Report No. FAA-RD-76-127

INDEPENDENT ALTITUDE MONITOR: A LITERATURE SEARCH, ANALYSIS, AND BIBLIOGRAPHY

Jack J. Shrager

AUGUST 1976

FINAL REPORT

Document is available to the public through the
National Technical Information Service
Springfield, Virginia 22151

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-76-127		

4. Title and Subtitle	5. Report Date
INDEPENDENT ALTITUDE MONITOR: A LITERATURE SEARCH, ANALYSIS, AND BIBLIOGRAPHY	August 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Jack J. Shrager	FAA-NA-76-2
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405	
	11. Contract or Grant No.
	~~076-311-000~~
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final Rept. May 1974 — July 1975
U.S. Department of Transportatior Federal Aviation Administration Systems Research and Development Service Washington, D. C. 20590	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A literature search of recent activity to provide an independent indication of aircraft altitude was undertaken. Results indicate that there are several existing techniques in use which can readily be expanded to enhance altitude awareness to avoid inadvertent terrain collisions. Also identified are other new potential candidate systems concepts.

17. Key Words	18. Distribution Statement
Altitude monitoring Airborne techniques Air navigation	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	50	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

iii 240 550

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

The most frequent commercial aviation accident which results in serious injuries or fatalities is inadvertent collision with the terrain. There has been, and still is, a continuing need to explore techniques for reducing the various factors identif'ed as probable causes which relate to this accident type.

There are several recent Federal Aviation Administration (FAA) programs which are dedicated to enhancing flight safety in this category. Among these efforts are:

1. Advanced Electronic Display System (ADEDS),
2. Airborne Independent Landing Monitor (AILM),
3. All-Weather Landing System (AWLS)
4. Altitude Alerting System (AAS),
5. Ground Proximity Warning System (GPWS), and
6. Independent Altitude Monitor (IAM).

This literature search is a continuation of the IAM program, with special emphasis on airborne techniques for independent altitude monitoring. To a lesser degree, airborne-generated information which can be used by air traffic control (ATC) is also considered. Specifically, this effort relates to an in-depth literature review and analysis, an informal review of current experimental efforts by industry, and discussion of current systems and techniques.

The frequency of inadvertent collisions with terrain could be reduced by providing the flight crew with an independent assessment of current terrain clearance and predictive clearance information. The predictive information would have to allow timely pilot reaction and safe maneuvering under high pilot workloads. Thus, there are several identifiable pieces of information that must be considered. Among the more obvious are:

1. Current terrain clearance height above ground level (AGL),

2. Terrain closure rate (a function of aircraft groundspeed, ground rise angle, and aircraft descent rate),

3. Obstacle and terrain characteristics ahead of the aircraft and along its ground track which are a collision threat,

4. Terrain characteristics that would influence the maneuvering of the aircraft,

5. Pilot response to an indication of a potential threat due to the altitude of the aircraft, and

6. Aircraft performance (a function of climb performance, power available, density altitude, aircraft gross weight, and control system response).

OBJECTIVE.

The objectives of this undertaking were:

1. Review current technical publications and other literature relating to airborne IAM techniques or procedures. This analytical review would identify the advantages and limitations of the IAM's. In addition, techniques which could be inferred from the analysis, but not specifically stated in the literature, would also be identified.

2. Determine the status of current related experimentation and developments in inadvertent terrain collision avoidance. Since some of these efforts could be proprietary, it was recognized that the potential IAM concepts identified through this phase would be general in nature and not identifiable as to source.

3. Indicate those techniques which may require experimentation and/or evaluation for enhancement of flight safety through independent altitude monitoring. A factor to be considered in this objective would be the cost effectiveness and cost benefit of any technology so identified.

LITERATURE REVIEW.

Each of the documents contained in the bibliography, which are listed in alphabetical order by title, was reviewed in detail. The alphabetical listing includes author, date of publication, cognizant organization, and, where applicable, a critical abstract or summary. Based on this review, the document titles were subsequently subgrouped by principal subject category. It is recognized that some publications may relate to more than one of the above subjects or may not be conveniently categorized within any of these subjects. Therefore, a document may appear by title in more than one of the subject categories or may not be listed in any of the subject categories. Such duplication or omission of listing should not be construed as a means of identifying the relative value of a given document. A subjective evaluation of each document was made. The listing within the categories is by title and document sequence number (index No.) as it appears in this report. As a further aid to the reader, an authors' index is provided with the index number cross referenced also.

A search of National Aviation and Space Administration (NASA) scientific and technical information documents, index No. 35, provided limited data in the IAM related areas. This search was supplemented by an independent search of the technical information libraries within the FAA and references contained in any publications thus identified. As a result of these efforts, 68 published documents were identified which relate to IAM.

The Boeing Airplane Company report of September 1973, index No. 18, indicated that most altitude-related accidents were associated with deviations from existing procedures and cockpit disciplinary practices.

Several of the concepts noted in index No. 18 have been the subject of recent or current FAA action items, as noted in the INTRODUCTION section of this report. As a result of the literature review, the following systems for providing an IAM function were identified:

1. En Route and Terminal Area Altitude Monitoring and Alerting, index No. 18.

2. Expanded Altitude and Minimum Descent Altitude Alerting, index No. 1.

3. Three-Dimensional (3D) Area Navigation (RNAV) and Instrument Landing System (ILS), index No. 1.

4. GPWS's, index No. 23.

5. Forward-Looking Radar, index No. 61.

6. Multifunction systems, index No. 14.

7. Optical Detection, index No. 15.

Each of the above are discussed in the DISCUSSION AND ANALYSIS section of this report. It should be noted that the documents identified above are not necessarily the only documents included which relate to the specified area, and the citing of these documents is not indicative of concurrence with the contents or conclusions of these publications.

CURRENT EXPERIMENTATION AND HARDWARE DEVELOPMENT.

During a series of informal conferences, flight tests, and telephone conversations with various segments of the aviation community, the following IAM-related areas were identified:

1. GPWS,
2. Sensors,
3. Forward-Looking Radar,
4. Cockpit Annunciators,
5. Optical Detectors,
6. Aircraft Performance, and
7. Altitude Alerting.

The two general subjects which predominated during these discussions were terrain avoidance systems, such as GPWS and cockpit annunciators, and especially the nuisance (not false) warning under pilot stress. A nuisance warning is a warning which is generated during proper operations within the protected envelope. A false warning is one which was not within the protected envelope and should not have occurred.

Subjects relating to terrain avoidance systems discussed during the informal conferences were focused on those instances in which the system does not produce any warning or sufficient warning time, and techniques to enhance such systems (i.e., forward-looking radar, aircraft ground or airspeed, etc.). One of the manufacturers of a current GPWS initially looked at forward-looking radar as opposed to downward-looking radar. Although this work did not look attractive at the time, there is a current program to develop a second generation GPWS using forward-looking radar and aircraft velocity information.

Another manufacturer of GPWS equipment is looking at the limitations imposed on the current GPWS techniques due to sensor characteristics (i.e., radar altimeter, barometric boxes, etc.). Here too, forward-looking radar, particularly in today's state-of-the-art weather-radar systems, is being reexamined for possible enhancement of the GPWS protection envelopes.

DISCUSSION AND ANALYSIS

AIR TRAFFIC CONTROL ENHANCEMENT.

In the previously noted Boeing report, index No. 18, it was proposed that more use could be made of mode C (automatic altitude reporting of the aircraft's FAA-required transponder). The technique suggested was to compare the preestablished minimum altitude for a terminal area sector to the mode C reported altitude and provide an alarm to the aircraft via the Discrete Aircraft Beacon System (DABS) data link if the minimum altitude were violated.

Recently, the FAA's National Aviation Facilities Experimental Center (NAFEC) undertook a related program entitled "Minimum Safe Altitude Warning" (MSAW). In this proposed technique, the area under ground-based radar surveillance was divided into 2-by-2-mile sections (bins), and the highest obstruction within that bin determined. When an aircraft transponder reported an altitude below the MSAW criterion (highest obstruction plus some preselected additional height), the controller would be alerted, and he, in turn, would alert the pilot. This alerting could also be accomplished by a data link. The results of these tests were not formally documented as of the date of this report. This concept might have provided an early IAM alarm in the case of the Eastern Airlines L1011 accident in Florida.

The MSAW program is not limited to the terminal area environment, nor is it limited to reported position. The system utilizes the ground-based Air Traffic System (ATS) computer and radar data to provide hazard warning for a limited distance ahead of the aircraft. Thus, there is a predictive capability which is also considered. With this mode, the MSAW might have provided an IAM alarm prior to the ground contact in the case of the Trans World Airlines (TWA) B727 accident in Virginia.

The MSAW program and the proposed techniques cited in index No. 18 did not consider the use of mode C information for reported altitude deviation from assigned altitude. Thus, one refinement of the MSAW would be the use of such ground-based IAM alerting mode on the controller's display for deviations from assigned altitude. The alerting mode could include not only absolute altitude deviations, but could also incorporate predetermined excessive descent rates when going from one altitude to another. The MSAW would provide a ground-derived altitude-alerting function to complement the current airborne function required by Federal Aviation Regulations (FAR) Part 91. In addition, the expanded version of the MSAW, as discussed above, would also provide a ground-based GPWS function.

A limitation to the MSAW program in the terminal environment is the size of the bins. During a perfectly acceptable approach, it is possible and probable that the aircraft's altitude is less than a high structure or terrain which is not along the aircraft's flightpath. Unless this concept can eliminate such nuisance warning, especially if used in an automatic data link mode, the concept would be severely handicapped. Another limitation to the MSAW is the rotation rate of the (ASDR) antenna. The MSAW concepts require two consecutive indications of altitude violation before the controller is warned. Thus, the warning delay to the controller is on the order of 8 seconds or more after the fact.

There are other potential uses of an expanded MSAW concept. Among these are the detection of potential or real in-flight problems, induced by severe turbulence, vortex encounter, wind shear, or control system malfunctions, which produce excessive changes in altitude as indicated by the mode C altitude information. Such a capability might have provided an IAM alarm in the recent Eastern Airlines B727 accident in the state of New York.

ALTITUDE ALERT.

One of the potential airborne IAM techniques discussed in the literature was the expanded use of the mandatory FAR Part 91 altitude alerting equipment. A technique for accomplishing this is discussed in index No. 18, which suggests a supplemental radar-tripping mode. The current GPWS equipment, which is covered by FAR Part 121, includes the feature suggested. The system suggested in the Boeing report, index No. 18, and that which has been incorporated in the GPWS does not consider such factors as (1) airspeed or groundspeed, (2) obstacle or terrain height along the projected flightpath, (3) aircraft climb performance limitations, and (4) pilot and aircraft response times. Another expansion of the aircraft alerting system (AAS) was incorporating minimum obstacle clearance altitude (MOCA).

The formerly suggested AAS would have provided an early IAM alarm in several recent civil air carrier accidents. The latter suggested mode might have provided an IAM alarm in the recent B727 accident in Virginia.

The FAA's advanced control and display study, index No. 1, looked at the presentation of altitude guidance information on an electronic flight director system, such as an electronic attitude display indicator (EADI). The independent altitude-monitoring function is an expansion of the altitude command information used in modern U.S. Air Force (USAF) aircraft. Thus, the potential incorporation of a command mode into the altitude alerting system was considered in the discussions with various segments of the aviation community based on the concepts suggested in index No. 1 and is currently under study by NASA and the military. Again, the logic associated with the expansion of AAS, such as airspeed, sink rate, ground clearance, aircraft longitudinal response, etc., were not covered in the published literature, nor in any depth during these informal conferences. It should be noted that some air carrier operators have an independent nonmandatory minimum decision height (MDH) annunciation system which performs a partial function of the suggested expanded AAS.

3D/RNAV AND INERTIAL NAVIGATION SYSTEMS.

There are several documents and magazine articles which discuss the potentials and experiences in the use of 3D/RNAV systems for 3D flightpath control. One of the documents which covers such an IAM function is the FAA report on advanced controls and display technology, index No. 1. In the description of the electronic horizontal situation display (EHSI), it covers the use of a moving map display with computer-generated obstacles and terrain features which could pose a threat along the aircraft ground track. The composite system covered in index No. 1 includes the limitations of the sensors, aircraft response characteristics, and anomalies in source information due to redundancy. While offering the most desirable capability for IAM, it is an experimental device for possible consideration in the next generation civil commercial aircraft. Its capabilities are derived from powerful general-purpose computers, new sensor concepts for generating the necessary signal inputs to the computers, and the maximum use of digital components.

The advanced concepts described in index No. 1 are being introduced into the military to accomplish such objectives as terrain following, terrain mapping, as well as the more conventional flightpath control functions. These systems utilize onboard digital computers and internal navigation systems to compute and display the 3D situation of the aircraft relative to its location to known ground references. The results of this application and service experience have not yet been acquired and assembled for publications. Such a system might have provided safe guidance information to avoid en route obstacles which were factors in the C141 accident on the west coast and the TWA B727 accident on the east coast (involving terrain), and the Beech C90 collision with a high obstruction in Washington, D.C. Potential problem areas in adapting existing airborne components and systems to current cockpit presentations are the limited performance characteristics of such devices which were certified for other applications. Examples of this are the use of slant distance measuring equipment (DME) information and very high frequency omnidirectional radio (VOR) navigation information to establish aircraft position. Without taking into account the operational accuracy limitation of such equipment and the time constants associated with the derived information, the usage could cause an accident, as opposed to preventing one.

GROUND PROXIMITY WARNING SYSTEMS.

The GPWS has been the subject of most of the IAM literature, especially following the FAA report on the subject entitled "Evaluation of a Terrain Proximity Warning System," index No. 22. The FAA has promulgated a recent change to FAR Part 121 requiring a GPWS device on civil turbojet-powered airplanes.

The USAF recently conducted functional bench and flight tests on all five United States-manufactured prototype systems. The flight tests were expanded to include selected accident profiles of both military and civil airplanes and certain approaches to a limited number of airports which could develop nuisance warning. The results of the USAF flight tests are contained in a report entitled "Ground Proximity Warning Systems, Flight Tests," index No. 32.

The initial results indicate that some of the protected flight envelopes would have to be modified to reduce nuisance warning under USAF normal operations. Examples of such operations are low-altitude airdrop support, advanced short-field ground-troop supply depots, radar-avoidance low-altitude flights, etc. An alternate to this would be a pilot cancellation capability as is currently incorporated for the glide slope deviation only, mode 5 protection envelope. These tests also indicated that the GPWS may have to be designed for a specific aircraft instalation as well as the mission orientation of a given aircraft. The shortfield-takeoff-and-landing-type aircraft may operate normally within the current protected envelopes of both mode 2 and mode 3 of the GPWS. As a result of such factors, the GPWS could be severely compromised in its general application.

Reported nuisance warning potentials that were identified by some of the U.S. air carriers were, in fact, experienced when flown by the USAF. Thus, the GPWS could be providing undesirable annunciation under certain instrument flight rules (IFR) approved approaches. This is, in part, due to the fact that such approaches intercept the protection envelope of one or more of the GPWS alarm modes. One way of eliminating such nuisance alarms is a pilot cancellation capability which would automatically reset after a time period or a landing.

The USAF also experience false malfunction warning as well as false annunciations during an evaluation of the GPWS on the Presidential fleet of aircraft. Most of these undesirable warnings were identified to being associated with the radar altimeter or auxiliary barometric altitude unit. Both of these devices are discussed later in this report under the section entitled SENSORS. The requirement of current FAA regulations which designate the GPWS as a GO/NO GO item would have delayed at least 20 percent of the legs flown during these USAF tests. Such unnecessary delays in normal commercial air carrier operations would have been economically prohibitive. In addition, the inconvenience to the flying public would be unacceptable. These USAF experiences suggest that there are problem areas which should be resolved.

One of the commercial accident profiles flown was the DC9 accident in Huntington, West Virgina. The current protected envelope of the GPWS was not penetrated in time to provide safe maneuvering. This was also reported for the GPWS as it existed during the tests noted FAA GPWS report, index No. 23.

With the exception of one early prototype system, all of the GPWS systems evaluated by the USAF performed within the defined operating envelopes for each of the modes tested.

Another preliminary USAF report, "Human Factors Evaluation of the Ground Proximity Warning System", index No. 33, covered that phase of the GPWS evaluation. This report also cited factors which the evaluator felt limits the use of the GPWS in its current configuration and suggested preferred inputs to such an IAM system. One of these factors recommended was the use of forward-looking radar, possibly a modified weather radar.

Another suggested input to a GPWS-type IAM is aircraft velocity, either groundspeed or airspeed. Groundspeed would require DME/INS/Doppler equipment, both on the aircraft and at the ground station. In addition, such a system would be limited to the minimum altitude at which airborne reception is possible, generally defined as minimum enroute altitude (MEA). Airspeed can use indicated airspeed as an input and compute true airspeed (TAS) or obtain the specific parameter from an onboard air data system. The rationale behind aircraft groundspeed or true airspeed corrected for the headwind component is to generate a signal which will allow time to execute an avoidance maneuver. One of the second-generation GPWS systems now under development is predicated on both forward-looking radar information and aircraft velocity.

The U.S. Navy and the USAF are entering into independent programs to develop GPWS concepts which could be used for high-performance military aircraft. The Navy's program is dedicated to the use of a digital system concept.

FORWARD-LOOKING RADAR.

Forward-looking radar, specifically weather radar, was initially considered by one of the manufacturers of GPWS. The advantage of forward-looking radar is that it provides closure information on what is ahead (future position) as opposed to downward-only radar, which gives past position information.

A proprietary industry in-house document prepared in 1972 identified some of the problems associated with the use of airborne weather radar which included:

1. "During approach maneuvers, when most collisions with high ground occur, the flight crew is too busy to monitor the radar indicator. Any use of the radar for obstacle indication would have to be automatic, and this feature is not included in weather radars."

2. "Automatic indication is precluded by the fact that, at low altitudes, returns from sidelobes of the antenna pattern would cause an unacceptable number of false alarms."

3. "The background coefficients of ground targets vary so greatly that it is not practical to set a fixed threshold level that will assure an acceptable probability of detection and false alarm rate under all conditions, even if the sidelobe return problem can be overcome."

Another problem which could develop if the weather radar is modified is an increase in the mean time between failures (MTBF). The current reliability of this dispatch item aboard civil transport aircraft could alter the MTBF, which would adversely affect its cost effectiveness for GPWS application.

A modified version of a GPWS using forward-looking weather radar is one in which a ground-based transponder, such as that considered for locating off-shore oil rigs, might be used in conjunction with pressure altitude. Such a system would solve the X, Y, and Z position of the aircraft and present a pseudo glide slope signal to the flight director as a function of distance from the runway-located transponder. This would permit an independent monitoring of altitude during ascent or descent. Recent nondedicated flight tests suggested that such an IAM technique is within the state-of-the-art. In these tests, the antenna was tilted up one-half the beam width to minimize return from the ground. This technique was also proposed in the previously cited in-house industry document of 1972. In the weather mode, the ground clutter was eliminated.

During the overwater flight, two ships were detected on the surface as targets, along with the weather, when the antenna was tilted to include the angle from the aircraft to the ships at the lower portion of the beam. Thus, the proposed additional potential use of a forward-looking weather radar for moving target detection was demonstrated in flight. Needless to say, these large metal ships have excellent radar return characteristics, and the use of weather radar for small targets with poor reflectivity would limit such application. However, a 1970 NASA contractor's report, "Hazard Warning and Avoidance Systems," index No. 14, discusses this subject in depth and suggests design criteria for implementation.

MULTIFUNCTION SYSTEMS.

A study was undertaken by NASA to define the characteristics of a multiple function airborne system, including IAM capability. The results of this 1970 study define the system requirements to accomplish:

1. Terrain Avoidance,
2. Independent Approach and Landing Monitor,
3. Rollout and Taxi Guidance,
4. Weather Avoidance,
5. Collision Avoidance, and
6. Independent Altitude Monitor.

The approaches discussed in these documents considered the state-of-the-art overall system concepts as opposed to a structured building-block system utilizing existing equipment. Its criterion was a single system to serve multiple uses as opposed to a series of independent systems.

The conclusion of the NASA study leads to specific hardware performance requirements to obtain the desired objectives. These specifications are changed to meet varying performance requirements, such as desired maximum range, obstruction detection dimensions, rain rate attenuation limits, system accuracy, aircraft performance, etc.

The sensor inputs (i.e., slant range) are defined and are not considered a limiting factor. Thus, the accuracy of determining pressure, altitude, aircraft groundspeed, etc., are not considered to be limiting on overall system performance.

SENSORS.

All the IAM concepts discussed in the literature and in this report, assume the sensor (the device used to generate a signal which relates to a desired measurement) meets the nominal requirements of the system.

One example is in the AAS, which uses as its sensor the aircraft's static pressure system. The assumption here is that the pressure within the system is an accurate representation of the aircraft's pressure altitude. Thus, errors due to partial or total blockage by water ingestion or other foreign matter are presumed to be minimal at worst.

An example in the GPWS concept is that the signal of the radar altimeter is an electrical output assumed to vary logarithmically with increasing altitude. In fact, the nonlinear amplitude output of the radar altimeter is a series of straight lines. The time-delay function is based on noise and irregularities of the terrain only. Thus, to avoid introducing closure alarms based on changes in radar height, it is necessary to smooth these data prior to determining the deviations electronically.

Another GPWS-related assumption is that the output of the pressure altitude transducer "Baro Box," (device required for those aircraft not equipped with an adequate central air data computer) is as accurate as that produced by the central air data computer (CADC). In fact, the Baro Box is not tied into the aircraft's primary static pressure system. Thus, its sensitivity (position error) to angle-of-attack is not known. Secondly, the temperature sensitivity of the sensor and the lag due to system volume are not considered. Thus, the actual performance of the GPSW is not defined.

In a downward-looking radar system, the change in the antenna position as a function of pitch and/or roll is assumed not to be an influencing factor. During the previously cited USAF flight tests, some nuisance warnings were believed to have been generated by the changes in closure due to aircraft maneuvering. Since the USAF tests were functional only, this phenomenon was not explored.

Forward-looking radar has its sensor limitations which must also be defined. The beam characteristics, sensitivities to aircraft body axis motion, and spurious returns are some of those factors which must be known before using in an IAM system.

The characteristics and limitations of sensors in some of the other more complex concepts, such as INS or 3D/RNAV, would also be limiting on these systems. The performance of the individual sensors (transducers) are assumed to be resolved by checking overall system performance. Thus, if the output of the system conforms to the input, within defined, acceptable accuracies, the system is acceptable. The GPWS is an example of this concept. The error in this assumption is that the factors which may introduce sensor errors are not included nor required in system testing.

It should be noted that the converse of this can also produce problems; that is, the interfacing of various sensing elements without system performance considerations can also result in undetected errors. An example is the pressure altitude-indicating system of an aircraft. In this case, the altimeter is manufactured to meet the minimum acceptable standards of the applicable Technical Standard Orders (TSO). The interconnecting plumbing must meet the requirements of the appropriate FAR's. In addition, if the aircraft is to be used for IFR operations, the altimeter and the interconnecting plumbing is checked biannually for compliance to FAR's. However, the response of the total system to a pressure change is not determined.

COCKPIT ANNUNCIATORS.

The independent altitude monitor raises the question of "how does it alert the flight crew?"

Various types of annunciators are currently employed in the cockpit. They include lights, horns, clappers, varying tone indicators, and more recently, with the GPWS, voice commands.

In the recent C141 tests, it was discovered that under normal pilot recurrency check-flight stresses, the GPWS varying tone was mistaken for the fire-warning tone which is similar only in tone. On many large aircraft, the altitude alert light and decision height (DH) light are the same color and are located in very close proximity to each other. Informal interviews with some flight crews indicated that these light annunciators have been mistaken for each other.

The number of annunciators in the cockpit also has added to the confusion and apparent ignoring of annunciators under high-stress conditions. In the case of the Eastern L1011, there was an altitude alerting for which no corrective action was initiated. In the TWA B727 accident, there was a DH warning which did not result in any initial corrective action.

The cockpit annunciation situation is the result of additive growth and not total system construction. Therefore, the form that the IAM annunciator might take should be considered from a total warning picture to avoid total rejection of all annunciators. Many of those interviewed from all segments of the aviation industry stressed this problem.

The USAF developed a complex verbal annunciation system which was used in the B58 aircraft. Although this system was complex, todays technology does allow for such concepts, as noted by the success in producing verbal alarms in the GPWS. Here too, are problem areas such as command versus guidance. A B58 landing gear accident was alleged to have been due to a malfunctioning or false verbal indication of incorrect landing gear position. The pilot apparently changed the landing gear lever from the proper position to the wrong position due to his reaction to a verbal command. One of the GPWS manufacturers went from a command "PULL UP" to a guidance "FLY UP" verbal warning.

Another form of annunciation was discussed in the previously referenced FAA report, index No. 1. In this report it was indicated that alphanumeric message displays could be generated for all forms of annunciation with or without a priority rating scheme.

An expansion of the information contained in index No. 1 is the use of existing IFR cockpit information display for multiple mode operations. An example would be the use of smoothed altitude encoder data on the glide slope pointer as an IAM annunciator for nonprecision approaches. This in turn could be expanded, wherein a double needle or split needle could be used as the IAM annunciator during precision approaches. In both of these concepts, the annunciation is in the form of conventional pilot information presentation. In the latter case, the system would be the more desirable type of IAM annunciation, since it would employ two different sources of vertical guidance, both of which provide height above the touchdown point (QFE).

AIRCRAFT PERFORMANCE.

Any IAM concept must consider the limitations imposed by the aircraft. The annunciation or guideline information has to be provided in time to allow the pilot to initiate corrective action and the aircraft to respond to pilot input.

An analysis of the avoidance manuever, assuming a 1.5-g pull up, was done by NTSB. The assumption also involves that the aircraft will attain the maximum climb rate 2 seconds after the alarm and neglects airspeed decay during such transition to climb (tables 1 and 2).

Thus, any airborne terrain avoidance system must either provide sufficient projected leadtime to allow for safe aircraft maneuvering or detect the actual threat in time to accomplish the maneuver. The former condition defines a much longer protection envelope, thereby inhibiting the mission or operational envelope of the aircraft to avoid nuisance warnings. A reduction in the protected envelope would reduce the effectiveness of the system as shown in the independent altitude monitor report, index No. 1. A downward-only radar system is an example of such an approach.

TABLE 1. CONDITION I-200-KNOT AIRSPEED WITH MAXIMUM CLIMB RATE OF 4,000 ft/min

	γ	H	d_1	h_1	Max. Height of Terrain Rise Which Can Be Cleared HTC
v = 20,254 ft/min	5.6	50	510	-	-
v = 337.6 ft/s (mode 4)	5.6	500	5099	436	No impact
γ_2= 10.6°	10.6	1500	8015	1251	No impact
γ_2= 5.6	20	1500	4121	855	1239
θ = 11.4°	30	1500	2598	442	377
d_2= 675 ft	40	1500	1788	-100	112
d_3= 1,399 ft	50	1500	1259	-832	26
h = 140 ft	60	1500	866	-1952	3
	70	1500	546	-4058	---

All terms used are defined below and shown pictorially in figure 1.

v = aircraft initial velocity.

γ = terrain gradient.

γ_1= terrain gradient necessary to produce mode 2 warning at 50 feet radio altitude.

γ_2= minimum terrain gradient which will produce mode 2 warning at 1,500 feet radio altitude.

h = radio height at time of alarm.

d_1= horizontal distance to terrain at time of alarm.

d_2= horizontal distance traveled during 2 seconds.

d_3= horizontal distance traveled during transition to maximum climb angle.

θ = maximum climb angle.

h = altitude gained during transition to maximum climb angle.

h_1= radio altitude at attainment of maximum climb angle.

W = weight

g = gravity

m = mass

a = acceleration

F = force

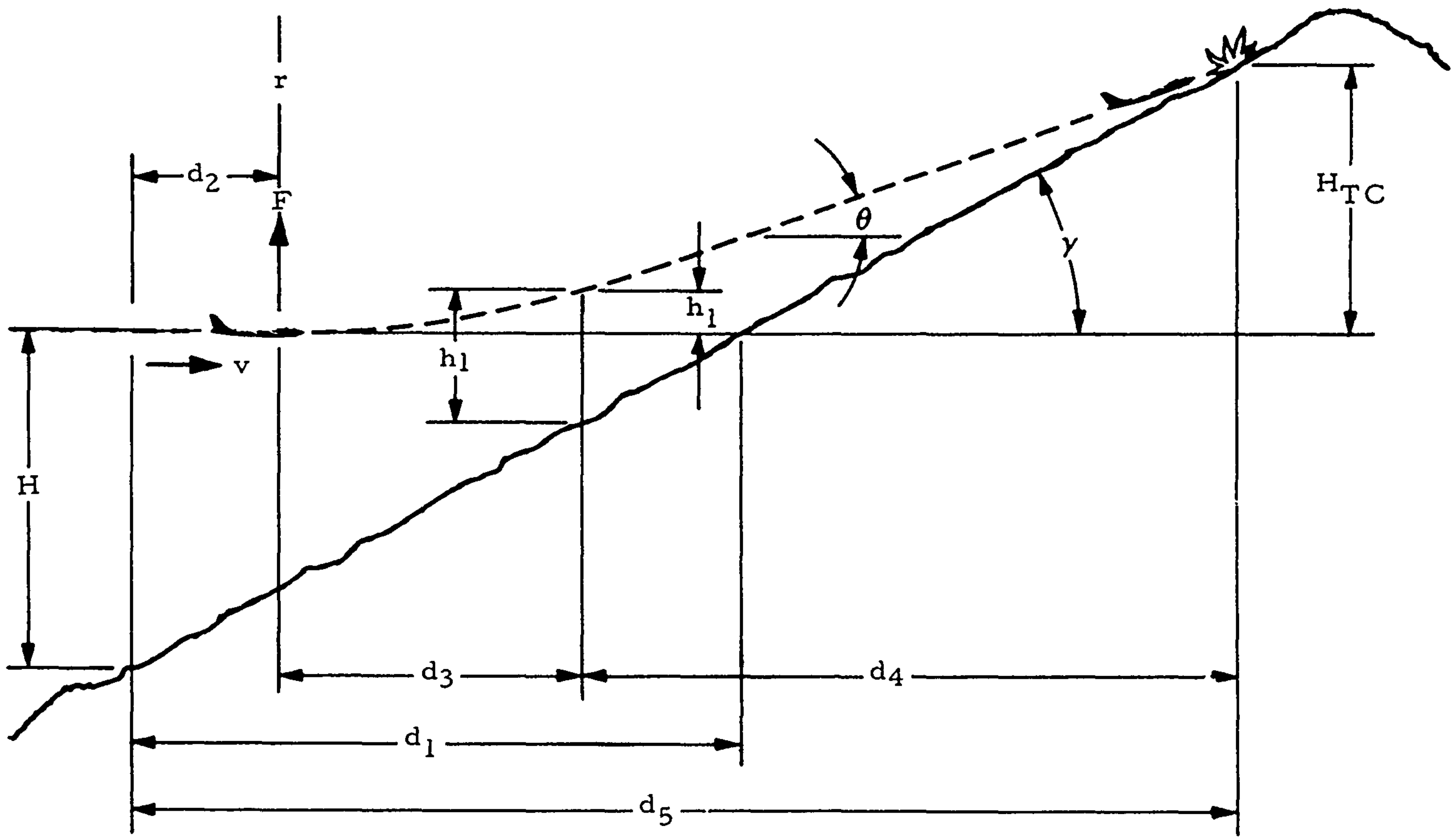

FIGURE 1. AIRCRAFT FLIGHT PROFILE BASED ON 1.5 g FLIGHT PROFILE

TABLE 2. CONDITION II-150 KNOT AIRSPEED WITH MAXIMUM CLIMB RATE OF 2,000 ft/min

	γ	H	d1	h_1	Max. Height of Terrain Rise Which Can Be Cleared HTC
v = 15,190 ft/min	7.5	50	380	-	-
v = 253.2 ft/s (mode 4)	7.5	500	3798	399	No impact
γ_1 = 14.0°	14.0	1500	6016	1278	1489
γ_2 = 7.5°	20	1500	4121	1160	700
θ = 7.56°	30	1500	2598	940	315
d_2 = 506 ft	40	1500	1787	671	161
d_3 = 524 ft	50	1500	1258	307	73
h = 35 ft	70	1500	866	-249	17
	70	1500	546	-1294	-

The equations used above in determining the rules shown were:

1. Determine angle of slope equivalent to GPWS logic; i.e.,

   A 3,800-ft/min closure rate will produce an alarm at an altitude of 1,500 feet and, a 2000-ft/min closure rate will produce an alarm at an altitude of 50 feet.

   Slope equivalent to 3,800 ft/min closure at

   $\gamma_2 = \tan^{-1} \frac{3800}{v}$ where v is in ft/min

   $\gamma_1 = \tan^{-1} \frac{2000}{v}$ ft/min

   For 200 knots γ_1 = 10.6, and γ_2 = 5.6

   For 150 knots γ_1 = 14.0, and γ_2 = 7.5

2. Horizontal distance to terrain (d_1).

   $d_1 = h/\tan \gamma$

3. Distance required for pilot action (d_2).

   d_2 = v (ft/sec) x 2 sec.

4. Maximum climb angle (θ).

   $\theta = \sin^{-1} \frac{R/C\ max}{V\ (ft/min)}$

TABLE 2. CONDITION II-150-KNOT AIRSPEED WITH MAXIMUM CLIMB RATE OF 2,000 ft/min (Continued)

5. Distance required to achieve maximum climb angle (d_3).

$d_3 = r \sin \theta$
where r is determined from

$$F = ma = m \frac{v^2}{r}$$

for 1.5-g maneuver, F =.5W,
and substituting W/g for m and transposing

$$r = \frac{v^2}{.5g}$$

6. Altitude gained in transistion (h).

$h = r - r \cos \theta$

7. Clearance from slope at completion of transition (h_1).

$h_1 = H + h - h_3$

where $h_3 = (d_2 + d_3) \tan \gamma$

$h_1 = H + h - (d_2 + d_3) \tan \gamma$

If h_1 is positive and $\theta > \gamma$ there will be no theoretical impact.

If h_1 is positive and $\theta < \gamma$ impact occurs after maximum climb is attained. Determine h_2 using step 8.

If h_1 is negative, impact occurs during climb transition. Determine h_2 using step 9.

8. Maximum height of hill which can be cleared HTC (h_2).

$$HTC = h + \frac{h_1}{\left(\frac{\tan \gamma}{\tan \theta} - 1\right)}$$

9. Maximum height of hill which can be cleared HTC (h_2).
Solve for θ

$$\tan \gamma \sin \theta + \cos \theta = \frac{r + H - d_2 \tan \gamma}{r}$$

where θ mm $\approx \sin^{-1} \frac{d_1 - d_2}{r}$

Then $h_2 = r - r \cos \theta$.

The other type system would require selective aircraft flightpath monitoring and identification of threat obstacles along its path. One such system is a forward-looking radar. However, such systems are more complex than the former system.

OPTICAL DETECTION.

Most of the development in optical concepts for height determination were sponsored by the military. The principal objectives of these programs were terrain avoidance during periods of darkness and ground fog and terrain mapping.

A NASA report, index No. 14, enters into the limitations of all optical techniques, infrared (IR), low-light television (LLT), and lasers. The principal problem of optical systems for an IAM function is the unacceptable attenuation of system performance under high rainfall rates. Recent studies indicated that the pulsed carbon dioxide (CO_2) lasers may overcome some of the short-range limitations due to atmospheric water vapor and liquid water content or rain.

One of the advantages of optical systems is their possible use during in-flight turbulence or wind shear detection. However, these applications are not the objective of this report. They are cited only to enlighten the reader of their potential application.

CONCLUSIONS

The following conclusions are based on the analysis of the information contained in the literature review and informal conferences with various segments of the aviation community.

1. Approach and landing accidents represent 40 percent of all commercial accidents and 24 percent of general aviation accidents. An independent monitor of altitude or indication of vertical height is believed to be a desirable flight safety enhancement device to prevent such accidents.

2. Several IAM techniques are currently scheduled for implementation by the FAA. These include the GPWS, which uses downward-looking radar, and enhancement of the automated radar terminal system (ARTS III) through use of the mode C transponder information (MSAW).

3. Forward-looking radar offers the potential of better terrain avoidance than downward-looking radar.

4. The multiple use of weather radar for enhancement of GPWS is within the existing state of the art. Some GPWS designs are amenable to such enhancement through up-grading.

5. Current radar technology can be adopted to provide not only independent altitude monitoring, but also detection of atmospheric turbulence, in-flight collision avoidance, and noncooperative precision approach. The multiple mode usage would be limited by the liquid water content of the atmosphere as a function of the system operating frequencies.

6. The greatest attenuation of the forward-looking radar concepts occur in the visible light spectrum (lasers) and decreases (improves range detection) with decrease in frequency (infrared, and K_a, K_u, X, and S band radar).

7. The multiple use of existing flightpath control guidance devices, such as the flight director, for independent altitude monitoring is a potential technique for providing IAM annunciation.

8. Multiple annunciation under high-stress conditions can lead to confusion or disregarding of existing annunciators.

9. Nuisance warnings can result in disregarding the annunciation system when it may be critical or when it may aggravate an already high-stress condition.

10. The extended use of onboard sensors for later design systems without consideration to sensor limitations could compromise later system usefulness.

11. IAM systems must consider aircraft performance limitations and conditions of flight safety in order to be effective.

12. Different sources of vertical guidance or independent altitude monitoring would be preferable to multiple annunciation of the same generic information:

13. Redundant annunciation of critical altitude information does not necessarily preclude accidents which the redundant systems were designed to prevent.

BIBLIOGRAPHY

1. ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY, Shrager, Jack J., National Aviation Facilities Experimental Center, FAA-NA-73-78, June 1974.

A review of all literature published since 1967 relating to aircraft flight controls and displays was made. Special emphasis was placed on the contents of those documents as they related to the all-weather landing and takeoff operational envelope. The results of this review are evaluated, summarized, and conclusions drawn. This is supplemented by an annotated bibliography and author's index.

2. AIRLINES, MANUFACTURERS RUSH TO MEET DEC. 1 GPWS DEADLINE, Richardson, R. M., Air Transport World, Vol. 12, No. 3, pp. 31-34, March 1975.

3. ALL WEATHER LANDING SIMULATION FOR CATEGORY III AIRBORNE CONFIGURATION, Volume I. Summary of Studies on Flight Directors and Split Axis Control, Gainer, C. A., Monroe, R. D., and others, Bunker-Ramo Corp., Report No. RD 67-56, July 1967.

Two flight simulation studies were completed testing the feasibility of current display-control concepts and hardware for commercial subsonic jet transport all-weather (Category III) approach and landing. A total of 3,780 simulated landings were flown by 76 B707-720B qualified pilots. The percentage of successful touchdowns (Study 1 = 42%; Study 2 = 65%) was not acceptable for Category III operation. It was concluded that current flight director displays require modification for improved flare and decrab information. While pilots expressed a clear preference for integrated roll bar over crosspointer displays, performance data were essentially equivalent. Lateral control problems were the greatest single cause of unsuccessful touchdowns; an improved decrab presentation only slightly improved performance. The introduction of display and control failures during approach has a detrimental effect on performance at touchdown. While actively engaged on manual vehicle control, pilots overlooked many display failures, and, on some approaches where two successive display failures were given, a large number of pilots did not detect the second failure. The need for improved fault warning displays was clearly demonstrated. Current control-display concepts for this mission segment create a serious workload problem for the pilot; it was demonstrated that the use of autothrottle and split-axis control reduces workload and improves approach and landing performance.

4. ALTITUDE MONITORS, A REPORT BIBLIOGRAPHY, Anonymous, Defense Documentation Center, Alexandria, Virginia No. 031050, June 1975.

5. ANALYSIS OF CUMULATIVE ERRORS ASSOCIATED WITH CATEGORY II AND III OPERATIONS WITH REQUIREMENTS FOR ADDITIONAL RESEARCH,
Litchford, G. B., Litchford Systems, NASA CR-118 National Aeronautics and Space Administration, Washington, D.C. September 1968.

This report presents the results of a study and investigation of conventional and unconventional terminal flightpaths for CTOL aircraft in connection with low-visibility landing problems. The interrelationships of the geometry of possible approach paths, visual and electronic guidance equipments, and merous aircraft piloting problems are reviewed. Pilot display requirements for optimizing these interrelationships under typical airline operating conditions are described as well as the flightpath dispersions expected at the transition from instrument to visual flight guidance. Areas requiring improved simulation, flight validation, or other means of establising statistically significant data for these critical operations are identified. The ILS standards will be examined to identify errors that affect the transition from instrument to visual flight.

6. APPLICATION OF LIGHT-SCATTERING TECHNIQUES FOR MEASUREMENTS OF DENSITY, TEMPERATURE, AND VELOCITY IN GASDYNAMICS,
Lapp, M., Penney, C. M., and Asher, J. A., General Electric Company, SRD-72-085, April 1973.

Methods based upon light-scattering techniques for the three-dimensional measurement of density, temperature, and velocity are evaluated for application to wind tunnel studies over wide ranges of the stated variables for air: 0.001 to 100 psia, 30 to 2,000° R, and 0 to 5000 feet per second. Recommended approaches are laser Doppler velocimetry for velocity measurement and rotational and vibrational Raman scattering for temperature and density measurement. The laser Doppler velocimeter technique is in an advanced stage of development and its implementation is discussed in detail. The Raman approach is innovative and has been selected on the basis of potential advantages over alternative approaches. Although the projected capabilities are analyzed and presented in detail, the recommended system has not as yet been implemented in the laboratory. The Raman techniques are shown to be applicable over the entire range of flow parameters, which correspond to the entire range of flow parameters, which correspond to the pressure-temperature loci from stagnation conditions to the design point for the three major test facilities under consideration at Wright-Patterson Air Force Base. The most extreme test facility conditions correspond to a Mach 14 flow from 2,000° R and 1500 psia stagnation conditions, which leads to a density of 6.6×10^{18} to 1.7×10^{15} molecules per cubic centimeter). To provide for alternate techniques at the lowest densities, in the event that experimental implementation of the Raman techniques encounters unforeseen difficulties, electron beam fluorescence, and Rayleigh scattering methods are discussed. It should be noted that the density measurement based upon vibrational Raman scattering is almost completely independent of temperature, and the temperature measurement technique (involving the ratio of rotational to vibrational Raman scattering) is entirely independent of density. A thorough discussion of the underlying physics is included to support the performance projections.

7. AURAL GLIDE SLOPE CUES: THEIR EFFECT ON PILOT PERFORMANCE DURING IN-FLIGHT SIMULATED ILS INSTRUMENT APPROACHES,
Hasbrook, A. Howard and Rasmussen, Paul G., Civil Aeromedical Institute, Report No. FAA-AM-71-24, May 1971.

Forty instrument-rated commercial and ATR pilots with 250 to 12,271 flight hours each flew simulated ILS approaches in a single-engine, general aviation aircraft. Divided into five groups, each group used a different glide slope cue display in combination with a modified "T" instrument panel configuration. Two types of aural glide slope cue displays were utilized: (1) voice, and (2) Morse code signals. No significant differences were found among the five groups relative to accuracy in glide slope tracking. There was no apparent improvement with practice. The presence of aural glide slope cues resulted in the aircraft being flown slightly higher across the middle marker than when only the conventional visual display was utilized. Localizer performance showed a slight but significant initial decrease in the presence of aural glide slope cues with respect to only one performance measure. This difference was minimized as a function of the number of approaches flown. No significant differences appeared among groups with regard to stress levels as measured by heart rate and heart rate changes. Mean heart rates declined over successive approaches but increased during each approach. Transition from the conventional visual cross-pointer display to the aural (voi- glide slope cues was achieved with a minimum of familiarization and with n parent difficulty.

8. AUTOMATIC ALTITUDE TRANSMISSION,
Parmentier, J. C., L'Onde Electrique, Vol. 49, pp. 622-626, June 1969.

9. BLIND LANDINGS MADE EASY,
Anonymous, Canadian Aviation, pp. 16-19, May 1972.

Report on seven landings in a small aircraft under simulated zero-zero conditions using an experimental "Flitegage" pilot display.

10. THE CASE FOR GROUND PROXIMITY WARNING SYSTEMS,
Scott, A. W., Airline Pilot, Vol. 43, No. 11, pp. 18-21, 58, November 1974.

A summary of events leading to the requirement for a GPWS with the Trans Global DC9 accident at Charlotte, N.C.

11. COLLISION AND OBSTACLE/TERRAIN AVOIDANCE WARNING SYSTEM (COTAWS),
Chanzit, L., United Aircraft Corp., Norden Div., ECOM 0362-1, May 1970.

12. COLLISION AND OBSTACLE/TERRAIN AVOIDANCE WARNING SYSTEM (COTAWS) MALFUNCTION SENSOR STUDY (U),
Confidential Report, AD-519599L, ECOM-0362-F, Feb. 1972.

This report describes the technical progress on work accomplished during the fourth and final quarter of contract No. DAAB07-69-C-0362, entitled Collision and Obstacle/Terrain Avoidance Warning System (COTAWS) Multifunction Sensor Study, with the U.S. Army Electronics Command, Fort Monmouth, New Jersey. The report also includes a summary of the investigation presented in detail in the three previous quarterly reports issued under this contract. The reader is requested to consult those documents for further information.

During the reporting period, work continued on each of the following principal tasks:

(a) Mission Analysis,
(b) Terrain Avoidance, and
(c) Combined Sensor Techniques.

The results of the investigations of each area are presented in this report.

13. COLLISION AVOIDANCE AN ANNOTATED BIBLIOGRAPHY, Sept. 1968 - April 1972, Bulford, D. E., NAFEC, Report FAA-NA-72-41, August 1972.

A bibliography containing 828 references with annotations which supplement a previous FAA report, FAA-NA-68-54 (AD 677 942), which consisted of 1,013 references without annotations.

14. COMMERCIAL AIR TRANSPORT HAZARD WARNING AND AVOIDANCE SYSTEM, VOLUME I SUMMARY, VOLUME II REQUIREMENTS STUDIES, VOLUME III RADAR PERFORMANCE STUDIES, APPENDIX A OPERATIONAL REQUIREMENTS, Bolz, E., et al., Polhemus Navigation Sciences, Inc., Contract No. NAS 12-2108, May 1970.

Analysis of the operational requirements for a Commercial Air Transport Hazard Warning and Avoidance System was performed in conjunction with a study of the available sensor technology suited to such a system. Particular emphasis was placed on the problem of low-visibility landings through a comprehensive investigation into such factors as meteorological and visibility data, aircraft accident statistics, airline-related economic benefits, current and future landing aids, and present operating procedures. The technology study was concentrated primarily in the area of microwave sensors at frequencies in the X, Ka, Ku, and V bands, with some additional analysis of electro-optical and infrared sensors. Operational requirements were studied for landings in visibility conditions down to and including Category IIIC.

Requirements for Independent Approach and Landing Monitor (IALM), High Ground Avoidance (HGA), and Rollout and Taxi Aid (ROTA) functions were developed. Several possible system configurations were postulated as they applied to the overall operational and functional performance requirements.

Volume I of this report is a summary volume, containing an overview of the conclusions and recommendations of the study. The main body of the report, the operational requirements, technology analysis, and system analysis is contained in volume II. Volume III is devoted to a detailed set of radar performance studies which provide the technical background for the study.

15. A COMPARISON OF VOICE AND TONE WARNING SYSTEMS AS A FUNCTION OF TASK LOAD, Kemmerling, Paul, et al., Wright-Patterson Air Force Base, ASD-TR-69-104, September 1969.

Twelve Air Force pilots current in high-performance aircraft flew a 100-nautical-mile simulated combat bomb sortie under varying task load and auditory saturation levels in order to compare voice and tone warning systems. An F111 flight simulator, with three-degrees-of-motion and Link SMK-23 visual system, was employed as the test bed for the experiment. Task loading was induced by giving the subjects no practice on the actual mission terrain prior to the first data run, introducing combat tapes to increase auditory saturation, and displaying pressure altitude commands instead of radar altitude commands on the HUD (head-up display). A noncritical emergency and an associated warning were given at three specific geographical points in the mission. Each of these geographical points represented a different task loading condition based on mission requirements. The pilot was warned by either a voice or a tone, in conjunction with an annunciator light. The voice and tone warning systems were evaluated by comparing the pilots' visual scan patterns and response times under various task load and saturation conditions. From the visual scan pattern, it was found that pilots who received tone warning were forced to cross-check the annunciator panel when receiving the noncritical failure. The voice warning afforded the pilot the option of responding to or completely ignoring a failure based on mission requirements. In addition, in those cases where voice-warned pilots chose to respond to the failure, they did so with faster response times than pilots receiving tone warning.

16. CONFORMAL PHASED ARRAY ANTENNA STUDY,
Moss, M. J. and Noneaker, D. O., Lockheed-Georgia Co., NASA-CR-86389, April 1970.

17. DESIGN CONSIDERATIONS FOR AN AIRCRAFT OBSTACLE AVOIDANCE SYSTEM BASED ON OBSTACLE STRIKE ACCIDENT EXPERIENCE,
Kellington, C. M, US Army Electronic Command, ECOM-4-30, October 1972.

Ninety-eight obstacle strikes by US Army aircraft are analyzed with a view toward influencing the design of airborne obstacle avoidance systems. Considered in the report are the salient factors relating to the accident location of the accident, type of aircraft involved, type of obstacle struck, aircraft mission, mode of flight, weather conditions, and altitude. Recommendations are made concerning operational features of an effective obstacle avoidance system.

18. DEVELOPMENT OF AN INDEPENDENT ALTITUDE MONITOR CONCEPT,
Parks, D. L., Hayashi, M. M., and Fries, J. R., Boeing Commercial Airplane Company, FAA-RD-73-168, September 1973.

Interest in increased safety for terminal area operations has led to a corresponding interest in methods by which safe altitude is monitored and conveyed to the crew, and in possible systems to provide an independent altitude monitor (IAM) function. This 7-month effort was to identify and describe alternative systems with the potential of providing such a function.

Study effort was in three phases. Phase 1, Initial Analysis and Survey, involved (a) terminal area operations analysis, to define the overall circumstances under which IAM requirements exist, (b) accident data analysis, for accident types and circumstances to which an IAM might apply, and (c) operations/research/manufacturer/vendor survey, to identify associated problem areas and to determine the nature of ongoing research and systems development. Phase 2, Data Collection/Requirements Analysis, included integration of phase 1 information in a detailed analysis of approach/land functions, including specific actions and associated information requirements.

Results provided the basis for identifying IAM system functional requirements, and for phase 3, IAM Concepts Identification and Technical Evaluation Concepts, covered a variety of possibilities related to (1) basic IAM trade study requirements, (2) visual aids, (3) present and future landing systems, (4) airborne IAM systems, (5) cooperative/ground IAM systems, and (6) procedures and training considerations.

19. DEVELOPMENT OF A MICROELECTRONIC ALTITUDE/DIVISION/ALERTING SYSTEM, Bergey, John H., Naval Air Development Center, NADC-AN-6902, February 1969.

An Altitude Advisory/Alerting Device was developed to increase pilot awareness of altitude. The system is complementary to the equipment developed under the AIMS Automatic Altitude Reporting program in that the encoded altitude output is displayed to the pilot and is used as a basis for command altitude information. The display consists of a direct reading, numeric altitude display and three shape-coded altitude alerting indicators. The indicators alert the pilot and/or crew members of approaches (proximity) to and deviations from a selected command altitude. The report includes detailed information on the theory and operation of the device. A prototype model was fabricated and operated satisfactorily in the laboratory.

20. EFFECTS OF A 100-FOOT OPTION ALTITUDE RULE AND AN ANNUNCIATOR PANEL ON FAILURE DETECTION, GO-AROUND DECISIONS AND LANDING PERFORMANCE, Semple, C. A., et al., Bunker-Ramo Corp. RD68-11, February 1968.

Twenty rated pilots participated in a simulator study designed to investigate pilot and system responses to control and display system failures occurring during automatic Category III-C instrument approach to landing. The "option altitude" rule used in the study required that (1) when a failure occurred above 100 feet, the pilot was required to execute a go-around, (2) when a failure occurred below 100 feet, it was the pilot's option to continue the approach or to go-around. The utility of a failure annunciator panel also was explored. Following failures below 100 feet, pilots continued the approach through landing and rollout 382 out of 400 times. Relative to preestablished criteria, only 20 percent of the manually controlled touchdowns were successful, due primarily to excessive sink rates. A majority of the unsuccessful landings occurred during tailwind shear conditions; however, many unsuccessful manually controlled landings also were observed when the tail shear was not present. Autopilot touchdown performance showed similar trends, although autopilot touchdown performance was considerably better. The failure annunciator panel used had no effect upon pilot decisions to land and little effect upon pilot-system performance. Failure detection performance was slightly improved by the annunciator panel.

21. EFFECTS OF PRECIPITATION ON PROPAGATION AT 0.63, 3.5, AND 10.6 MICRONS, Chu, T. S. and Hogg, D. C., The Bell System Technical Journal, Vol. 47, No. 5, pp. 723-759, May - June 1968.

The attenuation and scattering of laser beams by rain, fog, and snow have been calculated and measured at 0.63, 3.5, and 10.6. Attenuation of the infrared wavelengths by light fog is up to one order of magnitude less than at 0.6 microns. But for dense fog, calculation shows that the attenuation at 10.6 microns can exceed 40 dB per km. It is found that attenuation by rain can be calculated to good accuracy from average path rain rates provided that forward scattering is taken into account; this scattering reduces the attenuation.

Measurements of propagation through precipitation over a 2.6-km path are discussed in detail and are found to be consistent with predictions. The wavelength dependence of attenuation is found to vary from one fog to another because of different drop-size distributions. Attenuation of 0.63 microns in rain showers is about 20 percent less than at 3.5 microns and is, of course, much less than the attenuation in fog. But even for extremely heavy rain showers, the 0.63 microns attenuation never exceeded 20 dB per km, which is less than the attenuation of millimeter waves under such conditions. Both the attenuation and forward scattering properties of snow appear to be betweeen those of fog and rain.

22. EVALUATION OF FLIGHT DIRECTOR ELEMENTS--RISING RUNWAY, EXPANDED LOCALIZER AND ROLLOUT STEERING--DURING SIMULATED CATEGORY III-C MANUAL AND SPLIT-AXIS LANDINGS,
Vreuls, D., et al., Bunker-Ramo Corp., Report No. RD-68-10, February 1968.

This was the second of a series of four studies in the current contract to examine the feasibility of display and control concepts for commercial subsonic jet transport all-weather landing. The study examined the utility of the rising runway, expanded localizer, and rollout steering display elements of flight director systems during manual and split-axis Category III-C landings. A total of 19 commercial airline pilots flew a total of 684 ILS approaches through rollout without visual cues in a fixed-base research simulation of a Boeing 707-720B (STIR). Results indicated that both longitudinal and lateral plane performance deteriorated when the expanded localizer off, the rising runway improved full manual touchdown performance when it came into view at 200 feet of wheel height (47 percent successful). Pitch manual split-axis landings were best when the rising runway came into view at 100 feet (66 percent successful). Vertical-plane manual performance was excellent through 50 feet of altitude, but the flare caused problems. Data are presented to show why the flare computation was not compatible with the human pilot, and the need for improved flare computation for human pilot use is discussed. Roll manual split-axis touchdowns were 73 percent successful; manual lateral control was not tight enough to consistently land the simulator on the runway. Autopilot roll axis control to touchdown was the major determinant of rollout success. Following roll automatic touchdowns, the runway steering command slightly improved rollout performance; whereas, the expanded localizer had little effect. Pilots reported that they would not attempt a Category III landing without a rollout steering command. It was found that the pilots did little in the simulator during the first seconds of rollout to correct a lateral problem that would cause the simulator to depart the runway; spoiler extension and thrust reversing distracted the pilots from accurate steering control.

23. EVALUATION OF A TERRAIN PROXIMITY WARNING SYSTEM (DOWNWARD LOOKING RADAR) FOR POSSIBLE ENHANCEMENT OF FLIGHT SAFETY,
Shrager, Jack J., National Aviation Facilities Experimental Center, FAA-RD-73-134, August 1973.

A review of all literature and available test results of an airborne independent altitude monitor based on radio altitude information was undertaken. Results indicated that limited flight safety enhancement is attainable by use of such a device.

24. FAA ASKS GROUND PROXIMITY WARNING BE MADE MANDATORY,
Anonymous, Aviation Week and Space Technology, Vol. 101, No. 12, p 34, September 1974.

25. FEASIBILITY OF LASER SYSTEMS FOR AIRCRAFT LANDING OPERATIONS UNDER LOW-VISIBILITY CONDITIONS,
Viezee, William, Oblanas, John, and Glaser, Myron, Stanford Research Institute, FAA-RD-74-190, October 1974.

The effects of currently recommended eye-safety standards and of atmospheric scattering on the potential application of lasers to the low-visibility aircraft approach and landing operational environment are assessed. It is concluded that these two criteria are serious handicaps in any proposed development of a laser landing guidance system. The two criteria are interrelated: the application of high-power, narrow-beam lasers to overcome the large attenuation in dense fog increases the eye-safety hazard, whereas a lowering of laser power to guarantee eye-safety drastically reduces the distance over which the laser beam can be used effectively. Since the scattering coefficient during conditions of fog is essentially independent of wavelength, no laser wavelength that also falls within an absorption-free "window," appears to be significantly better than any other wavelength as far as penetration in fog is concerned.

The results of the evaluation of lasers as visual cues or optical guidance systems are based primarily on the performance characteristics of optical lasers under operationally important low-visibility conditions such as exist under Category III (700 feet and 150 feet RVR). In these dense fog situations, computations suggest that a laser would provide the pilot of a descending aircraft with a visual cue not much more than a second or two before the high-intensity runway edge lights can be seen. The data demonstrate that for visibility conditions better than Category II (1,200 feet RVR), lasers begin to provide a significant advantage over conventional runway and approach lighting. In this case, however, potential eye-safety hazards to the air crew become a critical issue.

Modification of the conclusions can be visualized as a result of possible future new developments in laser technology or revisions in the currently recommended eye-safety standards.

26. FOG MODIFICATION--A TECHNOLOGY ASSESSMENT,
Silverman, Bernard A. and Weinstein, Alan I, Air Force Cambridge Research Laboratories (LYF)AFCRL-TR-73-0159, March 1973.

This report is a comprehensive review of fog modification. It includes discussions of the physical structure and climatological characteristics of various types of fog. The three different methods of fog modification, that is, removal, evaporation, and prevention are discussed, as are the general requirements of fog dispersal. In depth descriptions are given of the techniques used to modify supercooled, warm, and ice fog.

27. CPWS FOR CORPORATE/BUSINESS AIRCRAFT: SUCH SYSTEMS SHOULD SIGNIFICANTLY REDUCE CFIT ACCIDENTS,
Penny, P. E., ICAO Bulletin, Vol. 30 No. 3., pp. 28-31, March 1975.

Control flight into terrain (CFIT) accidents account for the vast majority of all fatalities in aircraft accidents in the past 20 years.

28. GPWS SPECS APPROVED,
Anonymous, Aero Line, 75-011/AERO-03, March 1975.

AEEC approves project papers S94 (GPWS) and 595 (BARC).

29. GROUND-BASED COLLISION AVOIDANCE SYSTEMS FOR AIR TRAFFIC,
Culhane, L. G. and Horowitz, B. M., EASCON '74; Electronics and Aerospace Systems Convention, Washington, D. C., October 7-9, 1974. A75-26029 10-32, New York, Institute of Electrical and Electronics Engineers, Inc., 1974, p. 264-271, 6 refs.

This paper presents analytical, simulation, and experimental results which have been obtained in the process of designing and progressing toward the implementation of ground-based collision avoidance systems for air traffic control. Selective subsystem performance criteria established as part of the design process are also presented. Two different, but compatible system concepts are discussed. Firstly, for situations involving IFR aircraft, a conflict alert capability will provide the controller with a displayed alert of impending situations of separation being less than minimums. Secondly, an Intermittent Positive Control (IPC) function, utilizing data link and improved surveillance, provides an automated collision avoidance capability for VFR/VFR and VFR/IFR aircraft pairs, and provides an independent backup to the ATC system for IFR aircraft pairs. In addition, IPC includes pilot warning indications (PWI) for informing pilots of the location of proximate aircraft.

30. GROUND PROXIMITY WARNINGS,
Broadbent, S., Flight International, No. 3442, Vol 107, pp 341-342, February 1975.

An in-flight evaluation of the five modes of alarm by four airline pilots using the HS.748 test aircraft equipped with a Sundstrand Dash 060 GPWS. Limitations to each of the modes of warning were noted by the group.

31. GROUND PROXIMITY WARNING SYSTEMS: A MAJOR ENHANCEMENT OF AIRLINE FLIGHT SAFETY,
King, W. H. and Codish, N., ICAO Bulletin, Vol. 30, No. 3, pp. 223-27, March 1975.

32. GROUND PROXIMITY WARNING SYSTEMS (GPWS) FLIGHT TEST,
Hovde, Robert J., Maj. USAF, Air Force Flight Dynamics Laboratory, AFFDL-TD-75-1-FGT, October 1975.

The objective of this flight test was to evaluate the in-flight operation of five commercially manufactured Ground Proximity Warning Systems (GGPWS). The units were operated simultaneously aboard NC-141A/61-2775 to verify their compliance with Federal Aviation Administration specifications and Air Force mission requirements. The results are: 1. The prototype computer provided by EDC Corporation was inoperative during most of the test, and the data are not considered reliable. It did appear to be within the specified warning envelope when it provided warnings. 2. The other four computers (Bendix, Collins, Litton, and Sundstrand) worked according to specifications in most cases. The conclusions are: 1. The data do not show a clear operational preference of any one computer over the others. 2. The Air Force has special mission requirements that are not compatible with present GPWS specifications.

33. HUMAN FACTORS EVALUATION OF THE GROUND PROXIMITY WARNING SYSTEM (GPWS),
Geiselhart, R. ASD Preliminary Report, USAF Wright Patterson AFB, Dayton, Ohio, September 1975.

34. IMPLICATIONS OF ADVANCED AVIONICS ON AIRLINE OPERATIONS,
Olsen, K. 3., Wescon Technical papers, pp. 17-21, 17-27, August 1970.

35. IMPROVING LANDING/TAKEOFF AND TERMINAL AREA SAFETY,
Gilbert, G. A., Airline Pilot, Vol. 39, pp. 70-76, September 1970.

36. INDEPENDENT ALTITUDE MONITORING ALERT METHODS AND MODES STUDY,
Smith, W. D., et al., Boeing Commercial Airplane Company, FAA-RD-75-86, July 1975.

Several studies have been performed to investigate the effectiveness of and develop independent altitude monitoring (IAM) systems. These studies noted that all IAM system concepts featured the common problem that IAM systems applications may be futile if pilot attention and comprehension of the IAM alert is not assured. This contract was issued to study that problem. The objectives of this study were to define an operational IAM alerting philosophy, develop candidate concepts, demonstrate and refine selected candidates, and develop implementation schemes. The output includes a summary of the alert philosophies used in current aircraft and IAM systems, a data base of currently used alert characteristics including stimuli response characteristics, a recommended IAM alert philosophy for each of four categories of aircraft, and guidelines for developing (or completing development) and implementing IAM alert systems. Basic alerting system concepts were developed for each category of aircraft. Implementation feasibility was evaluated for each concept; implementation recommendations are made.

37. INDEPENDENT ALTITUDE MONITOR, LITERATURE SEARCH,
NASA, Scientific and Technical Information Div., No. 29525, June 1975.

38. AN INVESTIGATION OF ERRORS AND DATA PROCESSING TECHNIQUES FOR AN RF MULTILATERATION SYSTEM,
Britt, Charles L. Jr., Research Triangle Inst., NASA-CR-132609, February 1975.

The development of an RF multilateration system to provide accurate position and velocity measurements during the approach and landing phase of vertical takeoff aircraft operation is discussed. The system uses an angle-modulated ranging signal to provide both range and range rate measurements between an aircraft transponder and multiple ground stations. Range and range rate measurements are converted to coordinate measurements, and the coordinate and coordinate rate information is transmitted by an integral data link to the aircraft. Data processing techniques are analyzed to show advantages and disadvantages. Error analyses are provided to permit a comparison of the various techniques.

39. INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS,
Ralles, Homer A., Northrop Corporation, NORAIR Division, USAAVLABS Technical Report 66-78, November 1966.

This study evaluates the obstacle impact hazards incurred by operation of U.S. Army aircraft at treetop altitudes and describes techniques useful in alleviating those hazards. The magnitude of the problem of obstacle impacts is determined by a statistical analysis of aircraft tree strikes and wire strikes to identify the significant parameters involved. Investigation of sensor techniques and aircraft operating procedures is presented to aid development of obstacle warning systems.

40. LASER IN-FLIGHT OBSTACLE DETECTION DEVICE,
Hancock, John D. and Holbrook, James A., Honeywell Radiation Center, 1 E1-20601-A-219-03, April 1970,

This report contains results of a design development and a test effort performed by Honeywell Radiation Center on a laser in-flight obstacle detector (LIOD) under contract from ECOM, Fort Monmouth, New Jersey. It includes a brief summary of the Army Aircraft wire strike problem, describes the system design, and presents results of limited ground and flight tests performed in an HU19 helicopter. Recommendations for further developments are made. Appendices describe the major subsystem components.

41. LASER TECHNOLOGY IN AERODYNAMIC MEASUREMENTS,
Anonymous, NATO AGARD -LS-49.

42. THE LAST THOUSAND FEET,
Ramsden, J. M., Flight International, No. 3437, Vol. 107, pp. 107-112, January 1975.

43. LIDAR OBSERVATIONS OF THE LOWER ATMOSPHERE,
Davis, P. A., Stanford Research Institute, Report - Project 5812, August 1966.

44. LOW VISIBILITY LANDINGS II,
Litchford, G. B., Astronautics and Aeronautics, Vol. 16, pp 44-56, December 1968.

45. MONTE CARLO STUDIES OF LIGHT TRANSPORT THROUGH NATURAL ATMOSPHERES.
Blattner, Wolfram and Wells, Michael B., Radiation Research Associates, Inc., AFCRL-TR-73-0109, December 1972.

This report describes the work that was performed during the contract period on six major work areas.

46. NEEDED: A FRESH VIEW OF MILITARY AVIONICS,
Doran, R. J., Astronautics and Aeronautics, Vol. 7, No. 7, pp 72-77, July 1969.

47. AN OPERATIONAL LOOK AT GPWS,
Geiger, W. J., Flight Operations, Vol. 64, No. 3, pp 23-25/55, March, 1975.

Flight evaluation of an accident which occurred at Pago Pago.

48. PILOT FAILURE DETECTION PERFORMANCE WITH THREE LEVELS OF FAULT WARNING INFORMATION,
Vreuls, D., Barnebey, S. F., and others, Bunker-Ramo Corp., Report No. RD-68-9, February 1968.

The reported study was the first of a series of four studies to examine the feasibility of display and control concepts for commercial subsonic jet transport all-weather (Category III) approach and landing. The study was addressed primarily to fault warning. Pilot detection of autopilot and display system failures was examined with three levels of fault warning display information. Display failure detection and pilot decisions were additionally examined as a function of pilot task load, manual in one axis or automatic. A total of 702 simulated ILS approaches were flown by 18 commercial airline pilots in a Boeing 707-720B research simulator pilot/system performance and preference data indicated that the full annunciator display system tested was required in order to attain the best display failure and passive autopilot control failure detection. The failure warning utility of mode-progress information below 200 feet of altitude on the approach was found to be inadequate. The data suggested that: (1) mode-progress information be de-emphasized, (2) manual control of just one axis causes pilot fault-detection performance to deteriorate compared to monitoring full autopilot operation, (3) second failures following first failures which put the pilot into split-axis control were frequently missed, and (4) there is not enough time from 100 feet to landing to allow any complicated land-or-go-around decision process. Some general characteristics of fault-warning displays were discussed.

49. POINT MEASUREMENT OF DENSITY BY LASER RAMAN SCATTERING,
Leonard, Donald A., Jet Propulsion Center, Purdue University, AVCO-1-PU, June 1972.

This report describes an experimental feasibility investigation of the use of Raman scattering as a means of making point measurements of density in three-dimensional flows, such as in turbocompressor machinery. A 3371 Å ultraviolet pulsed nitrogen laser was used as the laser source. The major problem area considered was the ability to make measurements close to the walls and in confined internal geometries. The density in a flow past a heated cylinder was measured by both the Raman technique and a standard interferometer and the two methods were shown to agree.

50. THE POTENTIAL OF EXISTING AVIONICS TECHNOLOGY,
Ratcliffe, S., Institute of Navigation Journal, Vol. 24, No. 4, pp. 469-483, October 1971.

51. PRODUCTION OF OPTICAL LANDING GUIDANCE SYSTEM PERFORMANCE IN CAT.III-A MINIMUM WEATHER,
Kocher, David G., Lincoln Laboratory MIT, ESD-TR-73-258, November 1973.

The feasibility of using a laser optical system to provide precision guidance for the final 2 miles of aircraft landing approaches in low-visibility weather is examined. Since low visibility is caused most frequently by clouds and fog, approximate calculations of the optical signal, scattered light, and noise are made as a function of range for various cloud and fog densities. It is concluded that with current laser technology, performance of an optical landing-guidance system would be inadequate in the presence of Category III-a, minimum visibility clouds and fogs.

52. PROCEEDINGS OF CONFERENCE ON AIRCREW PERFORMANCE IN ARMY AVIATION,
Office of the Chief of Research Development and Acquisition (Army), Washington, D.C., N75-17963#, AD-A001539, July 1974.

The purpose of the conference was to explore the behavioral problems affecting pilots of Army helicopters, with special emphasis on Nap-of-the-Earth (NOE) flight. The technical papers included in this Proceedings deal with the nature of the future combat environment, next generation helicopters, cockpit configuration, map aids, avionics systems, night vision devices, training and simulation requirements and measurement criteria. Included also is a recommended behavioral research program to support Army Aviation.

53. THE PROX BOX RUSH,
Aarons, R. N., Business and Commercial Aviation, February 1975.

A summary which supports the need for an independent and distinct cockpit alarm to bring the flight crews attention to one of the apparently ignored unsafe flight modes protected by GPWS.

54. RAINFALL ATTENUATION OF CENTIMETER WAVES: COMPARISON OF THEORY AND MEASUREMENT,
Medhust, Richard G., IEEE Transactions and Antennas and Propagation, pp. 550-564, July 1965.

Numerical results for attenuation of centimeter waves by rainfall have been computed from J. W. Ryde's formula. These correct, and considerably extend, the previously published Ryde results. Comparison with available measurements suggests that the agreement is not entirely satisfactory; there is a tendency for measured attenuations to exceed the maximum possible levels predicted by the theory.

55. REPORT ON APPROACH AND LANDING ACCIDENT PREVENTION FORUM, OCTOBER 24-25, 1972,
National Transportation Safety Board, NTSB-AAS-73-2, September 1973.

This special study contains Aviation Safety Recommendations A-73-79 through A-73-103. This is a special accident prevention study which analyzes the

papers, recommendations, and views presented by aviation community participants at the National Transportation Safety Board Approach and Landing Accident Prevention Forum held on October 24-25, 1972. This part of the report presents the Safety Board's conclusions and recommendations relative the prevention of approach and landing accidents; a glossary of terms and a summary of previous recommendations by the Safety Board as a result of approach and landing accidents are provided.

56. SAFETY DEVICE OUTPUT BEING DEVELOPED,
O'Lone, R. G., Aviation Week and Space Technology, Vol. 102, No. 2, pp. 46-47, January 1975.

57. STUDY OF AIRBORNE MILLIMETER RADAR TECHNIQUES,
Chanzit, L., et al, Norden Division United Aircraft Corporation, ECOM-02125-F, June 1970.

An investigation of techniques developed for broadening antenna beamwidths is presented. The detection of a wire obstacle requires an antenna with a variable azimuth beamwidth to smooth out the nulls in the characteristic lobing pattern of the wire return. Beam-broadening techniques such as antenna defocussing and mutual feed interaction, originally developed for monopulse, are shown to be applicable to variable beamwidth antennas operating at millimeter wavelengths.

58. SUNDSTRAND CHALLENGED IN GPWS SWEEPS,
Anonymous, Aviation Week and Space Technology, Vol. 102, No. 13, pp. 36-37, March 1975.

59. SURVEY AND PRELIMINARY EVALUATION OF BAROMETRIC ALTIMETRY TECHNIQUES,
Harlan, R. B., MIT, Cambridge Measurement Systems Lab, Report RE-61, NASA-CR-86242, October 1969.

60. A SURVEY OF INSTRUMENT LANDING SYSTEMS,
Marino, D. J., Ward, A. E., The MITRE Corporation, ESD-TR-69-372, December 1969.

This paper presents descriptions of over 40 instrument landing systems which have been proposed, developed, or placed into service since World War II. It is intended that this information be used as a handbook and as the basis of analysis of such systems as well as for background in the evaluation of new concepts for the Integrated CNI Program.

61. A TECHNICAL DISCUSSION OF THE MULTIMODE WEATHER, INTRUDER DETECTOR ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION,
Texas Instruments, Inc., Equipment Group Proposal No. EG71-285, October 1971.

The combined weather and collision avoidance radar system described is intended principally, for airliner applications and airliner protection. It provides the airliner with effective and independent collision protection for general aviation, military, and other air carrier aircraft. It performs collision avoidance functions for both en route and terminal areas, requiring no cooperative equipment on the intruder aircraft, thus eliminating the major problem of equipping general and military aircraft with cooperative units to provide airliner protection.

The fundamental basis and validity of the collision-avoidance capability lies in the use of threat evaluation criteria and logic set forth in ANTC Report No. 117 for the time-frequency system. This criterion has been applied with very slight adaptation for the radar application.

62. A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION, ADDENDUM I, COLLISION AVOIDANCE RADAR, RELATIVE ALTITUDE MEASUREMENT ERROR ANALYSIS,
Texas Instruments, Inc., Prepared in Support of Texas Instruments Proposal, No. EG71-285, October 1971.

The results show the very excellent capability of the system to measure altitude of the intruding aircraft. This is particularly true where the vertical reference is mounted directly on the antenna mounting adapter plate. For this case, the two-sigma altitude determination is ±165 feet and ±120 feet at the Tau ONE maximum range of 3.8 nmi, corresponding to a closure rate of 500 knots (terminal area). The three-sigma values can be taken from the graph. A significant advantage the radar system has over the altimeter comparison method of determining relative altitudes is that the radar altitude error decreases directly as range decreases. Hence, each successive look at a Tau ONE intruder provides an improvement in the altitude determination.

63. TERRAIN REFLECTIVITY MEASUREMENTS USING AN EXPERIMENTAL GALLIUM ARSENIDE LASER TERRAIN SENSING DEVICE,
Kellington, C. M. and Shubert, W. C., U.S. Army Electronics Command, ECOM-4072, January 1973.

An experimental gallium arsenide laser radar has been assembled and tested in order to determine the utility of this type of device in a terrain following sensor for Army aircraft. Reflected energy at the receiver was measured. Measurement results are discussed. Technology improvements, projected flight tests, and potential utilization are also discussed.

64. VISIBILITY MEASUREMENT FOR AIRCRAFT LANDING OPERATIONS,
Collis, Ronald T. H., et al., Stanford Research Institute, AFCRL-70-0598, September 1970.

An experimental pulsed neodymium lidar system was modified and calibrated to obtain accurate data on atmospheric extinction properties in fog and low-cloud conditions. The objective was to establish the theoretical and practical basis of a system for measuring slant visibility conditions for aircraft landing operation. To operate in conditions of fog and low cloud, the lidar system's dynamic range was extended to 50 dB by using a two-stage receiver system. In addition, the transmitter and receiver beams were made coaxial to make close-range observations.

Field trials were carried out at a temporary site at Half Moon Bay, California, and at the National Bureau of Standards site at Arcata, California, in May/June and August 1970, respectively. At Arcata, data were collected in conjunction with measurements by an array of up to five AN/GMQ-10 transmissometers. Observations were made in clear weather and in conditions of fog and low cloud using arrays of passive targets to provide information on atmospheric extinction. The correlation between atmospheric transmittance derived from

lidar/target data and from AN/GMQ-10 transmissometers equalled that found between the data from individual transmissometers. Thus, a lidar with the support of passive targets could replace a transmissometer system with comparable accuracy in determining atmospheric transmittance.

Single-ended lidar data were obtained along horizontal paths adjacent to the passive targets and to a 500-ft base line transmissometer. Atmospheric transmittances were computed from these lidar data using analytical methods (which are discussed in detail of evaluating atmospheric extinction coefficients from a consideration of the "slope" of the lidar trace. A correlation coefficient of 0.97 was found between the lidar data and the transmissometer data for comparable path transmittances in a variety of low-visibility conditions.

The concept of remotely deriving coefficients aloft from observation by a ground-based lidar was applied to the aircraft landing problem. Using values of extinction coefficient for atmospheric layers above the surface derived from series of lidar observations at different angles of elevation, examples are given of the calculation of transmittance over the line-of-sight path from which a pilot would look (at a cockpit cut-off angle) from the critical height to the surface to acquire visual reference. No corroboration of these evaluations of slant path transmittance was available. Possible means of deriving and presenting such data for operational purposes are outlined, and the potential use of lidar for revealing the general conditions of cloud and fog conditions in the airfield approach are described. The problem of realizing an operational system in an ultimate form is considered and some potential approaches to this end are noted.

65. VISUAL APPROACH MONITOR BEING CERTIFIED,
Elson, B. M., Aviation Week and Space Technology, Vol. 96, No. 14, pp. 37-39, April 1972.

66. WAVE PROPAGATION IN A TURBULENT MEDIUM,
Tatarski, V. I., Institute of Atmospheric Physics, Academy of Sciences of the USSR, McGraw Hill, 1961.

Technical analysis of the micro structure of a turbulent flow and the theoretical scattering of electromagnetic and acoustical waves.

67. WHOOP, WHOOP, SORRY, MY MISTAKE,
Anonymous, Flight International, September 1975.

The potential nuisance warnings which will be generated through normal aircraft operations are cited which make current GPWS devices counterproductive.

68. WHY NOT LISTEN TO THE GLIDESLOPE,
Anonymous, Business and Commercial Aviation, pp. 70-71, February 1973.

SUBJECT INDEX

GROUPING

AIR TRAFFIC CONTROL ENHANCEMENT.

Index No.	Title
1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
14	COMMERCIAL AIR TRANSPORT HAZARD WARNING AND AVOIDANCE SYSTEM, VOLUME I SUMMARY, VOLUME II REQUIREMENTS STUDIES, VOLUME III RADAR PERFORMANCE STUDIES, APPENDIX A OPERATIONAL REQUIREMENTS
19	DEVELOPMENT OF A MICROELECTRONIC ALTITUDE/DIVISION/ALERTING SYSTEM
20	EFFECTS OF A 100-FOOT OPTION ALTITUDE RULE AND AN ANNUNCIATOR PANEL ON FAILURE DETECTION, GO-AROUND DECISIONS AND LANDING PERFORMANCE
29	GROUND-BASED COLLISION AVOIDANCE SYSTEMS FOR AIR TRAFFIC
35	IMPROVING LANDING/TAKEOFF AND TERMINAL AREA SAFETY
38	AN INVESTIGATION OF ERRORS AND DATA PROCESSING TECHNIQUES FOR AN RF MULTILATERATION SYSTEM
61	A TECHNICAL DISCUSSION OF THE MULTIMODE WEATHER, INTRUDER DETECTOR ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION
62	A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION, ADDENDUM I, COLLISION AVOIDANCE RADAR, RELATIVE ALTITUDE MEASUREMENT ERROR ANALYSIS

ALTITUDE ALERT.

Index No.	Title
1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
3	ALL-WEATHER LANDING SIMULATION FOR CATEGORY III AIRBORNE CONFIGURATION

Index No.	Title
4	ALTITUDE MONITORS, A REPORT BIBLIOGRAPHY
6	APPLICATION OF LIGHT-SCATTERING TECHNIQUES FOR MEASUREMENTS OF DENSITY, TEMPERATURE, AND VELOCITY IN GASDYNAMICS
7	AURAL GLIDE SLOPE CUES: THEIR EFFECT ON PILOT PERFORMANCE DURING IN-FLIGHT SIMULATED ILS INSTRUMENT APPROACHES
12	COLLISION AND OBSTACLE/TERRAIN AVOIDANCE WARNING SYSTEM (COTAWS) MALFUNCTION SENSOR STUDY (U)
14	COMMERCIAL AIR TRANSPORT HAZARD WARNING AND AVOIDANCE SYSTEM, VOLUME I SUMMARY, VOLUME II REQUIREMENTS STUDIES, VOLUME III RADAR PERFORMANCE STUDIES, APPENDIX A OPERATIONAL REQUIREMENTS
17	DESIGN CONSIDERATIONS FOR AN AIRCRAFT OBSTACLE AVOIDANCE SYSTEM BASED ON OBSTACLE STRIKE ACCIDENT EXPERIENCE
18	DEVELOPMENT OF AN INDEPENDENT ALTITUDE MONITOR CONCEPT
19	DEVELOPMENT OF A MICROELECTRONIC ALTITUDE/DIVISION/ALERTING SYSTEM
36	INDEPENDENT ALTITUDE MONITORING ALERT METHODS AND MODES STUDY
37	INDEPENDENT ALTITUDE MONITOR, LITERATURE SEARCH
39	INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS
42	THE LAST THOUSAND FEET
59	SURVEY AND PRELIMINARY EVALUATION OF BAROMETRIC ALTIMETRY TECHNIQUES
61	A TECHNICAL DISCUSSION OF THE MULTIMODE WEATHER, INTRUDER DETECTOR ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION
62	A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION, ADDENDUM I, COLLISION AVOIDANCE RADAR, RELATIVE ALTITUDE MEASUREMENT ERROR ANALYSIS

Index No.	Title

3D/RNAV AND INERTIAL NAVIGATION SYSTEMS.

1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
48	PILOT FAILURE DETECTION PERFORMANCE WITH THREE LEVELS OF FAULT WARNING INFORMATION

GROUND PROXIMITY WARNING SYSTEM

1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
2	AIRLINES, MANUFACTURERS RUSH TO MEET DEC. 1 GPWS DEADLINE
4	ALTITUDE MONITORS, A REPORT BIBLIOGRAPHY
7	AURAL GLIDE SLOPE CUES: THEIR EFFECT ON PILOT PERFORMANCE DURING IN-FLIGHT SIMULATED ILS INSTRUMENT APPROACHES
10	THE CASE FOR GROUND PROXIMITY WARNING SYSTEMS
11	COLLISION AND OBSTACLE/TERRAIN AVOIDANCE WARNING SYSTEM (COTAWS)
12	COLLISION AND OBSTACLE/TERRAIN AVOIDANCE WARNING SYSTEM (COTAWS) MALFUNCTION SENSOR STUDY (U)
14	COMMERCIAL AIR TRANSPORT HAZARD WARNING AND AVOIDANCE SYSTEM, VOLUME I SUMMARY, VOLUME II REQUIREMENTS STUDIES, VOLUME III RADAR PERFORMANCE STUDIES, APPENDIX A OPERATIONAL REQUIREMENTS
17	DESIGN CONSIDERATIONS FOR AN AIRCRAFT OBSTACLE AVOIDANCE SYSTEM BASED ON OBSTACLE STRIKE ACCIDENT EXPERIENCE
18	DEVELOPMENT OF AN INDEPENDENT ALTITUDE MONITOR CONCEPT
23	EVALUATION OF A TERRAIN PROXIMITY WARNING SYSTEM (DOWNWARD LOOKING RADAR) FOR POSSIBLE ENHANCEMENT OF FLIGHT SAFETY
24	FAA ASKS GROUND PROXIMITY WARNING BE MADE MANDATORY
27	GPWS FOR CORPORATE/BUSINESS AIRCRAFT: SUCH SYSTEMS SHOULD SIGNIFICANTLY REDUCE CFIT ACCIDENTS
28	GPWS SPECS APPROVED

Index No.	Title
30	GROUND PROXIMITY WARNINGS
31	GROUND PROXIMITY WARNING SYSTEMS: A MAJOR ENHANCEMENT OF AIRLINE FLIGHT SAFETY
32	GROUND PROXIMITY WARNING SYSTEMS (GPWS) FLIGHT TEST
33	HUMAN FACTORS EVALUATION OF THE GROUND PROXIMITY WARNING SYSTEM (GPWS)
47	AN OPERATIONAL LOOK AT GPWS
53	THE PROX BOX RUSH
55	REPORT ON APPROACH AND LANDING ACCIDENT PREVENTION FORUM OCTOBER 24-25, 1972
58	SUNDSTRAND CHALLENGED IN GPWS SWEEPS
61	A TECHNICAL DISCUSSION OF THE MULTIMODE WEATHER, INTRUDER DETECTOR ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION
62	A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION, ADDENDUM I, COLLISION AVOIDANCE RADAR, RELATIVE ALTITUDE MEASUREMENT ERROR ANALYSIS
67	WHOOP, WHOOP, SORRY, MY MISTAKE

FORWARD-LOOKING RADAR.

Index No.	Title
1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
11	COLLISION AND OBSTACLE/TERRAIN AVOIDANCE WARNING SYSTEM (COTAWS)
14	COMMERCIAL AIR TRANSPORT HAZARD WARNING AND AVOIDANCE SYSTEM, VOLUME I SUMMARY, VOLUME II REQUIREMENTS STUDIES, VOLUME III RADAR PERFORMANCE STUDIES, APPENDIX A OPERATIONAL REQUIREMENTS
16	CONFORMAL PHASED ARRAY ANTENNA STUDY
17	DESIGN CONSIDERATIONS FOR AN AIRCRAFT OBSTACLE AVOIDANCE SYSTEM BASED ON OBSTACLE STRIKE ACCIDENT EXPERIENCE

Index No.	Title
21	EFFECTS OF PRECIPITATION ON PROPAGATION AT 0.63, 3.5, AND 10.6 MICRONS
39	INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS
51	PRODUCTION OF OPTICAL LANDING GUIDANCE SYSTEM PERFORMANCE IN CAT. III-A MINIMUM WEATHER
61	A TECHNICAL DISCUSSION OF THE MULTIMODE WEATHER, INTRUDER DETECTOR ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION
62	A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION, ADDENDUM I, COLLISION AVOIDANCE RADAR, RELATIVE ALTITUDE MEASUREMENT ERROR ANALYSIS
66	WAVE PROPAGATION IN A TURBULENT MEDIUM

MULTIFUNCTION SYSTEM

Index No.	Title
1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
3	ALL WEATHER LANDING SIMULATION FOR CATEGORY III AIRBORNE CONFIGURATION, VOLUME I. SUMMARY OF STUDIES ON FLIGHT DIRECTORS AND SPLIT AXIS CONTROL
5	ANALYSIS OF CUMULATIVE ERRORS ASSOCIATED WITH CATEGORY II AND III OPERATIONS WITH REQUIREMENTS FOR ADDITIONAL RESEARCH
9	BLIND LANDINGS MADE EASY
19	DEVELOPMENT OF A MICROELECTRONIC ALTITUDE/DIVISION/ALERTING SYSTEM
22	EVALUATION OF FLIGHT DIRECTOR ELEMENTS--RISING RUNWAY, EXPANDED LOCALIZER AND ROLLOUT STEERING--DURING SIMULATED CATEGORY III-C MANUAL AND SPLIT-AXIS LANDINGS
61	A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION
62	A TECHNICAL DISCUSSION OF MULTIMODE WEATHER, INTRUDER DETECTION ASSESSMENT, AND TERRAIN WARNING RADAR SYSTEM FOR AIRLINER APPLICATION, ADDENDUM I, COLLISION AVOIDANCE RADAR, RELATIVE ALTITUDE MEASUREMENT ERROR ANALYSIS

Index No.	Title
48	PILOT FAILURE DETECTION PERFORMANCE WITH THREE LEVELS OF FAULT WARNING INFORMATION
67	WHOOP, WHOOP, SORRY, MY MISTAKE
68	WHY NOT LISTEN TO THE GLIDESLOPE

AIRCRAFT PERFORMANCE

3	ALL WEATHER LANDING SIMULATION FOR CATEGORY III AIRBORNE CONFIGURATION, VOLUME I. SUMMARY OF STUDIES ON FLIGHT DIRECTORS AND SPLIT AXIS CONTROL
5	ANALYSIS OF CUMULATIVE ERRORS ASSOCIATED WITH CATEGORY II AND III OPERATIONS WITH REQUIREMENTS FOR ADDITIONAL RESEARCH
20	EFFECTS OF A 100-FOOT OPTION ALTITUDE RULE AND AN ANNUNCIATOR PANEL ON FAILURE DETECTION, GO-AROUND DECISIONS AND LANDING PERFORMANCE
22	EVALUATION OF FLIGHT DIRECTOR ELEMENTS--RISING RUNWAY, EXPANDED LOCALIZER AND ROLLOUT STEERING--DURING SIMULATED CATEGORY III-C MANUAL AND SPLIT-AXIS LANDINGS
32	GROUND PROXIMITY WARNING SYSTEMS (GPWS) FLIGHT TEST
39	INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS
48	PILOT FAILURE DETECTION PERFORMANCE WITH THREE LEVELS OF FAULT WARNING INFORMATION
52	PROCEEDINGS OF CONFERENCE ON AIRCREW PERFORMANCE IN ARMY AVIATION

OPTICAL DETECTION

1	ADVANCED FLIGHT CONTROL AND ELECTRONIC DISPLAY SYSTEMS FOR ALL-WEATHER FLIGHT OPERATIONS: A LITERATURE REVIEW AND BIBLIOGRAPHY
6	APPLICATION OF LIGHT-SCATTERING TECHNIQUES FOR MEASUREMENTS OF DENSITY, TEMPERATURE, AND VELOCITY IN GASDYNAMICS
17	DESIGN CONSIDERATIONS FOR AN AIRCRAFT OBSTACLE AVOIDANCE SYSTEM BASED ON OBSTACLE STRIKE ACCIDENT EXPERIENCE
21	EFFECTS OF PRECIPITATION ON PROPAGATION AT 0.63, 3.5, AND 10.6 MICRONS

Index No.	Title
22	EVALUATION OF FLIGHT DIRECTOR ELEMENTS--RISING RUNWAY, EXPANDED LOCALIZER AND ROLLOUT STEERING--DURING SIMULATED CATEGORY III-C MANUAL AND SPLIT-AXIS LANDINGS
25	FEASIBILITY OF LASER SYSTEMS FOR AIRCRAFT LANDING OPERATIONS UNDER LOW-VISIBILITY CONDITIONS
39	INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS
40	LASER IN-FLIGHT OBSTACLE DETECTION DEVICE
41	LASER TECHNOLOGY IN AERODYNAMIC MEASUREMENTS
45	MONTE CARLO STUDIES OF LIGHT TRANSPORT THROUGH NATURAL ATMOSPHERES
49	POINT MEASUREMENT OF DENSITY BY LASER RAMAN SCATTERING
51	PRODUCTION OF OPTICAL LANDING GUIDANCE SYSTEM PERFORMANCE IN CAT-III-A MINIMUM WEATHER
54	RAINFALL ATTENUATION OF CENTIMETER WAVES:COMPARISON OF THEORY AND MEASUREMENT
63	TERRAIN REFLECTIVITY MEASUREMENTS USING AN EXPERIMENTAL GALLIUM ARSENIDE LASER TERRAIN SENSING DEVICE
65	VISUAL APPROACH MONITOR BEING CERTIFIED

AUTHORS' INDEX