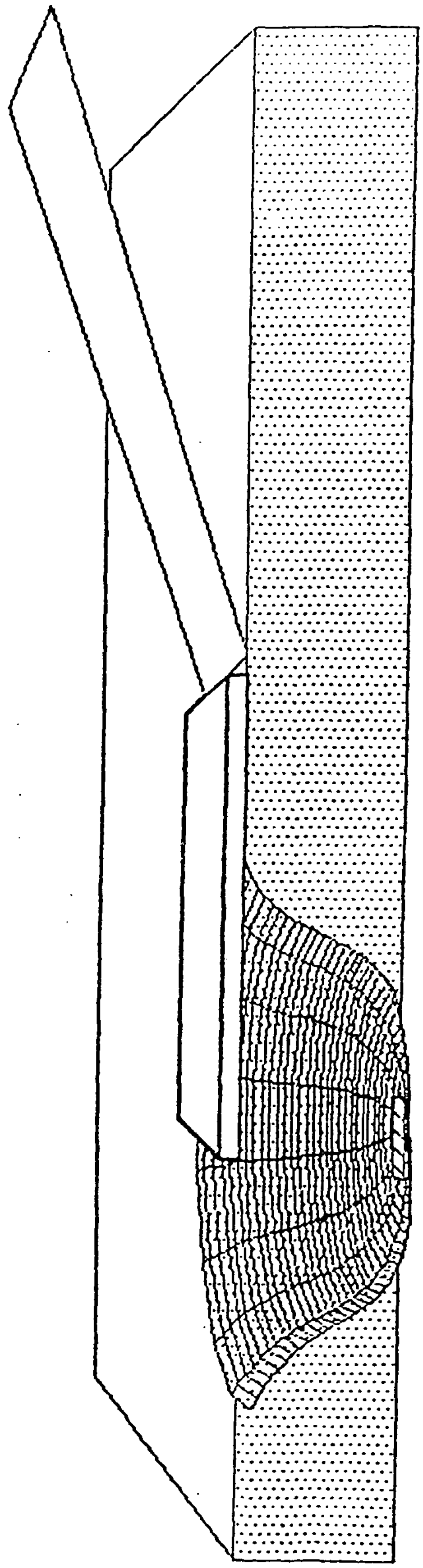
2. WHAT LOGIC TRAIL LEADS TO VARIOUS OPTIONS?

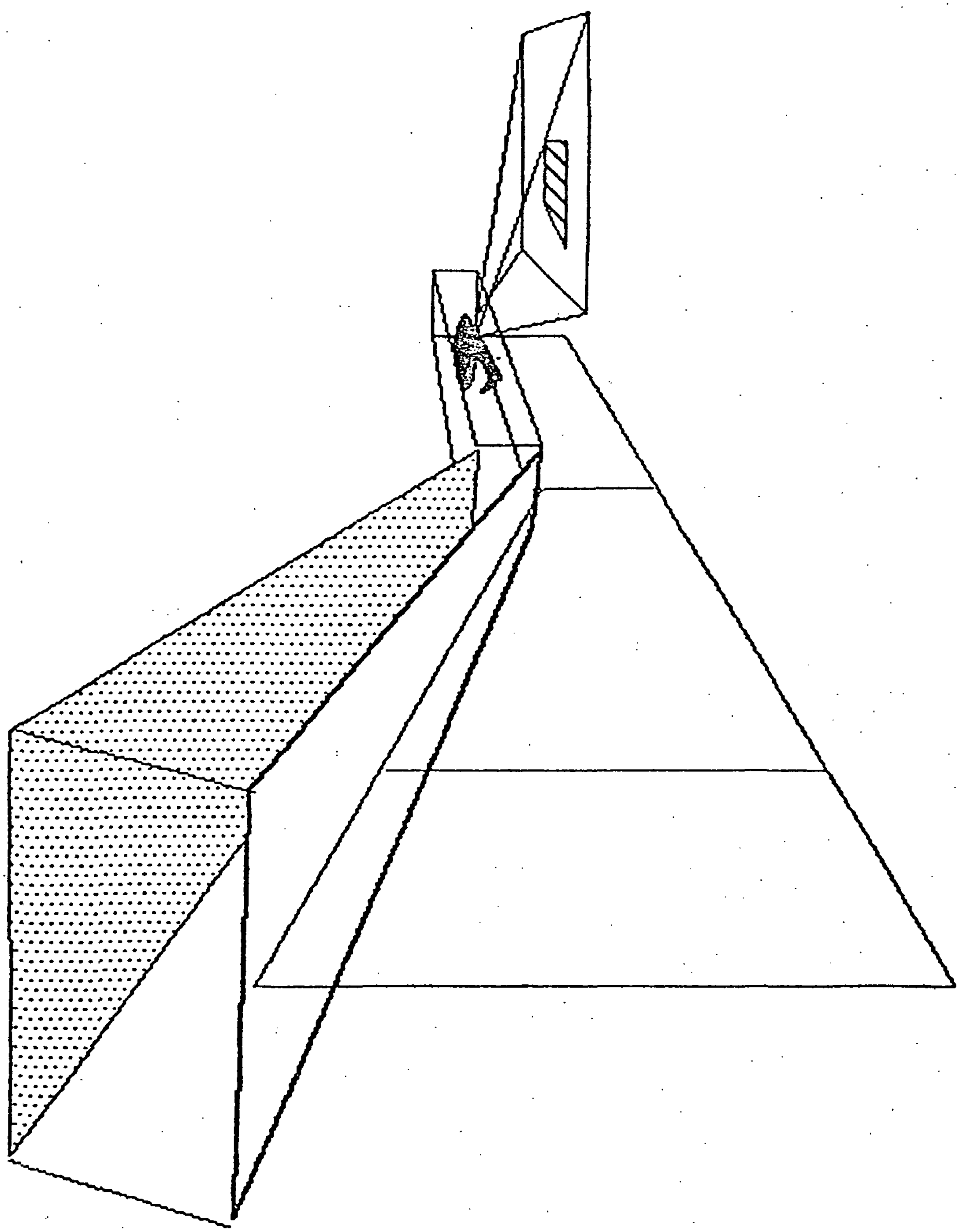
3. WHAT IS THE COMMON TRACK TO CERTIFICATION

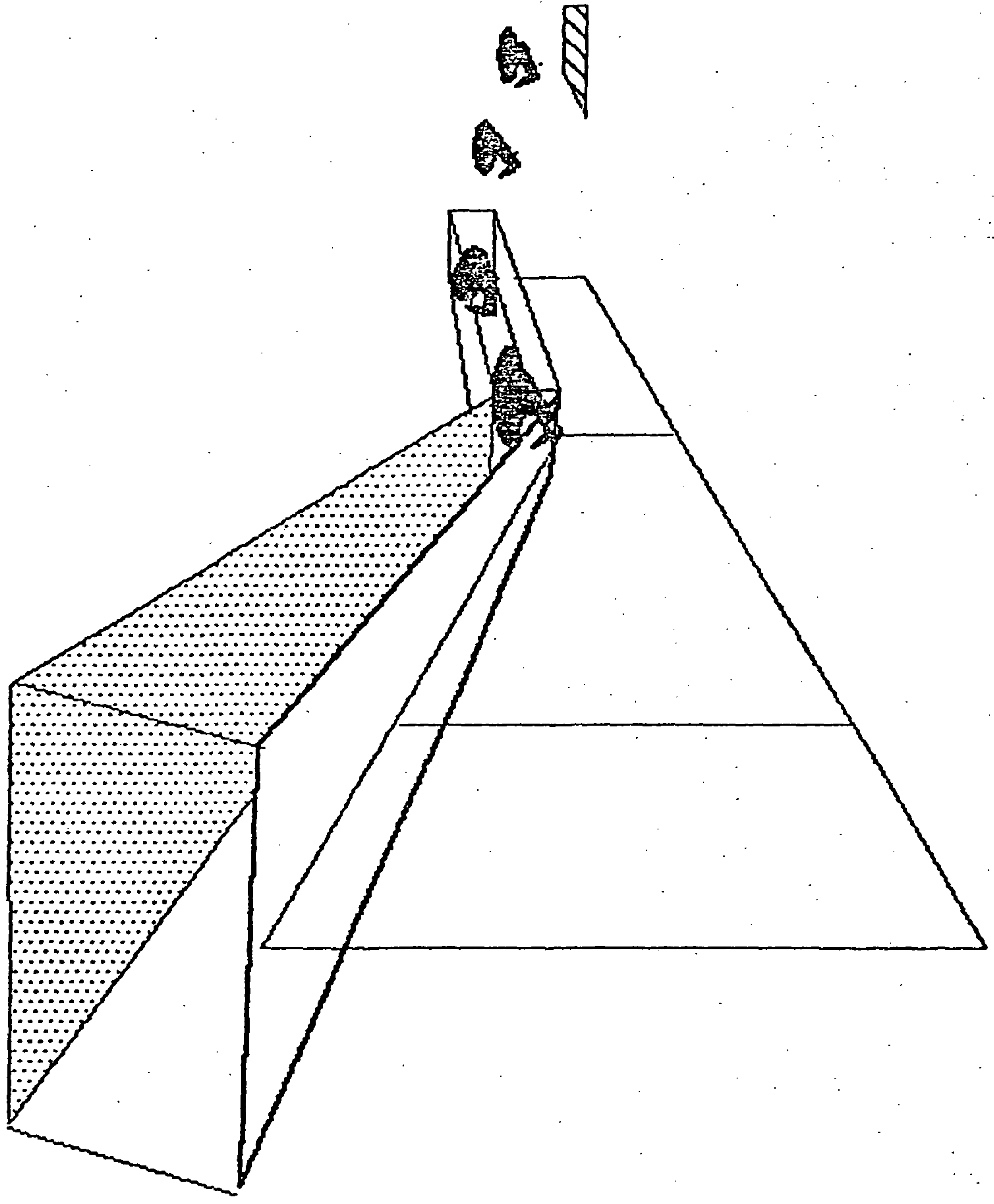

PROTECTED
AIRSPACE
OVER
RUN
GROUND
DECELERATION
FLARE
TOUCHDOWN

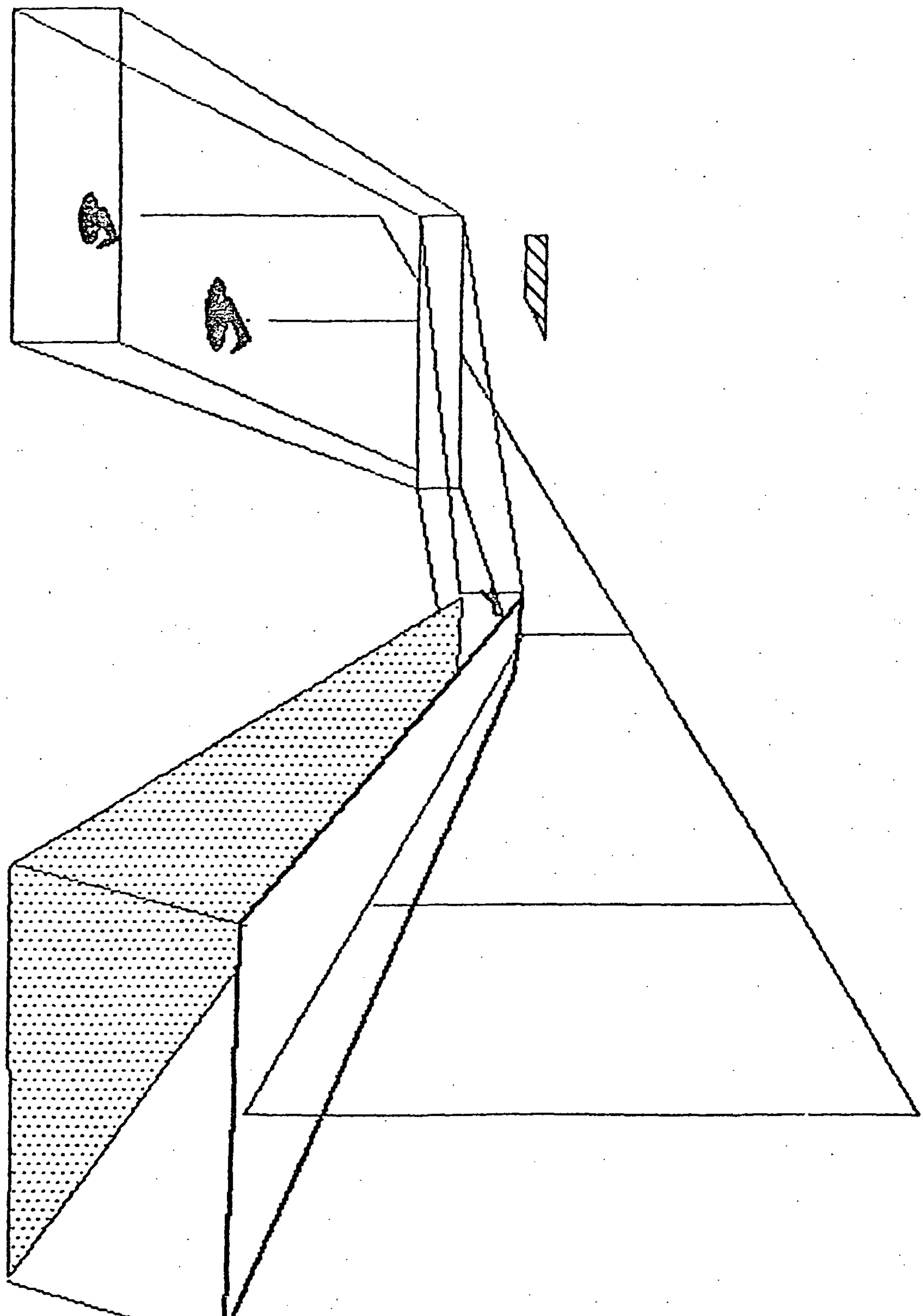

PROTECTED
OVER RUN
DESCEND
TO LANDING
LANDING SURFACE
DECELERATE
TO HOVER
DESCEND
DECELERATE
AND
APPROACH

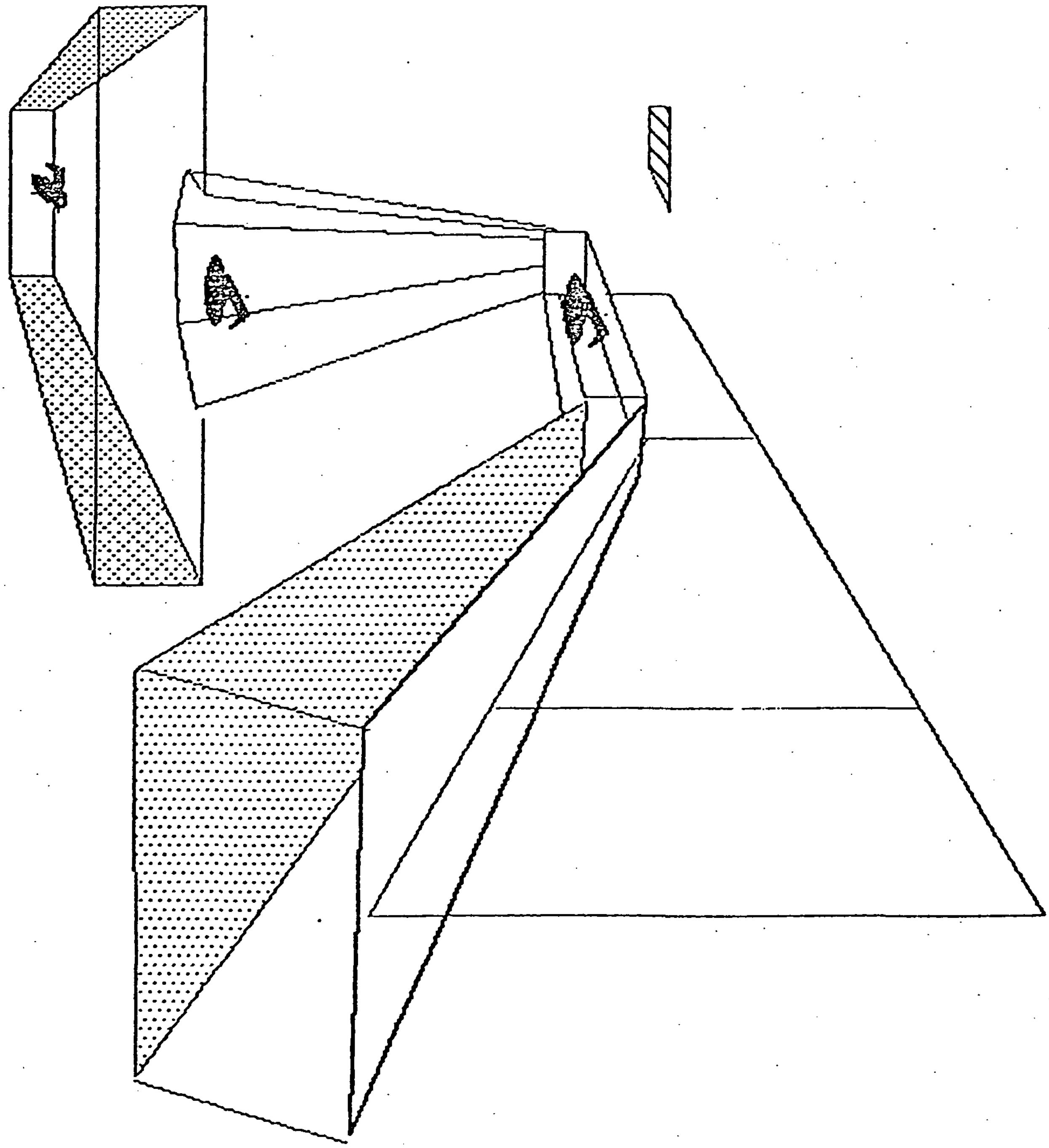












ELECTRONIC ENHANCEMENTS TO ACCOMPLISH ZERO/ZERO

BY

ERIC H. BOLZ

4.0 Electronic Enhancements to Accomplish Zero/Zero

There have been significant developments in many different technologies over the past several years which bear directly on the Extremely Low Visibility Instrument Rotorcraft Approach (ELVIRA) problem. These developments have been driven to some extent by national defense efforts. However, in general, they are the result of developments in many unrelated areas, both within and outside of the aerospace industry. In this section these technologies are examined in a manner organized by basic functional requirements (i.e. Obstruction Detection and Avoidance, Navigation and Guidance, Approach and Landing Systems).

4.1 Obstruction Detection and Avoidance

In relation to the ELVIRA problem, the obstructions of primary interest are:

- Terrain features and man-made obstacles
- Wires and cables
- Other aircraft

These various features exhibit different forms and characteristics which respond to the technologies available in different ways. The suitability of the technologies is also strongly influenced by the low-visibility environment, which is the result of one or more of the following factors:

- Darkness
- Fog
- Precipitation

The technology development areas reviewed below are examined from the viewpoint of the obstruction types which must be sensed, and the factors limiting visibility.

4.1.1 Low Light Level Television (LLLTV)

The LLLTV concept is based on image intensification technology (photomultiplier tubes) which detect and amplify extremely faint light sources. These have been developed primarily for military objectives and are designed to operate in the deep visible red or near infra-red spectrum. This matches the spectrum of star light, which peaks primarily in the near infra-red, and also attempts to avoid contamination from on-board light sources. This technology, exemplified in the Honeywell Integrated Night Vision System and the McDonnell Douglas Mast Mounted Site, is highly successful in providing TV-like imagery at night in good visibility with available starlight. Its usefulness diminishes as cloud cover, fog or precipitation is encountered. Its usefulness is strongly influenced by the size and reflectivity of an object. Thus some terrain features and small objects like wires may be obscured. Buildings, vehicles and aircraft would be visible.

4.1.2 Forward-Looking Infra-Red (FLIR)

The FLIR concept utilizes the ability of a cryogenic detector to sense radiation in the infrared spectrum. Fabricated with rotating mirrors, it produces an image analogous to television, but with quite different characteristics. The resulting image is basically a "heat picture" which is useful under day or night conditions, and in the presence of some fog cover and moderate precipitation. It is extremely useful in law enforcement and search and rescue applications, since it can display a warm object against a cool background even in underbrush. Because it is based on the latent heat emitted by an object, it will only reveal certain terrain features (in particular roads and man-made objects), vehicles and other aircraft. It is essentially useless against support cables and telephone wires, but brightly displays high-power wires.

4.1.3 LASER Detection

LASER-based systems are widely used in the military for purposes of range measurement and for target designation. They are based upon a steerable laser to be pointed at the region of interest, and optics and/or detectors to perform the range-finding function or to track the designated target. Without cooperative equipment at the landing site (reflectors, etc), they are not very useful to the ELVIRA environment. Also, they rapidly lose their usefulness in fog and precipitation.

4.1.4 Millimeter Radar

Millimeter radar systems are true radars which typically operate in the two (2) to four (4) millimeter band. The usage of such short wavelengths enables high resolution detection of small targets without requiring large antennas. The major disadvantages of such high frequencies are the relatively high attenuation rates of the atmosphere, fog and rain, and the relatively high expense of transmitting, receiving and processing these signals. Operation at these frequencies (75 GHz to 115 GHz) avoids a significant atmospheric attenuation peak at 60 GHz, while minimizing the attenuation due to fog and, to some extent, rain. The resulting systems are useful in most weather conditions over a limited range (1000 m), and provide identification of terrain features, many wires and cables, buildings, ships, rigs and masts. Resolutions on the order of 5m (range) and 1 degree (azimuth and elevation) may be attained. The resulting display can be two-dimensional plan-view with range depicted by grey scale or color graduations, as opposed to ordinary radars which display a map view (azimuth by range) of terrain without elevation information.

4.1.5 Evaluation of Alternatives

Two primary functions are neccesary to serve the needs of rotorcraft instrument approaches: prevention of collision with terrain and other objects, and guidance (laterally and vertically) through conduct of the instrument approach. The collision prevention function is needed even in clear day and night time conditions (many wire strikes occur in clear weather). The guidance function is needed mostly at night and in low visibility conditions. Since each of the above-mentioned sensors has limitations, some may not provide enough benefit to be useful in the ELVIRA environment, while others must be used in combinations to achieve operational success.

The ability of LLLTV to be useful for ELVIRA approaches is quite limited, since it is non-functional in fog, and has limited functionality in rain and overcast conditions, since it depends largely on starlight for illumination. It is very useful in clear night conditions for approach guidance and obstruction avoidance, although it gives no specific obstruction range/elevation descrimination other than that which may be interpreted from relative motion on the television-like display.

FLIR overcomes some of the problems inherent in LLLTV, but introduces a new set of limitations. FLIR is unaffected by overcast, or even the degree of light or darkness. The image, however, totally depends on the heat emitted by various objects in view, which means that non-power carrying wires and cables may be nearly invisible (while power lines show-up brightly). FLIR is less effected by intervening fog an precipitation, but still has a limited reliable range in low visibility conditions. Display resolution is also lower than LLLTV. The display is television-like, which requires interpretation to discriminate the range/elevation of objects in view.

Laser detectors, with suitable optics, can be useful to target and find range to specific fixed objects, but are generally not useful for terrain avoidance. Their usefulness is also very limited by low visibility atmospheric conditions.

The millimeter wave radar concept is much better suited to terrain avoidance and approach guidance, than the other techniques mentioned. It has good resolution, operates day or night, has a useful range even in low visibility conditions, and can provide direct elevation and range information on the display. It may be somewhat difficult to use as an approach guidance display since range is displayed as grey scales or color differences which results in sort of a "contour map" presentation of the real world. Millimeter radar could of course be configured in the standard terrain mapping mode (range versus azimuth) for guidance purposes, but this would be at the expense of its unique ability to display obstruction elevation for avoidance purposes. The range of millimeter radar is limited under low visibility conditions. This would require that it be used with a good transition NAVAID in order to initiate an instrument approach. Perhaps its best use will be as an approach path monitor during instrument approaches using area coverage navigation aids.

4.2 Navigation and Guidance

Rotorcraft operators are faced with navigation and guidance needs similar to fixed wing operators, except that they operate in regions and at landing sites which are out of the realm of the fixed wing operator.

Specific differences are: operations en route at very low altitudes, in rough terrain and in remote or offshore areas; and approaches and departures at heliports and unimproved sites in urban, rural and remote area. These differences put new requirements on navigation and guidance systems. For example, navigation coverage down to ground level must be available, and navigation service must be highly accurate. Instrument approach procedures must be implementable economically at low-density heliports and landing pads in urban, rural and remote area. And finally, the capability to define and fly safe instrument approach procedures on an ad hoc basis to support a variety of emergency and commercial operations is needed. The ELVIRA requirement takes this capability well beyond the common practice of establishing a point-in-space approach at or near MOCA. In this context approaches to low altitudes in the presence of obstacles and terrain would be conducted, resulting in stringent requirements on the navigation and guidance systems.

4.2.1 Inertial Navigation Systems

Traditional inertial platforms using electromechanical gyroscopes offer the advantage of operating totally independent of external reference information, providing navigation information anywhere at any altitude, regardless of coverage available from conventional NAVAIDS. Inertial platforms are capable of precise autonomous alignment with geographic North when at rest prior to departure. However, in flight they accumulate drift as time passes, resulting in growing errors in position estimation. While these errors would become unacceptably large at the destination for transport aircraft without use of some form of updating from radio-navigation systems, they do not become nearly as large for the short, low speed operation typical of rotorcraft. However, they would still be too large (or unpredictable) for the requirements of terminal navigation and instrument approach.

Inertial systems are most successfully used in combination with other sources of navigation data, such as DME, Loran-C or GPS. If position updates are available continuously, the inertial data provides invaluable assistance when used to filter the random errors from those updates. If update are available only occasionally, or only at the higher operating altitudes, the inertial system can fill in between navigation updates, and can even be used for terminal navigation and instrument approach where a precise update is available prior to conduct of the approach.

The technological developments that have recently occurred in the field of INS systems which are of greatest interest to rotorcraft operators mainly concern laser inertial sensors. These sensors are entirely solid state (involving no rotating components). They sense angular rotation by means of the doppler principal as applied to inherent laser light beams which traverse a closed course. Two counter-rotating beams form an interference pattern whose changes directly correspond to angular rotation in the plane of light path, and whose changes are easily instrumented to provide useful information. Three such sensors mounted orthogonally, in combination with three precision linear accelerometers mounted in like manner, form the basis of a useful inertial navigation system.

Due to the elimination of the high precision mechanical gyroscopes, and the fact that the laser sensors may be mounted in a "strap-down" configuration, rather than on a precision gimbaled platform, considerable cost savings and reliability improvements result. Development efforts by manufacturers have brought the accuracies of these systems up to nearly match their gyroscope-based predecessors. Drift rates of 0.8 nmi per hour are commonly advertised for laser inertial systems. Furthermore, laser sensors are much better suited to the higher shock, vibration and maneuver-severe environment of helicopter operations than are gyroscope-based systems.

4.2.2 Loran-C

Loran-C has long been considered a potential solution to the navigation requirements of helicopter operators. This is based upon the intrinsic characteristics of the Loran-C concept: relative stability of the navigation information provided, and coverage down to ground level anywhere within the coverage zone of a triad of Loran-C stations. Coverage over much of the United States has also been available for a long time. While the characteristics and technology of the Loran-C ground system have been relatively static (with the exception of replacement of tube-type transmitters with solid-state equipment, and improvements to inter-station time correlation control), the technology of the airborne equipment has evolved rapidly over the past ten years. The Loran-C signals themselves are very suitable for digital signal processing. The coordinate conversion problem requires digital computer implementation. The recent downward spiral in the cost of digital computing power has resulted in excess computational capability at reasonable cost. This excess capability has been harnessed to refine the quality of the navigation information through application of propagation correction factors, and ease the usage of the system through permanent storage of large quantities of navigation aid and fix coordinates, airport coordinates, etc.

In order to be useful as a terminal navigation and instrument approach aid, the FAA is implementing a program of local Loran-C monitor installations which will be used to assure the quality of the data utilized in instrument approach operations. Also, coverage-gap-filling station chains are being built in the central U.S.

4.2.3 Navstar GPS

The Global Positioning System being sponsored by the Department of Defense is based on a constellation of active satellite stations positioned around the world, several of which would be in view at any given time. Ranging information derived from each satellite is used to calculate position, velocity and precise time. Signals are available at any altitude, except as limited by obstructions and the horizon. Potential accuracy is very high (a few meters), while actual accuracy is controllable/limited by the military (absolute accuracies and repeatabilities on the order of 100m.). Actual accuracy in derived position is further limited by the users geometry relative to the available satellites.

GPS will undoubtedly be very useful for en route and terminal navigation. The potential as a highly accurate non-precision approach aid is high if accuracy and signal monitoring factors can be resolved. Also, signal coverage to ground level may be limited in adverse terrain by line of sight limitations. Otherwise, the adaptability of GPS to remote areas, non-instrumented and ad hoc landing zones should be quite high.

Both military efforts and civil avionics manufacturers have been developing the receiver technology necessary to utilize GPS. The receiver cost/performance tradeoff is an issue regarding helicopter operators, but shows promise for solution as the cost of electronics systems drops.

4.2.4 Other Navigation Methods

Besides the conventional aircraft navigation systems such as VOR and NDB, which have very significant coverage and accuracy limitations, other possibilities include VLF/Omega and scene matching. VLF and Omega are Very Low Frequency systems that have long been used for air navigation, since uninterrupted coverage is available world wide at all altitudes. Both systems offer very low accuracy and so are not suited to the en route, terminal and approach system requirements of helicopters. Advanced techniques such as scene matching, which has been widely used by the military (particularly for missile guidance), could be applied to helicopter operations. The advantages are that the sensor required (optical, IR, radar or laser-illumination) is totally self-contained, requiring no cooperation ground elements. Accuracy is only limited by the resolution of the sensor used. Coverage and availability is limited by atmospheric absorption in the frequency bands used (therefore leaving radar as the primary candidate for helicopter IFR applications). The major operational limitation of scene matching is the fact that calibrated images of any and all routes and destinations flown must be available on-board. This very seriously impacts cost and limits the operational flexibility available.

4.2.5 Evaluation of Alternatives

In this section the relative merits of Inertial, Loran-C and GPS will be discussed relative to their role as en route and terminal navigation aids and approach transition aids. Their potential usage as precision approach systems will be covered in Section 4.3.3.

All three systems have much in common relative to the operational needs of rotorcraft in IFR conditions. All three provide useful coverage throughout CONUS and offshore areas (when the Loran-C Mid-Continent chain is operational and when the GPS constellation is in place). All three allow autonomous navigation in that no cooperative stations need be implemented to support a given route or destination. All three should provide coverage or availability down to any reasonable en route or terminal altitude. While inertial systems require periodic updating, crosschecking against conventional NAVAIDS is good procedure when using any area coverage system such as Loran-C or GPS. Monitor stations are being implemented for Loran-C. A monitoring scheme must also be implemented for GPS for civil use. However, the importance of these monitors regards the use of these systems for instrument approaches, not en route/terminal navigation.

In the en route and terminal environments, the major system tradeoff is cost. Laser Inertial systems with their precision mechanical manufacturing processes, and GPS receivers with highly complex receiving and tracking hardware, cannot compete on a cost, weight and ease-of-use basis with the much simpler Loran-C system.

4.3. Landing Systems

The problem of providing safe and reliable rotorcraft landing guidance during IFR conditions at helipads, remote sites and unprepared landing sites is one of the greatest challenges in the ELVIRA problem. The alternative technologies available to potentially solve this problem are presented here, categorized by their basic mode of operation (Locally-sited systems, area-coverage systems, and independently-derived systems).

4.3.1 Locally-Sited Approach and Landing Systems

These are the systems which require usage of some cooperative piece of equipment sited at, or near, the desired landing site. While that equipment is most commonly permanently sited, it would not necessarily be permanent. Nor does it need to be powered or electrically active (as in passive radar reflectors). The conventional Instrument Landing System (full ILS and Localizer only), the Microwave Landing Systems (MLS), Non-directional Beacons (NDB), and VHF Omnidirectional Range (VOR) all fit in this category, Airborne Radar Approach (ARA) fits in this category if ground beacons or reflectors are used. Beacon Landing System (BLS) and Portable Approach Guidance (PTAG) also use cooperative ground equipment. Each of these systems has potential application to helipads and remote, fixed landing sites. The possibility of using any of these systems at ad hoc landing sites is limited by the requirement for ease of portability and setup and siting at the desired location. Tactical MLS and PTAG may be the only system with such potential.

The Microwave Landing System is the first Federally sponsored precision landing system with the technology needed for potential application to helicopter landing sites. Due to the high frequencies and scanning technique utilized, the equipment can be installed at or near heliports and helipads. The availability of up to $\pm$ 60 degree scan at airports (in azimuth) means that instrument approaches to many helipads and landing zones may be implemented. This contrasts with the older VLF technology of ILS, which requires extensive site preparation over large areas (inappropriate to heliport application), and which provide centerline guidance only.

The remaining systems (VOR, NDB, ARA, BLS, and PTAG) offer varying levels of suitability to helicopter operations. Only PTAG offers full precision (glide path and azimuth) guidance. It is lightweight, easy to install and site, requires little prepared terrain, and has a cost range which falls between the cost of MLS and low cost methods, such as NDB and ARA beacons. It can be set up quickly and so has some potential application in the area of emergency and some other ad hoc landing requirements.

Airborne Radar Approach (ARA) has proven in operation to be very useful for conducting approaches to offshore oil platforms. Due to the difficulty in discerning desired targets from surrounding terrain, ARA has not proven useful in the onshore remote environment. Methods to aid target identification are required, such as reflectors and beacons. Standard corner reflectors do provide strong returns, but are still difficult to discriminate from surrounding terrain. Tests, under NASA sponsorship, of an advanced dihedral reflector concept (which requires modified radar receiver processing) showed promising results in that reflectors could be discriminated from the surrounding terrain. In any case, reflectors present set up and maintenance problems even though they required no power for operation. They tend to be large, must be very securely mounted, and their effectiveness can be temporarily defeated by snow and ice.

Another means of enhancing target identification is through the use of transponder beacons: They are remarkably inexpensive and easily sited in comparison to other electronic approach aids. Power, limited maintenance and protection from the elements are required, although many small, durable, battery-powered beacons are in successful use. The beacon identification function is now a readily available option on many weather radar models. Enhancements to the beacon concept, such as the Beacon Landing System (BLS), utilize electronically-linked sets of beacons surveyed onto a landing area. Through pulse time coordination, these beacons can provide approach guidance command information when processed by a specially modified weather radar system.

VOR is widely used as a non-precision approach aid. However, cost and site preparation requirements eliminate it as a potential landing aid for general use in remote areas and offshore. Non-directional Beacons (NDB), on the other hand, are useful for approach guidance are low in cost and are easily sited (although they require power, maintenance and protection from the elements). Private (non-federal) NDBs have become a popular NAVAID in the offshore environment. Their widespread usage however presents frequency protection problems which are as yet unresolved.

A problem common the the presently-implemented techniques (including ARA, ARA with beacon, VOR and NDB) is that none provide for precision approach guidance. In fact, of these only VOR provides position course guidance. The resulting approach procedures are better than none at all, but are very limited in that high approach minimums are required. Of all the localy-sited systems reviewed, the only real candidates for application to the ELVIRA problem are the Federally-sponsored MLS and the privately-developed PTAG system.

4.3.2 Area Coverage Approach and Landing Systems

In general, area coverage landing systems are simply extensions of existing (or planned) area coverage navigation systems. In extending these system to approach aid status, new requirements (which may not have been part of the original system design) must be met. Potential area coverage systems include VOR/DME RNAV, Loran-C and GPS. Another potential system, VLF/OMEGA, is much too inaccurate to support approaches in a variable terrain environment.

VOR/DME RNAV offers promise as an approach aid in many areas, typically high density areas where NAVAIDS abound. Due, however, to line-of-site limitations, and guidance errors which grow with distance from the VORTAC station, usage of VOR/DME RNAV is severely limited outside of high density areas, and is prohibitive in most terrain and remote/offshore environments. Due to a lack of general availability, it is not suitable as an area coverage instrument approach aid.

Both Loran-C and GPS have been undergoing a period of technical innovation over the last decade. Regarding Loran-C, the innovation has been primarily in receiver technology rather than in ground chain technology. GPS, being a new system, is an expression of advanced technology on all fronts: ground control system, satellite system, and receiver system. Improved signal processing and propagation modeling, along with a Federal program to implement regional monitoring networks, are aimed at demonstrating that Loran-C has the accuracy, reliability and availability necessary to be widely used as an approach and landing aid in all regions of helicopter operations. While structured as a two-dimensional navigation system (and therefore non-precision landing aid), FAA tests have demonstrated the performance of Loran-C coupled with altimetry to provide computed glide path guidance on approach, opening up the additional potential of Loran-C vertical navigation (VNAV), a non-precision enhancement, implimentable without requiring additional ground equipment.

Given the capabilities of Loran-C and GPS for making nearly universal availability of a quality signal in space, instrument approaches cannot be implemented under present criteria without an extensive site analysis and procedure design process. Though the FAA has developed extensive procedure design automation tools, the process requires a significant amount of labor and lead time. If area coverage system performance has already been verified in a given region, this process essentially amounts to an analysis of terrain and obstructions, and development of relevant approach plate information. A flight check is also required before commissioning the procedure. The objective of implementing instrument approach procedures on an as-needed basis to ad hoc landing points is not possible with area coverage approach aids alone.

4.3.3 Independently-Derived Approach and Landing Systems

These are instrument approach techniques that either utilize navigation information from a self-contained reference or information derived from on-board terrain and obstruction sensors. The self-contained references include INS and radar scene mapping. As previously discussed, both have limitations regarding instrument approach procedures. INS accumulates significant errors unless currently updated, and thus serves only as an extension or filter technique to radio navigation aids. Scene matching requires development of an extremely extensive data base which must be accessable when needed, and does not apply to the ad hoc landing point problem.

On-board terrain and obstruction sensors were discussed earlier, and include IR sensors, Low Light Level TV, standard radar and millimeter radar. IR and LLLTV sensors do not apply in the low visibility situations of interest here. Standard radar provides only a ground mapping function, and does not warn of obstructions when no elevation information is available. It has the potential, however, of being a very useful tool for verifying proper execution of an area coverage system instrument approach procedure. In this application standard radar imagery at a predetermined point on the approach could be printed as a part of the chart, for use by the pilot as an independent verification of system performance.

Millimeter radar systems, when configured to display azimuth, elevation and (by grey scale or color gradations) range, can be extremely useful tools during an instrument approach. However, it is difficult to imagine that they could be utilized alone as an approach aid, since it is difficult to identify the landing zone on the image, and because of their very limited range (1 km) under precipitation and fog conditions. Millimeter radar could, however, serve two critical operational functions which could significantly enhance implementation of ELVIRA procedures:

- Verification of system performance during area coverage landing aid approach procedures, and prevention of inadvertent deviations into areas of terrain or obstructions.

- As the primary terrain and obstruction separation system during area coverage approaches to ad hoc landing sites.

Naturally, eventual utilization of millimeter wave radar in either of these roles would first require extensive testing and standards development. However, the combination of a precise area coverage navigation system with millimeter wave radar for separation assurance could provide a very real solution to virtually all of the ELVIRA procedural objectives.

NEW CONCEPTS, STATUS, UNRESOLVED PROBLEMS, ETC.

BY

RICHARD J. ADAMS

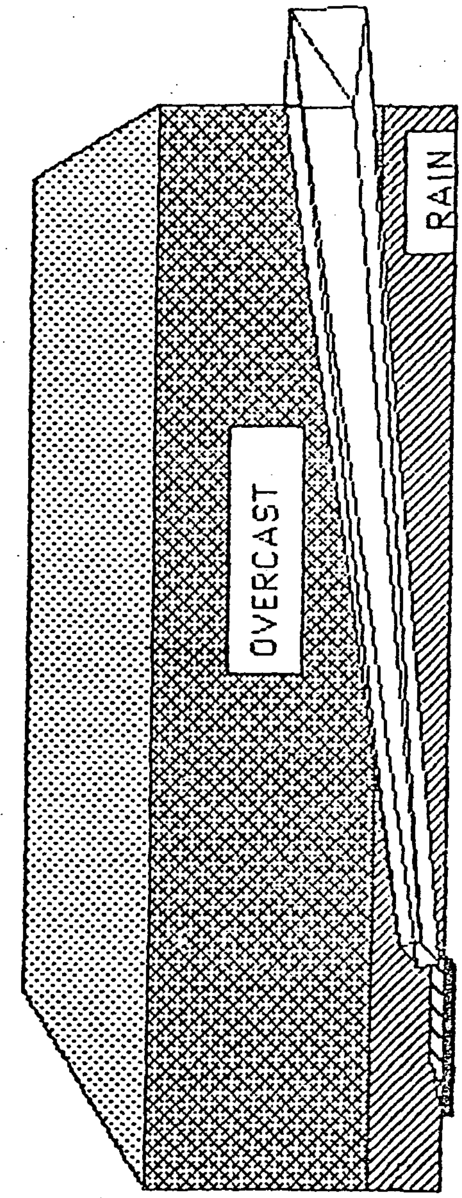
AUGUST 1987

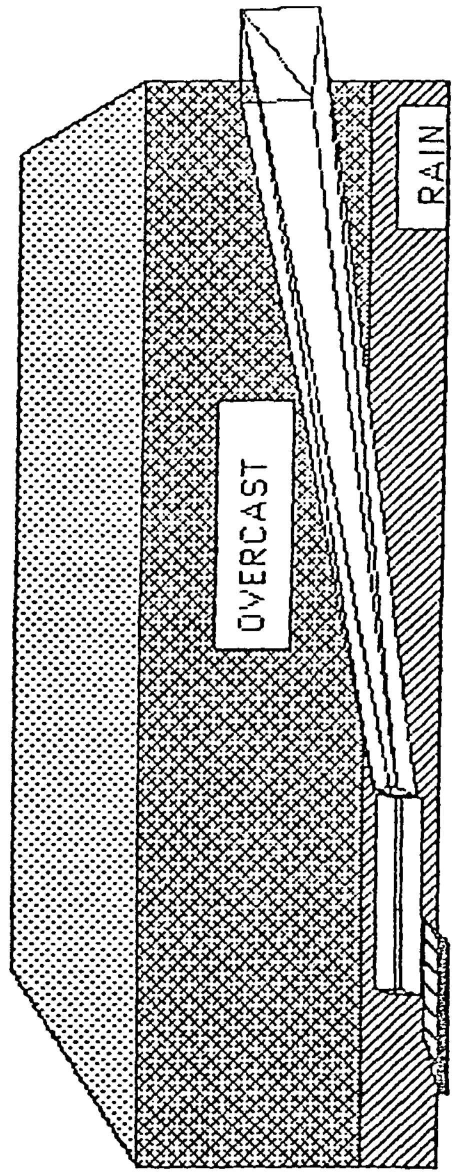
A CONTROLLED DESCENT & DECELERATION

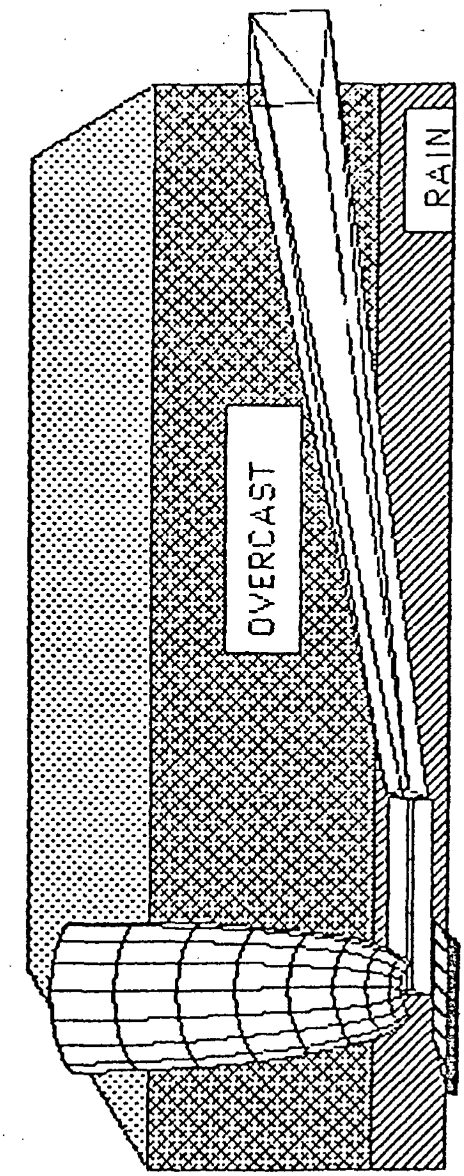
A. IN PROTECTED AIRSPACE

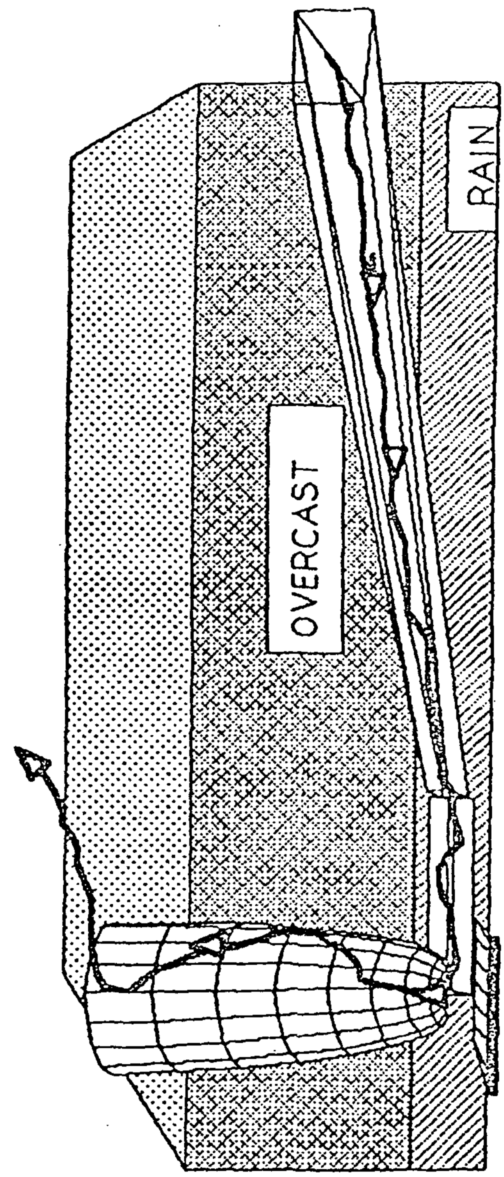
B. PRECISION APPROACH GUIDANCE

C. NON PRECISION MISSED APPROACH


RAIN
OVERCAST


OVERCAST
RAIN


OVERCAST
RAIN


RAIN
OVERCAST

UNRESOLVED PROBLEMS

1. DIMENSIONS & LIMITS OF PROTECTED AIRSPACE TO BE DETERMINED:
   A. ANALYTICALLY = F(HELICOPTER DYNAMICS)
   B. EMPIRICALLY = FAATC TESTING
2. ACHIEVABILITY OF "UNATTENDED PERSISTENCY"
3. GUIDANCE SYSTEM RELIABILITY & REDUNDANCY
4. OPERATIONAL MINIMUMS VS NUMBER & SYSTEMS
5. REDUNDANCY OF DISPLAYS & CONTROLS
6. SLANT VISUAL RANGE REQUIREMENTS
7. GROUND SYSTEM MARKING/LIGHTING REQUIREMENTS
8. OVERRUN AIRSPACE REQUIREMENTS
9. ON BOARD ELECTRO-OPTICAL SYSTEM REQUIREMENTS

BIBLIOGRAPHY

BY

ERIC H. BOLZ

PRECEDING PAGE BLANK NOT FILMED

6.0 BIBLIOGRAPHY

6.1 FAA Performed or Sponsored Documents

1. 86N27273, "Technical Support of the Wall Street/Battery Park City Heliport MLS (Microwave Landing System) Project," Billman, B.R., Enias, J.H., Webb, M., FAATC, DOT/FAA/CT- TN85/58, 1985.

2. "Helicopter Zero/Zero Landing Systems Certification Issues," Schlickenmaier, H., FAA, 1985.

3. "Evaluation of Sikorsky S-76A 24 Missed Approach Profiles Following Precision MLS Approaches to a Helipad at 40 KIAS (Knots Indicated Airspeed)," Webb, M.M. (Technical Note, Aug 85-Jul 86).

4. 84A12450, "Helicopter GPS Navigation," Till, D.R., (IEEE) Plans 1982: Position Location and Navigation Symposium - p. 206--213, 1982.

5. 83N12068, "Application of the Microwave Landing System to Helicopter Operations," McConkey, E.D., McKinley, J.B., Ace, R.E., FAA (SCT), FAA-RD-82-40, 1982.

6. 83N12061, "Instrument Approach Aids for Helicopters," McConkey, E. D., Ace, R.E., FAA (SCT), FAA-RD-82-6, 1982.

7. 83N36011, "Advisory Circular (AC-29-2) Certification of Transport Category Rotorcraft", FAA, 1983.

8. "Precision IMC Approaches to Heliports Using Collocated MLS - Instrument Meteorological Conditions," Shollenberger, S., Enias, J.H., Demko, P.S., FAATC, Army, AHS 41st Annual Forum, May 15, 1985, p. 137-143.

9. 81A41764, "Analysis of Helicopter Operations and the Use of MLS in the Offshore Environment," Loh, R., FAA, Navigation v.27 #3, p. 226-236, Fall, 1980.

10. 80N25519, "Flight Evaluation of a Radar Cursor Technique", Perez, J., FAA NAFEC, FAA-RD-80-18, FAA-NA-80-8, 1980.

11. 80N19054, "Airborne Radar Approach System Flight Test Experiment", King, L.D., Adams, R.J., FAA (SCT), FAA-RD-79-99, 1979.

12. 80N28331, "Flight Evaluation of a Radar Cursor Technique as an Aid to Airborne Radar Approaches," Perez, J., FAATC, FAA-NA-80-8, 1980.

13. 73N13261, "Flight Test and Evaluation of Heliport Lighting for IFR," Paprocki, T.H., FAA NAFEC, FAA-NA-72-89, 1972.

14. 69N26358, "Flight Test and Evaluation of Heliport Lighting for VFR," Paprocki, T.H., Sulzer, R.L., FAA NAFEC, FAA-RD-68-61, 1969.

15. 69N13573, "Evaluation of Helicopter Steep Slope GCA Operations," Fleming, R.S., Hunting, A.W., FAA, AD676528, 1968.

6.2 NASA Performed or Sponsored Documents

1. 86A26509, "Civil Helicopter Flight Operations Using Differential GPS," Edwards, F.G., Loomis, P.V.W., NASA Ames (Tau Corp), ION (Institue of Navigation) Proceedings for 41st Annual Meeting, 1985, p. 54-63.

2. 86N28931, "Evaluation of the Usefulness of Various Simulation Technology Options for TERPS Enhancement," Phatak, A.V., Sorenson, J.A., NASA Ames (Tau Corp.), NASA CR-177408, 1986.

3. 86N31551, "Simulation Evaluation of Display/FLIR Concepts for Low-Altitude, Terrain-Following Helicopter Operations," Swenson, H.N., Paulck, C.H., Jr., Kilmer, R.L., Kilmer, F.G., NASA Ames (IBM Federal Systems Div.), NASA TM-86779, 1985.

4. 86A10945, "Simulation Evaluation of Display/FLIR Concepts for Low-Altitude, Terrain-Following Helicopter Operations," Swenson, H.N., Paulck, C.H., Jr., Kilmer, R.L., Kilmer, F.G., NASA Ames (IBM Federal Systems Div.), AIAA, AHS & ASEE Aircraft Design Systems and Operations Meeting, 14 October 85, AIAA-85-3093.

5. 86N29811, "Feasibility Study for Ergonomic Analysis and Design of Future Helicopter Cockpit Systems", Hawkins, H.L., NASA Ames (Bio-Dynamics R&D Corp.), NASA CR-176942, 1985.

6. 86A35622, "Directional Handling Qualities Requirements for Nap of the Earth (NOE) Tasks", Bivens, C.C., NASA Ames, USAIAL, AHS 41st Annual Forum, May 19, 1985, p. 297-314.

7. 86A26438, "Helicopter Flight Test Demonstration of Differential GPS", Denaro, R.P., Beser, J., NASA Ames (Tau Corp.), ION National Technical Meeting, Jan. 15, 1985, p. 116-121.

8. 85K10786, "Autonomous Flight and Remote Site Landing Guidance Research for Helicopters, Phase I," Denton, R.V., Mastafari, H. Beser, J., Denaro, R.P., NASA Ames (Tau Corp.), in progress.

9. 85K10009, "TERPS Operational Enhancement", Phatak, A.V., Sorenson, J.A., NASA Ames (AMA, Inc.), in progress.

10. 85N27843, "Investigation of Imaging and Flight Guidance Concepts for Rotorcraft Zero Visibility Approach and Landing," McKeown, W.L., NASA (Textron Bell), NASA CR-166571.

11. 85A31993, "NASA-FAA Helicopter Microwave Landing System Curved Path Flight Test," Swenson, H.N., Hamlin, J.R., Wilson, G.H., NASA Ames, Army, AHS Proceedings, 1984, p. 447-459.

12. 85N16821, "Development and Flight Test of a Helicopter Compact, Portable, Precision Landing System Concept," Bull, J.S., Clary, G.R., Davis, T.J., Chishalm, J.P., NASA Ames (Sierra Nevada Corp.), AGARD-CP-359, May 1984, pp. 29/1-29/8.

13. 85A43857, "Investigation of Outside Visual Cues Required for Low Speed and Hover," Hoh, R.H., NASA (STI), AIAA AFM Conference, 1985, August, AIAA Paper-85-1808.

14. 85N26691, "Navigation and Flight Director Guidance for the NASA/FAA Helicopter MLS Curved Approach Flight Test Program," Phatak, A.V., Lee, M.G., NASA Ames (Tau Corp.), NASA CR-177350, 1985.

15. 85A17858, "Application of Differential GPS to Civil Helicopter Terminal Guidance," Denaro, R.P., NASA Ames (Tau Corp.), AIAA 6th Digital Avionics Systems Conference, Dec. 3, 1984, AIAA Paper-84-2676.

16. 85A17857, "Digital Avionics and Flight Path Director Functions of the HH-60 Helicopter," Kilmer, F.G., et al, NASA Ames (IBM Federal Systems Division), AIAA 6th Digital Avionics Systems Conference, Dec. 3, 1984, AIAA084-2674.

17. 85A17823, "Aircraft Automatic Digital Flight Control System with Inversion of the Model in the Fee-Forward Path," Smith, G.A., Meyer, E., NASA Ames, AIAA 6th Digital Avionics Systems Conference, Dec. 3, 1984, AIAA Paper-84-2627.

18. 84N23617, "NASA-FAA Helicopter Microwave Landing System Curved Path Flight Test," Swenson, H.N., Hamlin, J.R., Wilson, G.W., NASA Ames, Army, NASA TM-85933, 1984.

19. 84N24566, "Development and Flight Test of a Helicopter Compact, Portable Precision Landing System Concept," Clary, G.R., Bull, J.S., Davis, T.J., Chishalm, J.P., NASA Ames (Sierra Nevada Corp.), NASA TM-85951, 1984.

20. 84N10041, "Development and Flight Test of an X-band Precision Approach Concept for Remote Area Rotorcraft Operations," Clary, G.R., Chishalm, J.P., NASA Ames (Sierra Nevada Corp.), NASA TM-84398, 1983, IEEE/AIAA 5th Digital Avionics Systems Conf., Oct. 31, 1983.

21. 84N16216, "A Helicopter Flight Investigation of Roll-Control Sensitivity, Damping and Cross Coupling in a Low Altitude Lateral Maneuvering Task," Corliss, L.D., Carico, D., NASA Ames, Army ARDC, NASA TM-84376, 1983.

22. 84A45576, "Automatic Helical Rotorcraft Descent and Landing Using a Microwave Landing System," McGee, L.A., Foster, J.D., Xenakis, G., NASA Ames, AIAA Atmospheric Flight Mechanics Conference, Aug. 19, 1981, AIAA Paper-81-1857, July 1984.

23. 84A46349, "Development and Flight Test of a Weather Radar Precision Approach Concept," Clary, G.R., Anderson, D.J., Chisholm, J.P., NASA Ames (Lear Fan and U. of Nevada), AHS 39th Annual Forum, May 9, 1983, AHS Proceedings, 1984, p. 240-246.

24. 84A43468, "The Design of a Model Following Control System for Helicopter," Hilbert, K.B., Bouwer, G., NASA Ames, IFF West Germany, AIAA Guidance and Control Conference, Aug. 20, 1984, AIAA Paper-84-1941.

25. 83N18704, "Helical Automatic Approaches of Helicopters with Microwave Landing Systems," Foster, J.D., McGee, L.A., Dugan, D.C., NASA Ames, NASA TP-2109, 1982.

26. 83N11101, "Modeling Methodology for MLS Range Navigation System Errors Using Flight Test Data," Karmali, M.S., Phatak, A.V., NASA (AMA), NASA CR-166411, 1982.

27. 83A45461, "Ground Simulation Investigation of Helicopter Decelerating Instrument Approaches," Lebacqz, J.V., NASA Ames, AIAA Atmospheric Flight Mechanics Conference, Aug. 9, 1982, Journal of Guidance, Control and Dynamics, Sept/Oct 1983, Vol. 6 #5, pp. 330-338.

28. 83A48346, "Evaluation of Control and Display Configurations for Helicopter Shipboard Operations," Paulk, C.H., et al, NASA Ames (USN/MC, USN/NATC), AIAA Aircraft Design, Systems and Technology Meeting, Oct. 17, 1983, AIAA Paper-83-2486.

29. 83A41079, "A Summary of NASA/FAA Experiments Concerning Helicopter IFR Airworthiness Criteria," Lebacqz, J.V., Chen, R.T.N., Gendes, R.M., Weber, J.M., NASA Ames, AHS Journal, Vol. 28 #3, p. 63-70, July 1983.

30. 83N33904, "NASA/FAA Experiments Concerning Helicopter IFR Airworthiness Criteria," Lebacqz, J.V., NASA TM-84388, 1983.

31. "83N10049&50, "A Piloted Simulator Investigation of Stability and Control, Display and Crew - Loading Requirements for Helicopter Instrument Approach," Lebacqz, J.V., Forrest, R.D., Gerdes, R.M., NASA TM-84258 Parts I and II, 1982.

32. "Sensitivity Analysis of Helicopter IMC Decelerating Steep Approach and Landing Performance to Navigation System Parameters - Instrument Meteorological Conditions," Karmali, M.S., Phatak, A.V., Bull, J.S., Peach, L.L., Demko, P.S., NASA Ames, AVRADA, 39th AHS Forum 1983 p. 270-280.

33. "Navigation and Flight Director Guidance for the NASA/FAA Helicopter MLS Curved Approach Flight Test Program", Phatak, A.V., Lee, M.G., NASA CR-177350, 1985.

34. 82N33398, "A Ground Simulator Investigation of Helicopter Longitudinal Flying Qualities for Instrument Approach," Lebacqz, J.V., Forrest, R.D., Gerdes, R.M., NASA TM-84225, 1982.

35. 82N23219, "Results of NASA/FAA Ground and Flight Simulation Experiments Concerning Helicopter IFR Airworthiness Criteria," Lebacqz, J.V., Chen, R.T.N., Gerdes, R.M., Weber, J.M., Forrest, R.D., NASA Ames, in Helicopter Handling Qualities, NASA CP-2219, N82-23208, 1982, pp. 121-138.

36. 82N23220, "State-of-the-Art Cockpit Design for the HH-65A Helicopters," Castleberry, D.E., McElreath, M.Y., in Helicopter Handling Qualities, (NASA CP-2219), N82-23208, 1982, p. 139-143.

37. 82A40531, "Flight Test Evaluation of a Video Tracker for Enhanced Offshore Airborne Radar Approach Capability," Clary, G.R., Glary, G.R., Cooper, P.G., NASA Ames, AHS 38th Annual Forum, May 4, 1982, p. 287-293.

38. 82A16914, "Helical Helicopter Approaches with Mircrowave Landing System Guidance," McGee, L.A., Foster, J.D., Dugan, D.C., NASA Ames, AIAA VSTOL Conference, Dec. 7, 1981, AIAA-81-2654.

39. 81N27061, "ATC Simulation of Helicopter IFR Approaches into Major Terminal Areas Using RNAV, MLS and CDTI," Tobias, L., Lee, H.Q., Peach, L.L., Willett, F.M., Jr., O'Brien, P.J., NASA Ames, TM-81301, 1981.

40. 81N19042, "Flight Tests of IFR Landing Approach Systems for Helicopters," Bull, J.S., Hegarty, D.M, Peach, L.L., Phillips, J.D., Anderson, D.J., Dugan, D.C., Ross, V.L., NASA Ames, 1981.

41. 81N10077, "A Piloted Simulator Investigation of Static Stability and Stability/Control Augmentation Effects on Helicopter Handling Qualities for Instrument Approach," Lebacqz, J.V., Forrest, R.D., Gerdes, R.M., NASA Ames, TM-81188, FAA-RD-80-64, 1980.

42. 81A44556, "Automatic Helical Rotorcraft Descent and Landing Using a Microwave Landing System," McGee, L.A., Foster, J.D., Xenakis, G., NASA Ames, AIAA Atmospheric Flight Mechanics Conference, Aug. 19, 1981, AIAA-81-1857.

43. 81A46623, "A Flight Investigation of Static Stability, Control Augmentation, and Flight Director Influences on Helicopter IFR Handling Qualities," Lebacqz, J.V., Weber, J.M., Corliss, L.D., NASA Ames, AHS 37th Annual Forum, May 17, 1981, p. 237-251.

44. 81A44110, "Investigation of Control, Display and Crew-Loading Requirements for Helicopter Instrument Approach," Lebacqz, J.V., Gerdes, R.M., Forrest, R.D., Merrill, R.K., NASA Ames, AIAA Guidance and Control Conference, Aug. 19, 1981, AIAA-81-1820.

45. 81N13958, "Evaluation of a Computer-Generated Perspective Tunnel Display for Flight Path Following," Grunwald, A.J., Robertson, J.B., Hatfield, J.J., NASA Langley, NASA TP-1736, 1980.

46. 81A40147, "Navigation Errors Encountered Using Weather-Mapping Radar for Helicopter IFR Guidance to Oil Rigs," Phillips, J.D., Bull, J.S., Hegarty, D.M., Dugan, D.C., NASA Ames, AHS 36th Annual Forum, May 13, 1980, AHS preprint 80-16.

47. 81A40180, "NASA/FAA Flight Test Investigation of Helicopter Microwave Landing System Approaches," Peach, I.L., Jr., Bull, J.S., Anderson, D.J., Dugan, D.C., Ross, V.L., Hunting, A.W., Pate, D.D., NASA Ames, FAA AVN, AHS 36th Annual Forum, May 13, 1980, AHS preprint 80-55.

48. 81A40160, "A Piloted Simulator Investigation of Static Stability and Stability/Control Augmentation Effects on Helicopter Handling Qualities for Instrument Approach," Lebacqz, J.V., Forrest, R.D., NASA Ames, AHS 36th Annual Forum, May 13, 1980, AHS preprint 80-30.

49. 81A22549, "Flight Test Evaluation of a Digital Controller Used in a VTOL Automatic Approach and Landing System," Downing, D.R., Bryant, W.H., NASA Langley, IEEE Conference on Decision and Control, Dec. 12, 1979.

50. 80N31408, "A Simulator Study of Control and Display Augmentations for Helicopters," Adams, J.C., Born, G.J., Dukes, J.A., NASA (Princeton University), NASA CR-163451, 1980.

51. 80N28341, "A Pilot's Assessment of Helicopter Handling Quality Factors Common to both Agility and Instrument Flying Tasks," Gerdes, R.M., NASA Ames, TM-81217, 1980.

52. 80N28330, "Analytical Methodology for Determination of Helicopter IFR Precision Approach Requirements -- Pilot Workload and Acceptance Level," Phatak, A.V., NASA Ames (AMA, Inc.), NASA CR-152367, 1980.

53. 80N22321, "Pilot Assessment of Two Computer-Generated Display Formats for Helicopter Instrument Approach," Niessen, F.R., Deal, P.L., Patton, J.M., Jr., NASA Langley, NASA TM-80151, 1980.

54. 80N11058, "Study for Incorporating Time-Synchronized Approach Control into the CH-47/VALT Digital Navigation System," McConnell, W.J., Jr., NASA (Sperry Flight Systems), NASA CR-159151,1979.

55. Navigation, Guidance and Control for Helicopter Automatic Landings", Kelly, J.R., Niessen, F.R., NASA Langley, TP-1649, 1980.

56. 79N23080, "Comparison of Electro-mechanical and Cathode-Ray-Tube Display Mediums for an Instrument Approach Display," Abbott, T.S., NASA Langley, TM-80069, 1979.

57. 79N20111, "Survey of Helicopter Control/Display Investigations for Instrument Decelerating Approach," Lebacqz, J.V., NASA Ames, TM-78565, 1979.

58. 79A49104, "Flight Investigation of Helicopter IFR Approaches to oil Rigs Using Airborne Weather and Mapping Radar," Bull, J.S., Hegarty, D.M., Philips, J.D., Sturgeon, W.R., Hunting, A.W., Pate, D.P., NASA Ames, AHS Annual National Forum, May 21, 1979, AHS preprint 79-52.

59. 79A49078, "Piloted Simulator Investigation of Helicopter Control Systems Effects on Handling Qualities During Instrument Flight," Forrest, R.D., Chen, R.T.N., Gerdes, R.M., Alderete, T.S., Gee, D.R., NASA Ames, FAA, AHS Annual National Forum, May 21, 1979, AHS preprint 79-26.

60. 79A45413, "Piloted Simulator Investigation of Helicopter Precision Decelerating Approaches to Hover to Determine Single-Pilot IFR (SPIFR) Requirements," Phatak, A.V., Peach, L.L., Jr., Hess, R.A., Ross, V.L., Hall, G.W., Gerdes, R.M., NASA Ames (AMA, Inc.), AIAA Guidance and Control Conference, Aug. 6, 1979, AIAA 79-1886.

61. 79A45358, "Flight Test of a VTOL Digital Autoland System Along Complex Trajectories," Downing, D.R., Bryant, W.H., Ostroff, A.J., NASA Langley, AIAA Guidance and Control Conference, Aug. 6, 1979, AIAA 79-1703.

62. 79A45345, "A Review of Helicopter Control-Display Requirements for Decelerating Instrument Approach," Lebacqz, J.V., NASA Ames, AIAA Atmospheric Flight Mechanics Conference for Future Space Systems, Aug. 6, 1979, AIAA 79-1683.

63. "A Piloted Simulator Investigation of Helicopter Precision Decelerating Approaches to Hover to Determine Single-Pilot IFR/SPIFR Requirements", Phatak, A.V., Peach, L.L., Jr., Hess, R.A., Ross, V.L., Hall, G.W., Gerdes, R.M., NASA Ames (ARC) AIAA Conference, 1979, AIAA-Paper-79-1886.

64. "Study for Incorporating Time-Synchronized Approach Control Into the CH-47/VALT Digital Navigation System," McConnell, W.J., Jr., NASA (Sperry) CR-159151, 1979.

65. "Description of the VTOL Approach and Landing Technology (VALT) CH-47 Research System," Kelly, J.R., Niessen, F.R., Garren, J.F., Jr., Abbott, T.S., NASA, TP-1436, 1979.

66. "Survey of Helicopter Control/Display Investigations for Instrument Decelerating Approach", Lebacqz, V.J., NASA Ames, NASA TM-78565, 1979.

67. 78A45439, "VALT Parameter Identification Flight Test -- VTOL Approach and Landing Technology," Tomaine, R.L., Bryant, W.H., Hodge, W.F., NASA Langley, Army, 4th European Rotorcraft and Powered Lift Forum, Italy, Sept. 13, 1978, Paper #73.

68. 77A35918, "Analytical Display Design for Flight Tasks Conducted Under Instrument Meteorological Conditions," Hess, R.A., NASA Ames, IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-7, June 1977, p. 453-462.

69. 76N30223, "Analytical Display Design for Flight Tasks Conducted Under Instrument Meteorological Conditions-Human Factors Engineering of Pilot Performance for Display Device Design in Instrument Landing Systems," Hess, R.A., NASA Ames, TM-X-73146, 1976.

70. "A Technique for Generating Arbitrarily Shaped Curved Approach Paths," McConnell, W.J., Jr., NASA (Sperry), CR-2734, 1976.

71. 75N33685, "A Model for Simultaneous Monitoring and Control by Pilot During Helicopter Approaches," Curry, R.E., Kleinman, D.L., Hoffman, W.C., NASA Ames (MIT), 11th Annual Conference on Manual Control, 1975, pp. 144-150.

72. 75N12933, "Simulation Study of Intracity Helicopter Operations Under Instrument Conditions to Category I Minimums," Callan, W.M., Houck, J.A., Dicarlo, D.J., NASA Langley, TN-D-7786, 1974.

73. 75N33697, "A Model-Based Analysis of a Display for Helicopter Landing Approach -- Control Theoretical Model of Human Pilot," Hess, R.A., Wheat, L.W., NASA Ames, 11th Annual Conference on Manual Control 75N33675, 1975, p. 338-355.

74. 74N28102, "Flight Investigation of Manual and Automatic VTOL Decelerating Instrument Approaches and Landings," Kelly, J.R., Niessen, F.R., Thibodeaax, J.J., Yenni, K.R., Garren, J.F., Jr., NASA Langley, TN-D-7524, 1974.

75. 71N20305, "Fixed-Base Simulation Evaluation of Various Low-Visibility Landing Systems for Helicopters," Koziok, J.S., Jr., Rempfer, P.S., Stevenson, L.E., NASA LRC, TN-D-5913, 1971.

76. 71A18423, "An Evaluation of Low-Visibility Landing Systems by Simulation," Koziok, J.S., Jr., Rempfer, P.S., Stevenson, L.E., NASA LRC, Vertiflite, Vol. 17, #1, p. 4-7, 10, 11.

77. 70N41183, "Evaluation of a Moving Graph Instrument Display for Landing Approaches with a Helicopter," Dunham, R.E., Sommer, R.W., NASA Langley, TN-D-6025, 1970.

78. 69N27177, "Evaluation of a Contact-Analog Display in Landing Approaches with a Helicopter," Sommer, R.W., Dunham, R.E., NASA Langley, TN-D-5241, 1969.

79. 68N16594, "Evaluation of a Closed-Circuit Television Display in Landing Operations with a Helicopter," Gracey, W., Sommer, R.W., Tibbs, D.F., NASA Langley, TN-D-4313.

80. 68N27391, "Evaluation of Two Instrument Landing Displays in Simulated IFR Approaches with a Helicopter, "Gracey, W., NASA Langley, TM-X-59866, 1967.

81. 68N27550, "Operational Aspects of Steep VTOL Approaches as Determined from Helicopter Tests Under Simulated IFR Conditions," Gracey, W., NASA Langley, TM-X-60457, 1967.

6.3 Military Agency Research

1. 86A23750, "Simulator Design Features for Helicopter Landings on Small Ships," Westra, D.P., Lintern, G., Human Factors Society Proceedings, 28th Annual Meeting, p. 1018-1022, 1984.

2. 86N26501, "A Comparison of Voice and Keyboard Data Entry for a Helicopter Navigation Task," Malkin, F.J., Christ, K.A., Human Engineering Labs, HEL-TM-17-85, 1985.

3. 86N22115, "A Multiple Regression Model of Pilot Performance in Vertical and Translational Flight," Wiedemann, J., Roscoe, S.N., New Mexico State University, BEL-85-2/ONR-85-2, 1985.

4. 86N19321, "Horizontal Display for Vertical Flight: A Direction of Motion Experiment," Trujillo, E.J., Roscoe, S.N., New Mexico State University, BEL-85-1/ONR-85-1, 1985.

5. 86N70840, "Airworthiness and Flight Characteristics Test of the OH-6A Configured to a Light Combat Helicopter," Webre, J.L., Woratsheck, R., Mitchell, E.L., Adler, R.S., Army Avionics Engineering Flight Activity, U SAAEFA-81-04, 1983 (JOH-6A LCH).

6. 86A26642, "Realtime Piloted Simulation Investigation of Helicopter Flying Qualities During Approach and Landing on Nonaviation Ships," Jewell, W.F., Clement, W.F., Johns, J.B., AIAA, Aerospace Sciences Meeting, 24th, Jan. 6, 1986, AIAA Paper 86-0490.

7. 85X10196, 7, 8, "Development of ADOCS Controllers and Control Laws," Volumes, I, II, III, Landis, K.H., Glushmam, S.I., Army AVSCOM (Boeing Vertol), USAAVSCOM-TR-84-A-7, 1985.

8. 85N72484, "Airworthiness and Flight Characteristics Test (A&FC) of the CH-47D Helicopter," Bender, G.L., Yamakawa, G.M., Herbst, M.K., Sullivan, P.J., Robbins, R.D., Army Aviation Engineering Flight Activity, USAAEFA-82-07, 1984.

9. 85A34263, "The Role of Testing in Qualification and Certification of Aircraft," Crawford, C.C., Jr., Vertiflite, V. 31 #3, p. 64-68, 1985.

10. 85A38529, "Helicopter Flight Test of a Ring Laser Gyro Attitude and Heading Reference System," Niemela, J., Delguercio, V., Welker, J., Klemes, M.S., Institute of Navigation, National Technical Meeting, Jan. 17, 1984, p. 20-23.

11. 84N26696, "Preliminary Airworthiness Evaluation of the UH-60 Helicopter with T700-GE-701A Engines Installed," Nasata, J.I., Miess, J., Haworth, L.A., Army Aviation Engineering Flight Activity, USAAEFA-83-17-F, 1983.

12. 84N14140, "Fixed-Base Simulator Investigation of Display/SCAS Requirements for Army Helicopter Low-Speed Tasks," Carico, D., Blanken, C.L., Bivens, C.C., Morris, P.H., Army Research & Technology Lab, 1983, Moffett Field, AD-A134123.

13. 84A29494, "Testing Ground Proximity Warning Systems for Navy Tactical Aircraft," Hoerner, F.C., Aerospace Behavioral Engineering Technology Conf., 2nd, p. 191-193, also: SAE Paper 831456, Oct. 3 1983.

14. 84N71021, "Airworthiness and Flight Characteristics Evaluation, UH-60A (Blackhawk) Helicopter," Nagatu, J.I., Buckanin, R.M., Skinner, G.L., Robbins, R.D., Williams, R.A., Army Aviation Engineering Flight Activity, USAAEFA-77-17, 1981.

15. 83A16134, "Helmet Mounted Display Symbology for Helicopter Landing on Small Ships," Donley, S.T., Dukes, T.A., Naval Air Development Center, Advanced Aircrew Display Symposium 5th Proceedings, p. 216-240, 1982.

16. 83N12075, "Airworthiness and Flight Characteristics Test. Part 1: YAH-64 Advanced Attack Helicopter," Bender, G.L., Higgins, L.B., Savage, R., Ottomeyer, J.D., Picasso, B.D., III, Morris, P.M., Army Aviation Engineering Flight Activity, USAAEFA-80-17-1, 1981.

17. 81N21068, "Study of Pilot Visual Information Requirements for Navy Vertical Take-Off and Landing Capability Development," Mitchell, W.S., Douglas, C.A., Navy (Quanta Systems Corp.), NAEC-MISC-91-OR019, 1979.

18. 74N31455 "VSTOL Aircraft Control/Display Concept for Maximum Operational Effectiveness," McElreath, K.W., Klein, J.A., Thomas, R.C., Air Force Flight Dynamics Lab (Collins Radio), 1974.

19. 75N30081 "U.S. Navy VTOL Automatic Landing System Development Program," Buffum, R.S., Huff, R.W., Keyser, G.L., Naval Air Test Center, 1975.

20. 80N27334, "The Development and Test of a Tactical Self-Contained Landing System -- Landing Military Helicopters when the Safe Corridor is Unknown," Shupe, N.K., USA/ARDA, AGARD Air Traffic Management (N8027324), 1980.

21. 78N13055, "Flight Evaluation Pacer Systems Low Range Airspeed System LORAS 1000," Abbott, W.Y., Bolrun, B.H., Hill, G.E., Tavares, E.J., USA/AEFA, USAAEFA-75-17-1, 1977.

22. 79N19638, "Oculomotor Performance of Aviators During an Autorotation Maneuver in a Helicopter Simulator," Armstrong, R.N., Krueger, G.P., Sapp, J.H., Jones, Y.F., Army Aeromedical Research Unit, 1978.

23. 78N25084, "Environmental Requirements for Simulated Helicopter/VTOL Operations from Small Ships and Carriers," Woomer, C.W., Williams, R.L., Naval Air Test Center, NATC-TM-78-2-RW, 1978.

24. 78N19119, "VTOL/Helicopter Approach and Landing Guidance Sensors for Navy Ship Applications," Miyashiro, S.K., Morris, F.E., Naval Ocean Systems Center, Naval Postgraduate School Proceedings, p. 495-514. 1977.

25. 78N15037, "Flight Evaluation of J-TEC VT-1003 Vector Airspeed Sensing System," Abbott, W.Y., Stewart, R.L., Spring, S.C., Army Aviation Engineering Flight Activity, USAAEFA-75-17-2, 1977.

26. 78N15036, "Flight Evaluation of Rosemount Low-Range Orthogonal Airspeed System with 8536 Sensor," Abbott, W.Y., Guin, J.R., Army Aviation Engineering Flight Activity, USAAEFA-75-17-3, 1977.

27. 78N10067, "Low Airspeed Sensor Location Tests AH-1G Helicopter," Ferrell, K.R., Boirun, B.H., Hill, G.E., Army Aviation Engineering Flight Activity, USAAEFA-75-19-1,1977.

28. 77N13042, "Analysis and Design of an Electro-Mechanical Optical Landing System for Helicopters at Night in Varying Sea States," Bray, G.E., Naval Air Engineering Center, NAEC-ENG-7858, 1976.

29. 77N12701, "An Analysis of the Effect of a Flight Director on Pilot Performance in a Helicopter Hovering Task," Duffy, T.W., Naval Postgraduate School, 1976, M.S. Thesis, AD-A025680.

30. "Flight Evaluation of Pacer Systems Low-Range Airspeed System LORAS 1000," Abbott, W.Y., Boirun, B.H., Hill, C.E., Tavares, E.J., USAAEFA-75-17-1.

31. 77N77517, "Height-Velocity Test AH-1G Helicopter at Heavy Gross Weight, Part 1, Low Elevation," Helper, L.J., Free, L.M., Army Aviation Systems Test Activity, USAASTA-74-19-PT-1, 1974.

32. 77A26877, "A Study to Determine the Characteristic Shapes of Helicopter Visual Approach Profiles," Moen, G.C., DiCarlo, D.J., Yenni, K.R., USA/AMROL, NASA Langley, AHS Annual National Forum, May 10, 1976 (77A26851), p. 1044-1 to 1044-11.

33. 76A14579, "Manual Precision Hover with Superimposed Symbology on FLIR Image -- Forward Looking IR for Helicopter Tests," Milelli, R.H., Johnson, D.C., Tsoubanos, C.M., USA/AL, AHS 31st Annual National Forum, May 13, 1975 (76A14565), p. 922/1 - 922/13.

34. 76N14118, "Pilot Factor for Helicopter Refined ADI/HSI and Supporting Displays Evaluation," Armstrong, G.C., McCowell, J.W., Sams, D.D., Winter, F.J., Jr., USAF Instrument Flight Center, IFC-TR-74-5, 1975.

35. "Integration of 4-Cue Flight Director and 4 Axis Autopilot with MLS for Cat III Helicopter IFR," Boriss. R., Sabey, W., Army, 1975.

36. "Operational Test and Evaluation of an Omnidirectional Low Range Airspeed System, LORAS," Lusk, W.T., USAF Andrews, 1Hs-AS-1001-76-9, 1976.

37. 75N17347, "Helicopter TERPS Validation Study Phase 1," Clark, W.E., Jr., Intano, G.P., USAF Instrument Flight Center, IFC-TR-74-4, 1974.

38. 75N31065, "Pilot Factors for Helicopter Pre-Experimental Phase -- Flight Test/Flight Instruments," Armstrong, G.C., McDowell, J.W., Sams, D.D., Winter, F.J., Jr., USAF Instrument Flight Center, IFC-TR-74-2, 1975.

39. 75N31061, "Flight Evaluation: Rosemount Orthogonal Low Airspeed System Low Airspeed Sensor," Jefferis, R.P., O'Connor, J.C., Bullock, J.R., Army Aviation Engineering Flight Activity, USAAEFA-71-30-5-FR-5, 1974.

40. 75A19690, "Control-Display-Stability-Augmentation System -- for Low Visibility Helicopter Maneuvers," Rolek, E.P., USAF (SRL, Inc.), 18th Human Factors Society Annual Meeting, Oct. 15, 1974 (75A19676), p. 255-258.

41. 75N10917, "Integrated Avionics Controls and Displays for Helicopter IFR Operation," Winter, F.J., USAF/AFFDL, Society of Flight Test Engineers Advancements in Flight Test Engineering 5th Annual Symposium (75N10910), 1974, p. 2-31 - 2-42.

42. 74N17762, "Color Perception in the Transitional Zones of Tricolor Glide-Slope Indicators (GSI's)," Hennessy, R.T., Borden, G.J., Navy (Human Factors Research Inc.), 1973.

43. 74N31932, "Flight Evaluation, J-TEC Airspeed System," Dominick, F., Boirun, B.H., Kishi, J.S., Jefferis, R.P., Army Aviation Systems Test Activity, USAASTA-71-30-4-FR-4, 1974.

44. 74N31512, "Flight Evaluation: Pacer Systems, Incorporated, LORAS 2 Airspeed System," Boirun, B.H., et al, Army Aviation Systems Test Activity, USAASTA-71-30-3FR-3, 1973.

45. 74N31455, "V/STOL Aircraft Control/Display Concept for Maximum Operational Effectiveness," McElreath, K.W., Klein, J.A., Thomas, R.C., USAF/AFFDL (Collins Radio Co.), AGARD Advances in Control Systems (74N31429), 1974, AGARD-CP-137, p. 26-1-26-8.

46. 74A36584, "Controls and Displays for Helicopter IFR Operation -- Pilot Factor Considerations," Winter, F.J., Jr., USAF/AFFDL, AHS 30th Annual National V/STOL Forum, May 7, 1974, AHS Preprint 825.

47. 74A34839, "Flight Evaluation of Four Low Airspeed Indicating Systems," Dominick, F.L., Boirun, B.H., USA/ASTA, Flight Testing Today - 1973, Society of Flight Test Engineers Fourth National Symposium, Aug. 21, 1973 (74A34837).

48. 73N12686, "The Princeton Pennsylvania Army Avionics Research Program," Graham, D., Army (Princeton University), 1972.

49. 73N31430, "Flight Evaluation: Aeroflex True Airspeed Vector System," Ferrell, K.R., Winn,A.L., Kishi, J.S., Jefferis, R.P., Army Aviation Systems Test Activity, USAASTA-71-30-2, 1972.

50. 72N14019, "Stability and Control of Helicopters in Steep Approaches; Volume 3, Derivatives and Transfer Functions for the YHC-1A Tandem-Rotor Helicopter and the S-5B Single-Rotor Helicopter," Wokovitch, J., Hoffman, J.A., Army AVLABS (Mechanics Research Inc.), USAAVLABS-TR-70-74C, 1971.

51. 72N11934, "Precise IFR Hovering: An Operational Need and a Feasible Solution," Keane, W.P., Milelli, R.J., USA/AEC, AGARD Helicopter Guidance and Control Systems (72N11915).

52. 70N26948, "A Systems Analysis of Manual Control Techniques and Display Arrangements for Instrument Landing Approaches in Helicopters; Volume I, Speed and Height Regulation," Clement, W.F., Hofmann, L.G., Army Electronics Command (Systems Technology, Inc.), 1969.

53. 70N40514, "Wind Tunnel and Flight Evaluation of Rosemount Shielded Pilot-Static Tube Model 850N," Ferrell, K.R., Mishlof, J., Shapely, J.J., Jr., Army Aviation Systems Test Activity, USAASTA-68-12, 1970.