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ANALYSIS OF SOME CARRIER ALL-WEATHER FLYING PROBLEMS

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ANALYSIS OF SOME CARRIER ALL-WEATHER FLYING PROBLEMS

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June 1, 1948

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ABSTRACT

An analysis is made of some of the problems involved in Carrier All-Weather Flying based on the operational requirements and the scientific techniques most readily available and most easily adaptable. A comprehensive outline is drawn of a proposed solution utilizing the data relay techniques developed, originally, for the Airborne Early Warning program under Navy sponsorship. The proposal is based on the philosophy of deriving and gathering all navigational and traffic control information aboard the base, prior to its dissemination to all the aircraft. In most cases, several alternate methods of possible solution to the detailed problems are described.

PROBLEM STATUS

This is an interim report on this problem.

AUTHORIZATION

NRL Problem No. R04-20D.

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ANALYSIS OF SOME CARRIER ALL-WEATHER FLYING PROBLEMS

INTRODUCTION

General Requirements

The urgency and need for a Carrier All-Weather Flying (CAWF) system has been recently stressed by CNO and ONR letters, references 1, 2 and 3 which initially outlined the scope of the problem and the necessary functions to be satisfied by an acceptable system. Although the ideal goal for such a program is complete independence of all air operations from weather conditions, a less far-reaching set of aims is acceptable for the sake of expediency and in order to gain the experimental and operational experience. This experience is necessary for determining the form of the ultimate solution. In view of this expediency, the interim goal of the CAWF program, as expressed by ONR (reference 4) has been defined as a system which will provide satisfactory operational solutions to the following phases of Naval aircraft carrier operations:

- (a) Landing and take-off on the carrier deck
- (b) Approach of aircraft preparatory to landing
- (c) Control of air traffic in the neighborhood of carriers
- (d) Rendezvous and station keeping of aircraft
- (e) Personal identification
- (f) Performance of a strike or attack against a target
- (g) Navigation of aircraft to and from target areas, and homing to the carrier.

The maximum range of operations for the navigation function (g) has been set initially as 80 miles from the carrier in view of line-of-sight restrictions on high frequency radio transmissions. Although some of the phases of CAWF are aided to a certain extent by available or contemplated fleet facilities such as homing systems, ship-based radar, voice communications, links, radio direction finders (both ship-based and airborne), dead reckoning procedures, etc., no highly integrated use is made of these functions in present fleet tactics. Thus a "new" CAWF system might actually make use of these existing facilities in addition to entirely novel techniques and procedures.

A more complete analysis of the general Naval requirements and the scope of this CAWF problem is covered in references 1 through 4 and some allied problems in all-weather flying, as analyzed by the Air Force, are reported in references 6 and 7. It should be noted that the entire emphasis of the thoughts reported herein are on the Navy's carrier problems with no operational reference to shore bases. Although it is recognized that techniques and developments from the engineering viewpoint may overlap in the two cases, it is felt that the

problems of an aircraft carrier are so unique and (in the landing phase) so difficult, as to justify a concentrated, undivided prosecution, even though the interim solution may be inapplicable to Air Force, or civil aviation problems.

Operational Requirements

The operational tactics and the composition of carrier groups will, to a large extent, determine the performance factors of any CAWF system. In general, several aircraft carriers, operating in close cooperation form a consolidated fleet "air-unit," so that an evolved CAWF system should attempt to solve multiple carrier problems. Accepting such tactics, a closely-spaced group of carriers would, beyond short range, constitute a navigational "point" for all practical purposes so that the facilities providing long range information need be operated on only one of the carriers, as long as some maximum spread of the carriers were not exceeded. However, the shorter range operations involving traffic control of large numbers of planes and the approach and landing of aircraft obviously demands that any portion of the system satisfying these functions must center its data about a particular carrier. Since a large carrier can conceivably launch as many as 100 aircraft in one operation, a carrier group of 4 or 5 could have between 400 and 500 aircraft to be launched, navigated and retrieved. The variety of problems which arise out of switching from long range to short range functions; funneling each aircraft to its proper ship; the assimilation, by other ships, or aircraft whose home ship may have been damaged, etc.; are likewise major traffic control problems.

In order to be able to evolve the carrier landing aids necessary to CAWF, it must be postulated that the landing itself (i.e. the touchdown of the aircraft on the deck) and some arbitrary portion of the approach just prior to the landing, must be performed automatically. This proviso is necessary since the assumption of zero-zero visibility precludes the possibility of swift enough pilot reaction to error or control signals for guidance of an aircraft by the pilot himself from any manner of data presentation. It may, however, be desirable to present the position or error data to him not only for psychological reasons but also for monitoring purposes so that he may assume control immediately in a case of control failure. Likewise, the Landing Signal Officer should have such a monitoring control. In order to compare favorably with fair weather operations, a system should be capable of handling a continuous flow of aircraft at 30 second intervals, which is approximately the best deck clearance time at present. Provision must be included for automatic indications of wave-off or automatic control of wave-off to be initiated by any of the various ship centers concerned with deck conditions and approaching aircraft. We may also assume that the approach and landing speeds of aircraft to be handled in the near future will not be substantially different from those existing at present. Changes in landing speed should be able to be handled by corresponding changes in the system design factors.

From the very nature of the operational use to which such a CAWF system is to be put, a maximum of military security, reliability, and fail-safe features should be designed into the components.

Basic Method

The general theory of solving the CAWF problem evolved in this report is "predicated on the philosophy of gathering (all) the data relative to the operation of aircraft in a given area, at one central point, where it can be correlated and interpreted by equipment and personnel not preoccupied with the task of operating the aircraft. When this task of data evaluation is completed and unuseable intelligence discarded, the data can then be relayed in directly useable form to the pilot of each aircraft, as required. . . ." (reference 5). This philosophy would seem to be a necessity in view of the present operational condition of

crowded aircraft and overburdened pilots. In addition, the preponderance of carrier aircraft are small single-man, or at most two-men, craft. This fundamental distinction between Naval and, say, Air Force or civil aviation, imposes a difference between the Naval carrier philosophy adopted here and that adopted by the Radio Technical Commission for Aeronautics (Special Committee SC-31), as unofficial recommendations to civil and government agencies (reference 8).

The basic data to gather is the position information of each aircraft in the given area, e.g., range and azimuth from the central point and altitude above the sea surface. A practical choice must now be made as to a specific method for obtaining this data. The choice proposed at present of using radars for determining the range and azimuth information, is based on a consideration of the radar-relay techniques developed under Navy sponsorship for the war-time Airborne Early Warning (AEW) program. In fact, the operation of a radar navigation system employing data-relay techniques would so closely resemble AEW that combinations of usage and function would seem a logical consequence. If, in the limit, the central data gathering base were made airborne, there would be no discernible difference in the systems except that the data receivers would be in other aircraft instead of on carriers. It should be kept in mind, however, that the use of radar(s) for obtaining position information is merely a present choice which is not necessarily an optimum one. Other techniques such as the Omni-Directional Range (ODR) and Distance-Measuring-Equipment (DME) type of position finding which is being currently developed may eventually provide even better solutions in the future, provided the burden of weight and size can be delegated to the central gathering agency.

Although altitude information can be obtained from the radar data at the central base by various height-finding schemes, it may be more expedient to utilize some form of altitude reporting by each aircraft, from its radio or absolute altimeter and a suitable reporting beacon.

From the general CAWF requirements, the operational tactics to be satisfied and the choices of method, an analysis can now be made of the probable components of the system, the various critical and difficult problems to be encountered, and possible alternative methods for performing some of the necessary functions.

SYSTEMS ANALYSIS (Exclusive of Landing and Airborne Center)

Choice of Types of Radar

The decision to use radar techniques to gather the position data of aircraft immediately raises the question of the number of radars necessary to satisfy the CAWF requirements. As pointed out under "Operational Requirements," an entire carrier task force which is closely spaced could be served adequately by one long range radar located within the group. For obvious tactical reasons, every carrier would have to be similarly equipped, but, in group or task force operations, only one long range system need be operating. However, (1) such a long range facility could not provide sufficiently high information rates for the short range operations (within, say, 6 or 10 miles) and (2) the information would not be centered at the home ship of each aircraft seeking to approach and land. Therefore a second, precision radar for short range coverage would have to be located on each carrier in the group for use in approach and traffic control of aircraft within a 6 or 10 mile radius of each carrier.

When operations are confined to only one carrier, the change-over from the long range facility to the short range facility would probably not pose many tactical and technical difficulties. The multiple carrier problem, however, with its multiple short range facilities presents some very difficult problems both technically and tactically in identification and

traffic control since a group of, say, 5 carriers could easily have in the order of 300 or more planes in the air at a time. These considerations can be somewhat more easily seen when considered graphically as in Figure 1. Such problems cannot be fully solved or analyzed here,

but must be carefully studied before such a proposed system can be operationally feasible. With this functional breakdown into two radar types, we can set down some general requirements of design for each type.

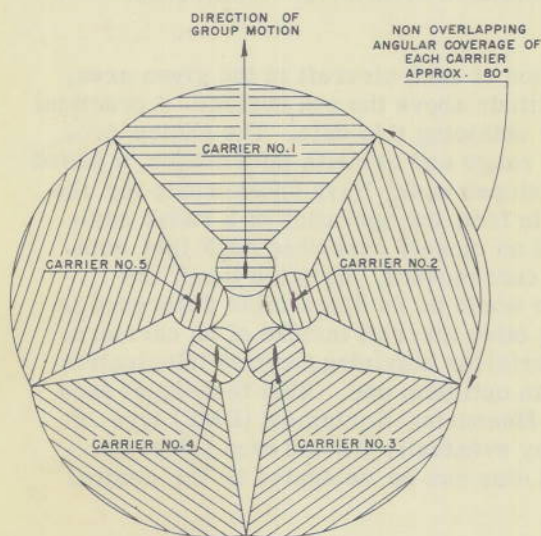


Fig. 1 - Possible Arrangement of Traffic Control Areas for a Group of Five Carriers

Long Range Search Radar—Reliable target information must be provided out to 80 miles on small fighter aircraft, as long as they are above the radar horizon. The peak power, antenna gain, etc., must be compatible with this requirement, and provision must be made for overcoming rain and cloud clutter either through the use of Moving Target Indication (MTI) techniques and other circuit methods, by going to lower radar frequencies, by using off-frequency airborne beacon operation, or perhaps by combinations of these.

Target information on the lower ranges must be reliable even in rough weather which might aggravate sea-clutter conditions. This means the use either of efficient anti-clutter circuitry such as MTI, or STC, or else airborne beacons. The tracking resolutions should be sufficient to provide continuous tracking at least in to the range at which the precision

radar takes over, i.e., in the neighborhood of 6 to 10 miles.

Wide spatial coverage in the vertical plane must be provided by means of suitable antenna design such as a cosecant-squared, multiple beam, vertical scan, etc. At the same time a narrow horizontal beamwidth is necessary to provide good azimuth resolution. Even a beamwidth of 1° however, would mean only 1.4 miles resolution in azimuth at a range of 80 miles so that formation flying would not be possible.

The shortest pulse length possible, consistent with other design factors, should be used in order to provide high range resolution. An 0.5 microsecond pulse, for example, will provide resolutions in the order of 100 yards, and this resolution will not materially change as the range changes.

Since some form of altitude reporting from the aircraft's own altimeter to the central base is presumed, no height-finding by the base radar is necessary.

For long term, future considerations, a study should be made of the problems and possibilities involved in applying relay-radar techniques to current long range radar developments such as the XDK or XDQ.

Short Range Precision Radar—The choice of a precision radar must also involve such questions as rain and cloud clutter, sea clutter, minimum acceptable range, azimuth and range tracking resolution, etc. Efficient anti-clutter circuitry must provide reliable target indications to within 0.5 miles of the radar site where, approximately, a landing facility would take over. Good spatial coverage must also be provided by means of a suitable antenna design.

Airborne Data Receiver and Indicator

The airborne components consist of a relay link receiver, a video decoder (since the present AEW type relay link provides for time-coded rotational and synchronizing pulses), and a PPI cathode-ray tube indicator. These components must be small enough in bulk and weight for installation in any Naval carrier aircraft. An approximate guess of the upper limits to these factors would be 50 lbs and 5 cubic feet, exclusive of an autopilot.

The presentation of the long range data which must be used directly by the pilot for manual control of his craft, would seem best on a PPI display. For optimum utility to a pilot, it might be necessary to investigate the various display factors such as picture brightness, contrast, etc. The short range data would have to be presented on the same indicator if manual control is used, but could alternately be presented on a crossed pointer meter if the actual information usage were automatic. For the sake of consistency and continuity for the pilot, however, it would seem best to maintain a uniform type of presentation, i.e., a cathode-ray tube.

An autopilot is necessary if automatic control is to be the primary operation for short range. The optimum type of autopilot to use, in view of recent developments in the field, is a matter of investigation and correlation with the data to be made available and used by it.

Traffic Control Provisions

Since it is impossible, without experimental data, to decide whether the traffic control operations will be performed, manually or automatically, it remains, as pointed out above, to provide possible solutions to either method. One obvious way of presenting the pilot with the high resolution short range radar data for manual control is to transmit this data, along with its associated rotational and synchronizing information, on a separate R. F. channel of the relay link. The primary disadvantages would be the additional radio spectrum required and the delay in picture stabilization as the pilot would switch from one channel to the other. No satisfactory method seems available which would not deteriorate the tracking resolution of the precision information when combined with the long range data on one channel.

For the purposes of discussing an automatic control method it is assumed that a method similar to the "tracking-while-scanning" technique is available, so that it would not be impossible to set up predetermined approach paths and holding patterns. Then the actual aircraft position and its desired position may be compared and error voltages derived therefrom for control purposes. These error voltages could then be transmitted to each aircraft by the same techniques as used for including the rotational information on the data link, i.e., time displacement of a pulse from an arbitrary zero position, the displacement being proportional to the error voltage. These control pulses would be synchronized with the system repetition rate, and inserted on the time base of the relay transmitter output as shown in Figure 2 so that each aircraft would receive its information on a time-shared basis. That is, if a timing pulse is emitted once every second in the relay output and the repetition rate of the data is 320 video "block" per second (system repetition rate), then an aircraft previously assigned to a control channel, say 28, would receive the 28th set of control signals after every timing pulse. With such a system, each plane would receive control information at the rate of once per second and the theoretical limit to the number of aircraft capable of being handled is the ratio of the video repetition rate to the received control rate, i.e. 320. Whether a control rate of once per second is sufficient is again a matter for experimental evaluation, although it would seem accurate enough if the maximum speed of the aircraft in the control area did not exceed approximately 200 knots. In any event the control rate can be increased merely by increasing the antenna scan rate of the precision radar.

Identification and Data Reporting

The method of selective automatic control outlined in the paragraph immediately above involves a definite problem of proper identification, aside from IFF, in order to be able to feed the proper control information into the properly assigned time-sequenced channel. A method of coincidence-pulse beacon operation developed during the AEW program is well suited for providing individual identification of reporting aircraft, with a reasonable degree of insurance against random and spurious triggering of the replying airborne beacon. The matter of an optimum type of code, and an efficient method of identification display aboard ship in order to prevent operational delays between the reporting of an aircraft and its positive identification with a corresponding radar echo, must certainly be settled by investigation.

In the foregoing analyses of the radar and data link systems, it has been assumed that no altitude information of the aircraft is available at the ship so that a method of altitude reporting of sufficient accuracy must be devised. It has been considered, tentatively, that the identifying beacon should also be put to use in this regard, although the exact method of conveying the information, its shipboard and airborne display, etc., have not been determined. The altimeter used in the aircraft to derive the information should almost certainly be of the radio (or absolute) type because the sea surface, even in rough weather, provides an almost ideally flat terrain. The accuracy required of the altitude data below 500 ft is quite stringent, being in the neighborhood of 5 percent of the altitude, while above 500 ft the accuracy will depend to some extent on whether any method of altitude-layer separation will be exercised.

In addition to these two possible functions to be performed on a reporting basis from the aircraft, it would also be desirable to have command acknowledgment from the aircraft. In effect, it would provide a "closed" system of command, whether it were used manually or automatically, so that a knowledge of "obedience" of an aircraft to command or control signals would be available both at the base and in the aircraft.

SYSTEMS ANALYSIS - LANDING PHASE

Technical Requirements

The operational requirements to which any landing system for CAWF must conform were essentially covered in paragraphs so titled. In addition, an estimate of the aircraft position tolerances just prior to touchdown are listed in Table I. These tolerances, peculiar to the landing phase only, are relative to the carrier deck. In order to meet these tolerances the landing system must positively control with sufficient accuracy, the range, bearing, altitude and vector velocity of the aircraft relative to the carrier. The required accuracy of control must be such that any set of landing conditions will bring an aircraft within the maximum allowable tolerances when it arrives over the fan-tail. It can be presumed that any system capable of meeting these tolerances would also be able to handle the inverse operation, i.e., the automatic control of take-off.

The problems of data stabilization against pitch, roll, and yaw of the carrier have not been previously mentioned. However, these problems are most critical in the landing phase. In addition to stabilizing the control information with respect to deck motions, it may be necessary to predict the attitude of the carrier deck with respect to the aircraft and its predicted touchdown.

As mentioned previously, it will be necessary to provide automatic indication of wave-off or automatic control of wave-off, in order to take into account any possibility of equipment failure or foul deck conditions.

TABLE I
AIRCRAFT POSITION TOLERANCES

		Tolerance
Just Prior to Touchdown		
Attitude:	Wing Dip	$\pm 10^\circ$
	Heading (Relative to Center-Line).	$\pm 10^\circ$
	Angle of Attack	Flat
Position:	Lateral Displacement (From Center-Line)	± 25 feet
	Range (From Fan-Tail).	+200 ft -0 ft
	Altitude (From Deck)	20 ft to 40 ft
Motion:	Speed (Relative to Wind)	Above stall
	Course (Relative to Center-Line)	$\pm 10^\circ$
	Rate of Descent.	0

Proposed Solutions

Beam Rider—One method of providing carrier landing control is by means of a "beam-rider" which is a type of localizer-glide path control employing conically scanned pencil beams that is being developed at NRL. Such a method would be a departure from the philosophy of approach as defined in the first paragraph under "Basic Method" since the control information would actually be derived in the aircraft instead of at the base. However, range information, and hence speed information, is available at the base for necessary control of these parameters, by transmission over the data relay link. There are several serious problems which must be solved before such a system or any method of localizer-glide path control can be considered satisfactory. These include (a) provision for curved path approach, (b) attitude of the aircraft at the cut point and control after the cut where the aircraft must leave the beam, (c) sea reflection of the beam causing possible false path, (d) coordination of such a system with the traffic control feed in.

Tracking Radar—If tracking information can be obtained for each landing aircraft with sufficient continuity and sufficient accuracy, then tracking techniques may be used. This tracking may be performed on a continuous basis by means of one automatic tracking radar for each landing aircraft, or on a "tracking-while-scanning" basis as already outlined for the traffic control phase. Both these techniques require computers to provide a reference path from which to derive path deviations. The base computers will have to convert the error information which has been derived, into the proper type of control information which must be sent to the aircraft. For the automatic tracking radar method, a probable minimum of two radars will be necessary to meet the operational requirements of handling capacity so that problems arise of coordination not only between the landing radars and the traffic control phase, but also between the landing radars themselves. If tracking-while-scanning

is used, the rate of flow of information is dependent on the antenna scan rate. It may be possible to utilize the same radar for both landing and traffic control if this information flow is at a great enough rate. If not, then a separate landing radar with a higher scan rate must be used. The usual problems indigenous to radar, i.e. sea clutter, sea reflection, etc., must be carefully investigated.

It is recognized that such a brief analysis of the carrier landing problem is in no way indicative of the enormous problems that will be encountered operationally, technically and psychologically. In fact, the landing portion of the entire CAWF program is undoubtedly the most critical and will probably be the most difficult to bring to a successful conclusion. Therefore the present analysis may serve to indicate methods of approach which may eventually succeed but which will more likely provide the avenues for experimental evolution of newer techniques which have not as yet been considered.

AIRBORNE CONTROL CENTER

Because of the obvious close relation in some phases, of such a proposed CAWF system to the AEW program, it is relatively logical to use some of the same techniques developed for the earlier AEW system. Thus in AEW the heart of the system is the high powered search radar carried aloft in a carrier based aircraft. Since this CAWF system is predicated also on radar-gathered information, the long range navigation portions should be able to utilize the airborne radar in exactly the same way except that the data relay path would be to other aircraft instead of to the mother ship. Such a procedure would extend the outer radius of operation to that of the airborne radar horizon, i.e., in the neighborhood of 180 to 200 miles. The necessary additional components required to implement such an aviation system over and above those carried by present AEW aircraft would be determined by the functions required of such an airborne center. Space and weight, however, would be at such a premium that nothing even approaching the extent of the contemplated shipboard control could be accomplished. A serious analysis of an airborne center would necessarily depend on the success and extrapolation of shipboard results.

In a like manner, it may be possible that multiple airborne units could carry navigational information far beyond the radar horizon with, however, the attendant increase in complexity of the system and in its vulnerability to enemy action. Such possibilities and those of bringing limited radar relay techniques directly into aircraft formation for close rendezvous and formation keeping, are truly existent possibilities, but again are so intimately related to the successful development of the initial phases of the system that their accurate and detailed analysis must be subsequent to them.

CONCLUSIONS

The nature of the conclusions to be drawn from such as the foregoing analysis are more in the form of an emphasis of the salient points of the program to be pursued, rather than any clear-cut technical decisions. The extreme importance of such a program to future Naval air operations makes it imperative that prosecution of the technical solutions offered should include as many alternative or "insurance" projects as possible.

Comparing the details of the proposed system of Data Relay Navigation (DARN) with the general requirements of a CAWF system and the operational requirements, it can be seen that the successful development of a DARN system would provide the following functions for carrier-based aircraft:

- (1) Automatic control of the landing (and take-off) operation to the point of touchdown (or cruising condition) of the aircraft.

- (2) Coordinated automatic control of aircraft in the approach and traffic control areas extending to approximately 10 miles from the carrier, for one carrier.
- (3) A possibility of performing function (2) for more than one carrier within a task force group.
- (4) A visual cockpit display in all aircraft within an 80 mile radius of a carrier or carrier group for use in a navigation, homing, rendezvous, etc., with provision for visual command.
- (5) A possibility of extending the maximum range of operation at least to 200 miles and possibly even greater.

As projected, these functions might be accomplished with a total airborne weight of 50 pounds plus an autopilot, and the airborne indication would be on a PPI cathode-ray tube. The system would not, however, aid in actual strike operations to any great extent except in navigation to the target area. Nor would the system provide for close formation flying and airborne station keeping, unless the possibilities outlined under "Proposed Solutions" become much more realistic than they presently seem. It is felt, however, that the system properly places the burden of weight and complexity on the central bases, and provides a dynamic range of information, i.e., an increase in resolution and control as the aircraft approaches the carrier, ending in a precise and rigid automatic control of landing aircraft. In order to provide these facilities, however, a number of sub-programs or projects must be investigated. The following listing does not imply that techniques are wholly lacking in each problem, or that no group may be working on some phase of that problem, but it does mean that each category is essential either to a successful solution or to an optimum choice of means for a successful solution.

1. Data Gathering Operations.

- (a) Develop a long range search radar.
- (b) Develop a short range precision radar.
- (c) Investigate the choice between off-frequency airborne beacon operation and Moving Target Indication for the elimination of sea clutter without loss of target resolution, and then develop the better suited technique.
- (d) Carefully study the tracking-while-scanning being carried out at the Air Forces Electronic Research Laboratories in order to determine its applicability to automatic traffic control and landing problems.
- (e) In addition to (d), study the applicability of automatic tracking radar and beam-rider techniques to automatic landing methods.
- (f) Investigate and develop a means for using airborne beacon to provide personal identification, altitude reporting, and command acknowledgment. This should include a maximum of security against false information, a suitable display or channeling of each type of information, and the development of a suitable altimeter.
- (g) Study the airborne (and multiple airborne) center problems as techniques and solutions to the shipboard portions of the CAWF program become available.

2. Data Interpretation Operations

- (a) Study the problems and develop the equipment necessary to provide course computation, error computation, and proper channeling of error signals to the aircraft, for the automatic portions of the program.

This should include an analysis of the traffic control and approach problems during multiple carrier operations.

- (b) Study the problems of separation of position and identification information, and of suitable displays for each.
- (c) Develop high resolution video mapping techniques for data insertion.
- (d) Investigate the stabilizations of shipboard antennas (or information) with the pitch, roll and yaw of the carrier deck.

3. Data Relay

- (a) Improve the AEW relay equipment (both terminals) to include optimum frequency band, increased security of the coding and decoding operations and possible coding of the radar video signals, and high resolution.
- (b) Develop extremely light weight components for the airborne relay receiver and indicator.
- (c) Develop video storage equipment to enable transmission of both precision and long range information over one RF relay channel.

4. Data Resolution

- (a) Study the position and error data possible with such a proposed system to determine the limits of resolution to be expected and the specification of accuracy tolerances compatible with such limits.
- (b) Determine the necessity for automatic control in the traffic control areas, the amount and character of control that is necessary, and the need for an auxiliary display if automatic control is used.

Finally, it is concluded that a coordinated and intensive prosecution of the listed programs is necessary in order to provide operational and experimental data for the successful development of Carrier All-Weather Flying. It does not insure that a system such as described herein will provide increased knowledge and the probable development of techniques applicable to such a solution.

* * *

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