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Contents

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AERODYNAMICS AND THE OBSERVER

This issue of the OBSERVER continues the series of articles on post-graduate courses at CNS. The reader has undoubtedly noted the emphasis being placed, in all courses, on the subject of Aerodynamics and Aircraft Performance Engineering.

This subject may seem rather unnecessary for an Observer,but the question of cruise control,which is a fundemental navigation problem, is receiving increased emphasis every year. Jet and turbo-propellor aircraft with their critical performance,permit little latitude in the selection or amendment of their flight profile. The factors affecting the flight profile are determined by the airframe and engine performance criteria, which can only be understood through the study of aerodynamics. It is vital that the observer have a sound background in this subject, because failure to obtain optimum performance from the jet aircraft could not only result in an aborted mission, but could also jeopardize the safety of the aircraft.

Yet another factor is the point made by S/L Heide in his article in the last issue[1] when he stated"The missile era will be the era of the observer if he has the foresight and perseverance to prepare himself for it". As S/L Heide points out, guidance is one of the major factors in missile engineering; but the subject of control is closely allied to the guidance problem, because both the degree and rate of control are partly determined by the forces affecting the vehicle. The Observer must, therefore have a broad knowledge of aerodynamics, if he is to play an effective part in tomorrow's air force.

What will all this gain? First and foremost is personal satisfaction,but other benefits are a sound appreciation of air forces and their employment,more effective use of operational aircraft,an excellent background for a future position of command, and probably the most important of all, the assurance that one will progress at the same rate as the air weapon. Lack of "foresight and perseverence" carry a heavy penalty, and observers should ensure that they are equipped to meet the challenge of the future.

Note: 1. "The Era of the Observer". RCAF OBSERVER Jan 58.

LET'S RECOGNIZE THE PROFESSIONAL MILITARY NAVIGATOR

Text and Illustrations by
Flight Lieutenant D.J. Connolly
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Who are the truly professional navigators in the RCAF? If you walked into a strange Officers' Mess on a Friday night and encountered the inevitable herd of navigators clustered about the sea-food table, it's a sure bet that you couldn't identify the professionals from the tyros. "Of course I couldn't," you say. "They are not painted identifying colours, nor tattooed with merit badges; and in any event, so what?". Well, I think it desirable that you could We use ribbons to indicate a man's operational experience and rank badges to show his service experience, so why not a special wing or clasp; some symbol to brand him as an experienced, above-average navigator; to wit, a professional. Here are two arguments to support this proposition:

→ Firstly, it would ensure that the man got recognition for his attainments. It is a primary precept of leadership that if "old professional soldiers are honoured, morale will benefit". The man who has raised himself to a high level of technical proficiency must not be ignored; he should be rewarded.

→ With a tangible goal in sight, the new navigator has something to aspire to. Unfortunately, a posting to CNS is no longer relished by the average field navigator as a step up the ladder. It once was, but the prevalent attitude now is that it merely presages an undesirable tour of instructor duty. In its place we must substitute another incentive; some hall mark of achievement. Even if "a man's reach should exceed his grasp" there is a sense of fulfillment in trying to reach a standard. Under such a system, the professional cadre of the Air Force should grow because the average air-Magellan would be stimulated to pick up his socks and keep abreast of his more ambitious contemporaries.

How can we establish a dividing line between our old-pro senior navigators and the also-rans? Consider the criteria used by the USAF.

In the USAF a senior navigator is one who:

- Has seven years of service time as a rated navigator.
- Has at least 2000 hours of flying time.
- Can pass a comprehensive written exam relating to his speciality.
- Can pass a supervised flight check.
- Must be engaged in flying duties when the title is awarded.

No system is foolproof; morons still pass tests which a genius might fail but I believe this method of selection is stiff enough to weed out most of the weak sisters who are bound to try. The seven year requirement is stiff, but it is designed to eliminate the fresh-faced basic graduate who is lucky enough to amass 2000 hours in his first few years of flying. It will differentiate this individual with his esoteric knowledge of one navigation compartment in one aircraft, from the seasoned veteran with better-rounded experience. Conversely, the little travelled desk-flyer with nothing but years to his credit will have to get out and dig if he is shy the 2000 flying hours. The old-timer with one hours flying experience 4000 times will also meet a nemesis in the flight check and the tough written exam.

It is true that such a system can degenerate into uselessness if the title is awarded indiscriminately, but this can be avoided by judicious selection of examiners. If these officials respect the title for all it implies, they ensure close monitoring and marking of the exams and rigid passing standards on the flight tests.

Is there any evidence that such a grading system will work? Yes: several years ago, when I was serving in Transport Command, a categorization scheme was instituted. It impressed me as a workable system, and appeared to separate the men from the boys. It is still in operation, so we can assume it has proved worthwhile against the test of time. I'm sure it has resulted in a general upgrading of the ability of Transport Command Navigators. Maritime Command also uses a similar, though not idential, scheme. Unfortunately, these programs are parochial and once the navigator has been transferred, he resigns his status. Although modeled on somewhat similar lines, a senior navigator system would be Air Force wide. I recently conducted a junior-grade Gallup poll among USAF navigators, asking them their opinions of the value of their senior navigator system. All enthusiastically endorsed the program and though it had much merit.

Assuming we did adopt a similar program, how would we identify the honoured individuals who make the grade? Well, the USAF uses the wing shown in Figure 1. The senior navigator is identified by the star which is added to the top of the standard navigators wings. Obviously, for both aesthetic and patriotic reasons, we couldn't mimic this. However, we should be able to design something symbolic and suitable. A few of the ideas that have occurred to me are shown in Figure 2. Doubtless there are other designs fermenting in your minds and certainly there should be some ideas on the subject of senior navigators. Why not write the lonely editor and let him know your opinions and ideas on this subject. Is it thumbs up or thumbs down?

FIGURE 1

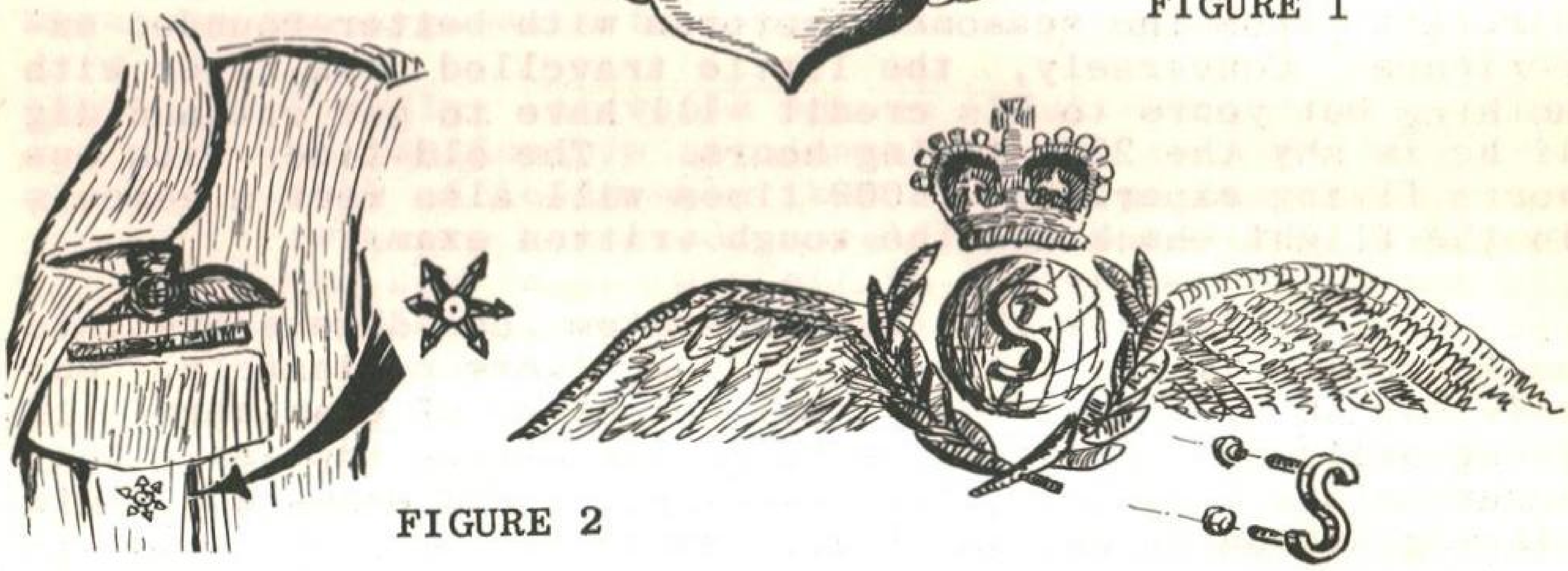
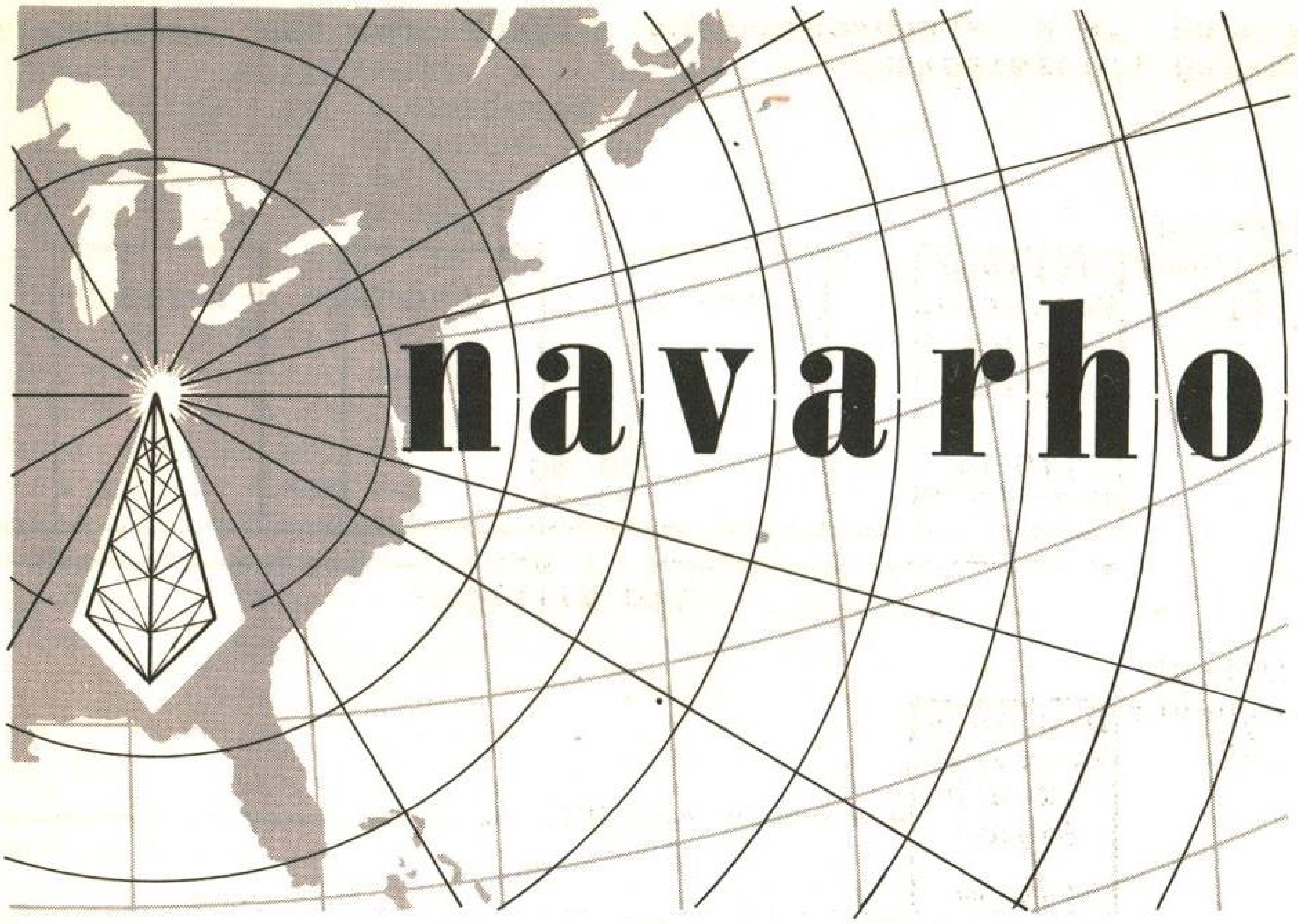


FIGURE 2

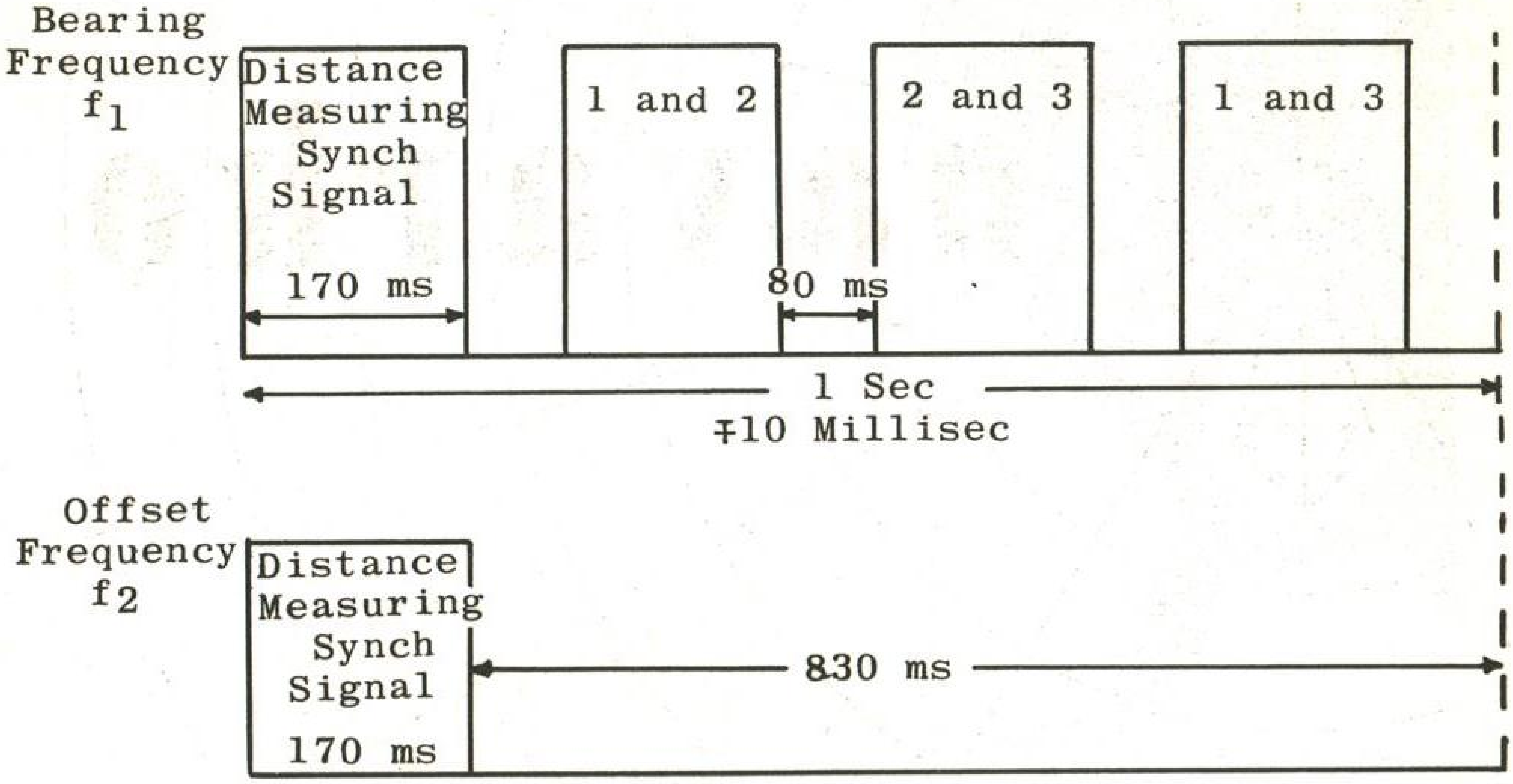


Navarho is a ground based electronic fixing system, being developed in the USA, to provide long range Rho-theta (distance and bearing) information. The system will operate in the Navaids portion of the LF frequency spectrum (90-110 Kcs) and provide 2,000 nm range over land, with an increase to 2,600 nm over water. Because the system gives bearing and distance information from the station site an automatic course line computer will be required if the pilot is to be provided with latitude and longitude, distance-to-go, and course-to-fly.

The advantages claimed for Navarho are its area of coverage (extending 2000-2600 nm in radius from the site), and its accuracy. A bearing accuracy of 0.5 degrees, and distance measurement within one per cent of range is planned.

PRINCIPLE OF OPERATION

Navarho combines an amplitude comparison system for bearing measurements with a phase measuring system for distance information. The distance information is transmitted for a period of 170 milliseconds (ms) in each second and the bearing data is transmitted by three sequential transmissions, each of 170 ms duration. Off periods between transmissions are of 80 ms duration. The transmission cycle is shown in Figure 1. The distance measuring signal is composed of two signals, one at the bearing frequency f, the other at f-100 cycles. This permits the distance signal to be used as a synchronization signal for the sequence of bearing transmissions.



Note:- $f_2 = f_1 - 100$ c/s

Pulse Duration = 170 Milliseconds

Pulse Spacing = 80 Milliseconds

Figure 1 Timing Cycle

<u>Bearing Measurement</u>

An antenna is located at each corner of an equilateral triangle. Bearing information is transmitted from the antenna array by sequentially exciting pairs of antennas with co-phasal equi-amplitude power. Each antenna is separated from the others by a distance dependent upon the wavelength spacing selected for the facility. In Navarho the wavelength spacing varies between 0.36 and 0.4 wavelengths, depending on the frequency of transmission. The sequential excitation of pairs of antennas produces ideal results in the radiation pattern, as shown in Figure 2. A rectangular plot of the relative amplitudes received in space from each of the three radiated signals is shown in Figure 3. In space an aircraft receiving Navarho signals would receive three signals, whose amplitudes were a function of the aximuth of the receiver with respect to the ground station. Thus, if the aircraft were located at the 30 degree point, the relative amplitudes of two signals would be equal, and the amplitude of the third signal would be maximum. As shown in the graph, if the aircraft were to move to 31 degrees, the amplitude of the A signal would decrease, the amplitude of the C signal increase. The resultant of the summation of these three signals is approximately constant,regardless of the aximuth. This factor is considered in setting the automatic gain control in the airborne receiving equipment. Conversely, if the summation of the three signals is known and the bearing is known, the amplitude of each of the three signals is defined. It will be noted that three relative amplitudes were repeated every 60 degrees, and a 60 degree ambiguity would be present in the receiving equipment if the start of the transmission were not known. For that reason it is necessary that a synchronizing signal be transmitted. The distance signal which is unique from the bearing measuring signals can be used for this synchronization. During tests, in which ground monitoring receivers were used, the absence of a signal was used for synchronization. In later tests, in which the airborne Navaglobe* bearing equipment was used, an offset signal was transmitted for the synchronizing signal.

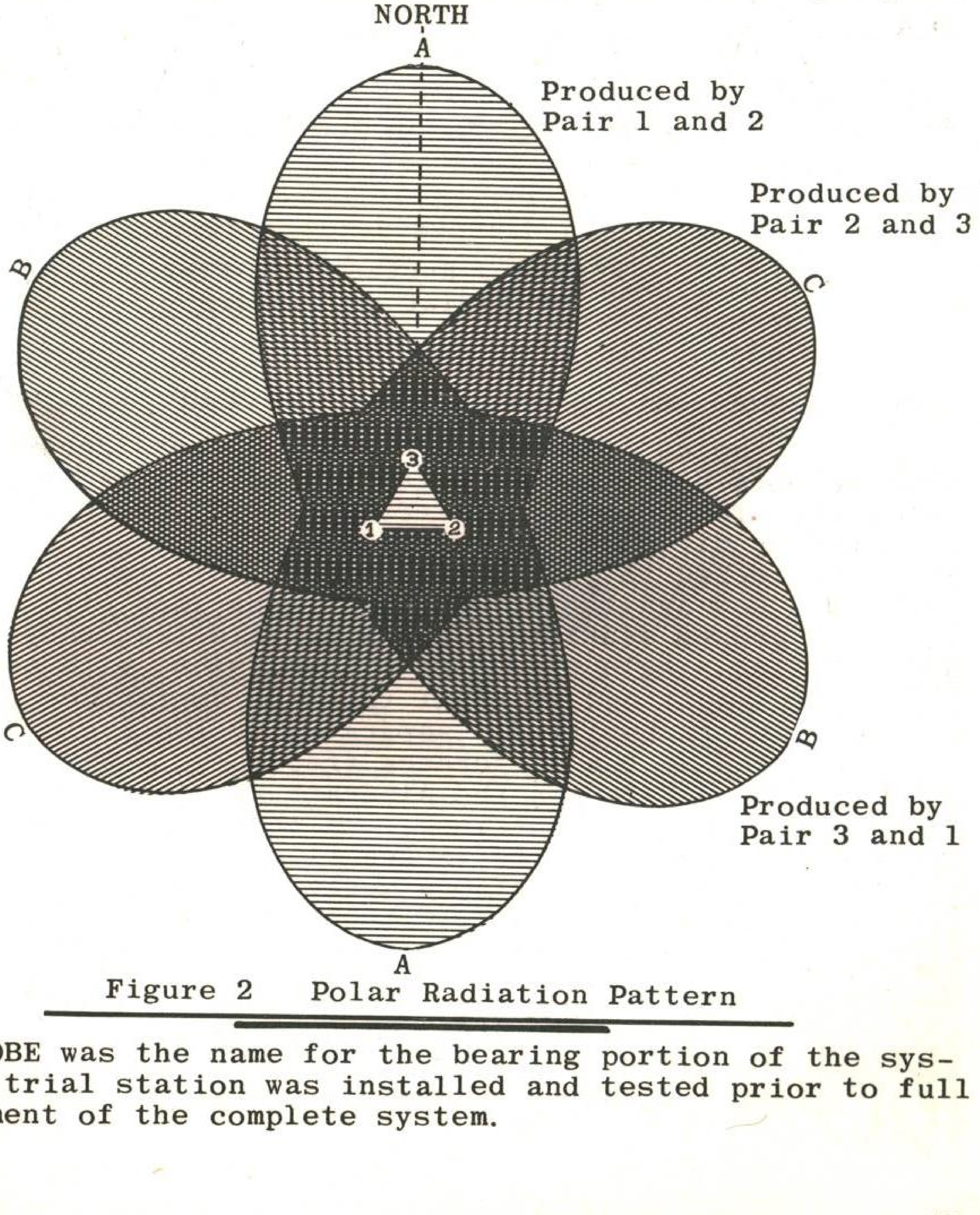


Figure 2 Polar Radiation Pattern

*NAVAGLOBE was the name for the bearing portion of the system. A trial station was installed and tested prior to full development of the complete system.

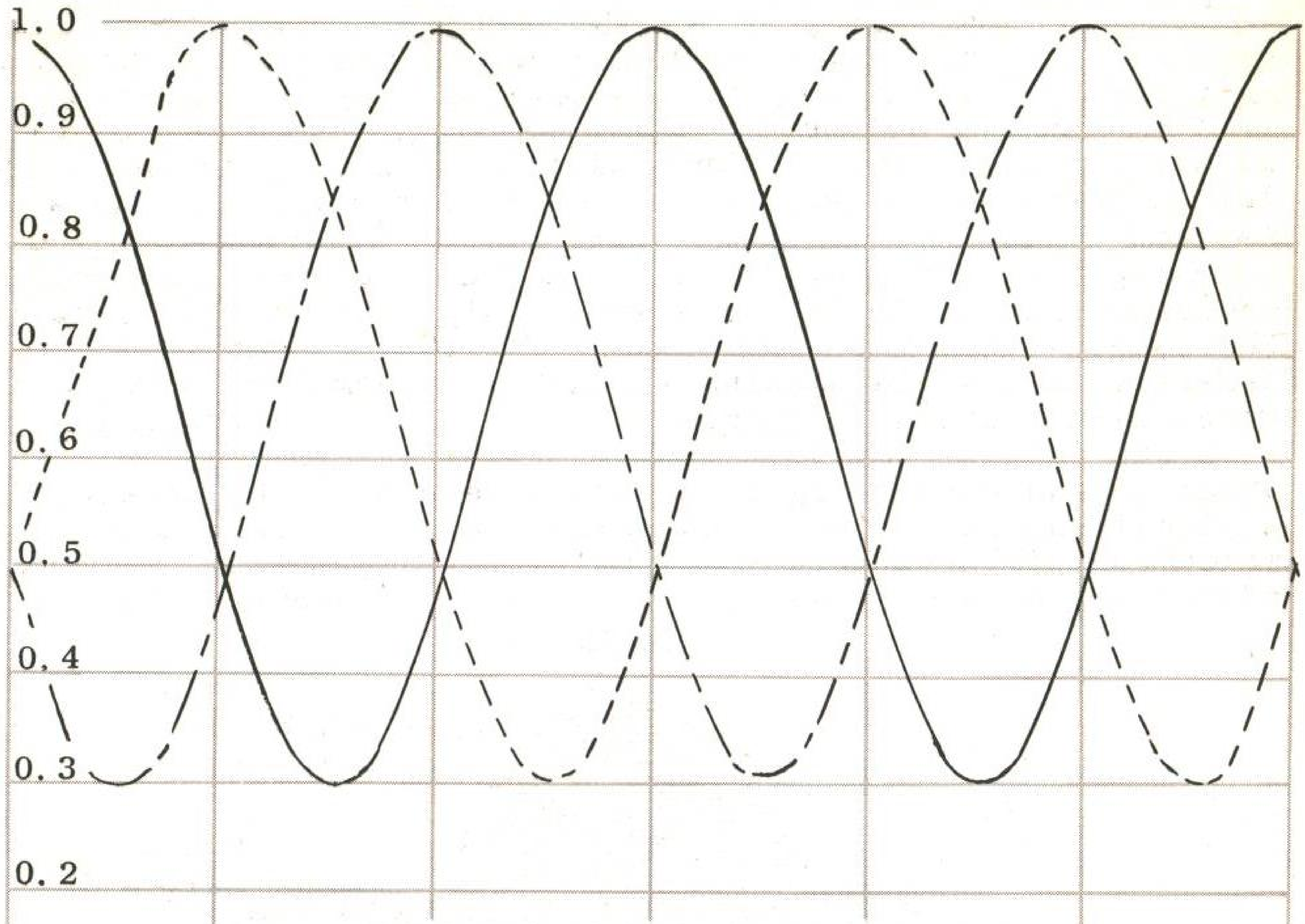
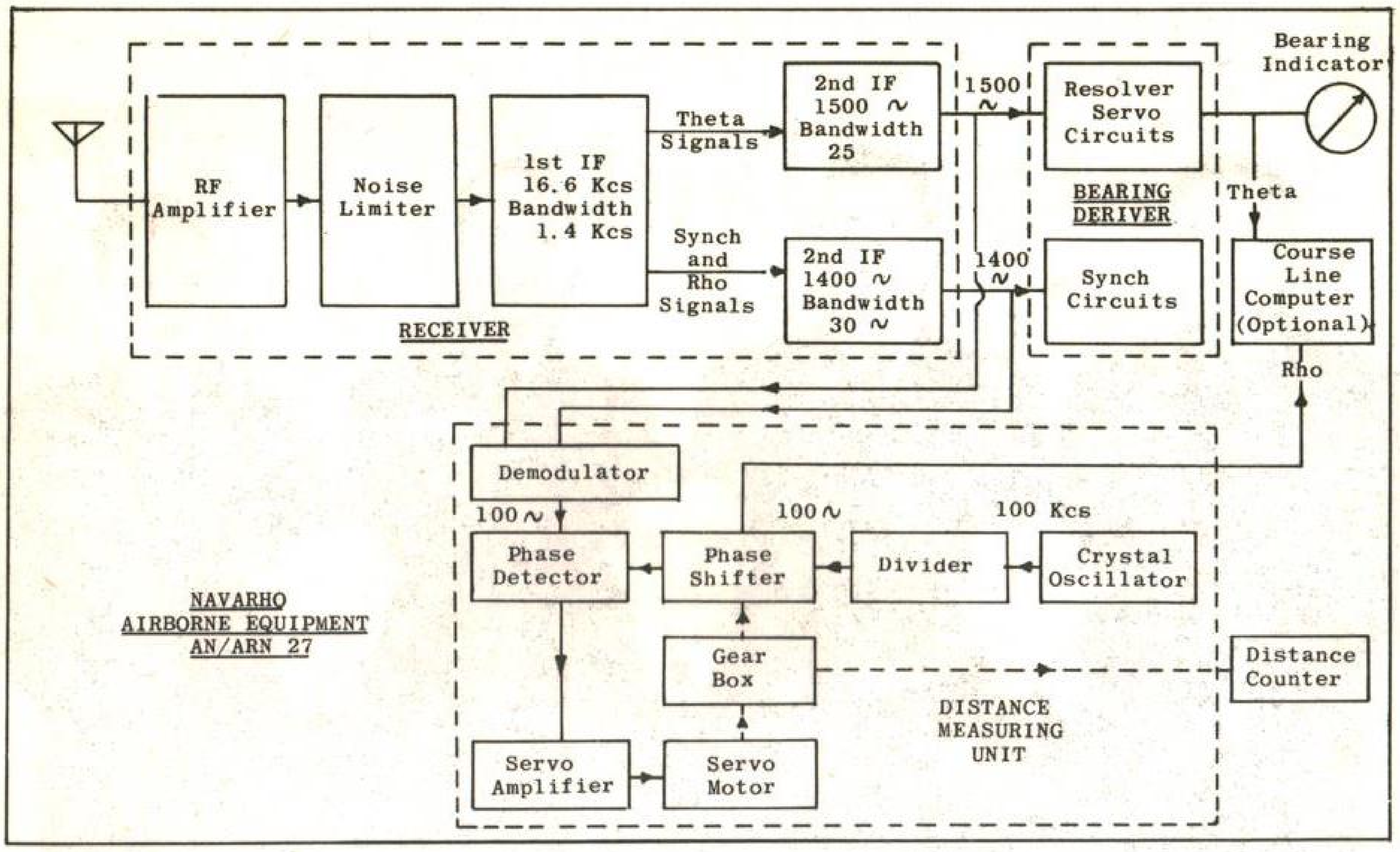


Figure 3 Rectangular Plot of Radiation Pattern

Choice of wavelength requires considerable compromise to obtain optimum results yet not suffer from possible ambiguity. The frequency selected was 100 cycles, which is obtained by dividing the output from the crystal clock and is phase locked to the 100 Kc output. This locally generated signal is now available for phase comparison with the signal from the ground stations. The 100 cycle frequency is transmitted using single side band transmission, with the carrier reduced in amplitude to equal the side amplitude. Thus, two carriers are transmitted, separated by 100 cycles which are phase related at the difference frequency. When these signals are demodulated in the aircraft receiver, the 100 cycle difference signal is obtained. A comparison of the two 100 cycle signals is measured in fractions of a degree of phase shift. The ambiguity of one cycle at 100 cps is 1620 nautical miles. The aircraft could therefore travel approximately 1620 nautical miles without receiving a signal. The distance from the station can be measured at extreme range, providing the transmitting signal can be received, with the same accuracy as though the equipment had operated continuously throughout that time. In the receiver modulation measure ments assume searching functions during temporary loss of signals.



NEW VERSIONS OF NAVARHO

Recent announcements have indicated that three alternate systems are possible, namely, Navarho-H, Navarho-HH, and Navarho-rho. Each of these systems has certain advantages and limitations, but the 3 nm accuracy claimed for Navarho-rho has resulted in its receiving considerable support in the USA. The high weight and cost of this system are limitations, however, particularly for commercial operators.

Navarho-H. Navarho-H is a rho-theta system. Bearing is obtained in the same manner as with Navarho but range is measured from a hyperbolic position line between two ground stations where it intersects the bearing line.

Navarho-HH. A fully hyperbolic system, Navarho-HH requires the reception of three ground station signals to generate two intersecting hyperbolic position lines.

Navarho-rho. A circular position fixing system, Navarho-rho measures distance in the same manner as Navarho but from two ground stations to determine position by the intersection of the two range circles. A third ground station may be used to resolve the ambiguity where the range circles intersect.

CONCLUSION

We have seen Navarho and its variations, but selection and adoption of this or any other system will, of course, depend to a great extent on which obtains ICAO support. In the next issue of the Observer this series of articles will be continued, introducing a further entry in the field of ground based aids.

1 SO(AI)I COURSE

20 JAN 58 - 2 MAY 58

Back Row

F/L RB Button F/O GE Stewart F/O P Michalchan F/O MG Kenny

Front Row

F/L KO Mitchel F/L GW Patrick(Course Director) F/L L Parakin

NAV Instructor training

The Navigator Instructor Training course is the oldest of the RCAF post-graduate observer courses, the first course having graduated in July 1948 -leading us to consider "A Decade of Progress" as the title for this article. During the last ten years the course has been known under the titles of Staff Navigator Instructor Navigator (SNIN), Staff Navigator (Staff "N"), Staff Navigation Officer (SNO), and the current title, in keeping with the combined observer trade, Staff Observer Navigation Instructor (SONI).

While the content of the syllabus has changed during its existence, the aims of the course have remained basically the same. In the current syllabus these are:

- To qualify aircrew list officers for appointment as a navigator instructor.
- To provide a candidate with a knowledge of navigation and allied subjects, beyond the basic graduate level, so that the officer may be better qualified to assume appointments on squadrons, in operational training units, and in staff positions at Group and Command headquarters.

During the past five years the RCAF had a heavy NATO aircrew training commitment and this resulted in the instructor aspects of the course being pre-eminent in the minds of most observers. Today, however, with the training commitment and hence the instructor requirement, being reduced the principal function has become the upgrading of personnel for squadron appointments. This is a good thing, especially if graduates of this course, and the other courses, accept their responsibilities and pass on their knowledge to improve the background of the less experienced squadron members.

Scope of the Course.

The SONI course lasts 17 weeks, of which the first two are normally spent at SIT. The general allocation of hours is as follows:-

Academic Instruction:	530 hours	
Flying and Flight Planning:	60 hours	
Student Administration:	90 hours	
	680 hours	(17 weeks)

It is apparent from the foregoing that the emphasis is on academic work with the student being taught subjects fundamental to the modern navigation problem, such as, mathematics and electronics, followed by applied navigation, astronomical navigation. electronic equipment and countermeasures, meteorology, maps, and navigation instruments. To gain a better understanding of the aims of the course we will examine the content of the syllabus itself and see the detailed allocation of hours. the scope of each subject, and the methods of assessment used.

Allocation of Hours.

A detailed allocation of course hours is shown in Table 1. If the reader is eligible for SONI training he would also be well advised to refer to the latest SONI syllabus (CAP 464 - E6, dated October 57) to obtain an appreciation of the content of specific subjects and references. This would aid preparation for any subjects that might be expected to cause difficulty.

TABLE 1 - ALLOCATION OF HOURS

SUBJECT	HOURS	SUBJECT	HOURS
ACADEMIC		FLYING AND TRAINERS	
Applied Navigation	74	Flying	40
Aerodynamics and Aircraft Performance Engineering	38	Preparation and Analysis	20
Navigation Instruments	55	Total Flying	60
Astronomical Navigation	36	INSTRUCTOR TRAINING	
Map Projections	21		
Electronic Theory	60		
Electronic Equipment	36	Instructor Training	137
Electronic Countermeasures	11	ADMINISTRATION	
Mathematics	42		
Meteorology	20	Student Administration	90
Total Academic Instruction	393	Total Hours (17 weeks)	680

Applied Navigation

The 74 hours devoted to the applied navigation syllabus are intended to increase the student's knowledge to the level required for a junior staff appointment; to give the student a knowledge of the instruction and tests given at AOS; and to provide the student with a background of air traffic procedures. The navigation topics include: review of plotting techniques, wind finding, convergency, homings, fourth vector navigation, grid, gyro steering, pressure pattern, and approximately 16 hours of practical plotting. The Air Traffic Control topics include: flight rules, flight planning, and control on international routes. Twelve hours are devoted to review, progress tests, and examinations.

Aerodynamics and Performance Engineering.

Thirty five hours are devoted to aerodynamics, covering general theory;lift, thrust and propulsion;cruise control; manoeuvres; helicopters; high speed flight; and guided missiles. These topics are all intended to provide the student with the background to instruct student observers in the subject; to assess the capabilities of air forces and aircraft; and to understand flying problems associated with engine and airframe design and performance. Seven hours are devoted to review and examinations.

Navigation Instruments.

Navigation Instruments is a combination of the "old subjects", Instruments and Compasses. The 55 hours devoted to this subject follow the pattern of heading and speed measurement, leading to their combination in navigation computers. Magnetism is considered from all its facets, followed by transmission systems, airspeed measurement, gyros, compasses, true airspeed devices, position indicators, and computers. Three hours are devoted to future developments, in addition to coverage of certain modern equipments currently in use in the RAF and USAF. This is also supplemented by information on current instrument development.

Astronomical Navigation

A total of thirty-six hours are devoted to this subject to ensure that the student has a sound knowledge of astronomical navigation. Topics include: elements of astronomy the celestial sphere, time, sextants, corrections , sight reduction, development of tables and risings,settings, and twilight.

Mathematics

The forty two hours of mathematics, is devoted to: algebra, measurement of angles, plane trigonometry and spherical trigonometry. It has been said that the mathematics portion of the syllabus is the cornerstone on which the postgraduate course is built, and its appearance in astronomical navigation map projections, navigation instruments, electronic theory, aerodynamics, and to a limited extent electronic equipment generally confirms this claim.

Syllabus hours in the subject are based on the assumption that the student has an adequate background in algebra, and eligible personnel should, therefore, review this subject (using a text such as "A New Algebra for High Schools" by Crawford, Dean and Jackson.) If time permits the student should continue with a review of trigonometry. (a suitable text for this subject being "Elementary Trigonometry" by Hall and Knight).

Map Projections

In the study of map projections the aim is to teach the principles and construction of projections used in the RCAF, thus permitting a proper assessment of their capabilities. Topics included in the twenty one hours devoted to the subject include: the form of the earth, and azimuthal, conical and cylindrical projections. Six hours are devoted to problem periods, review, and examinations.

Electronic Theory

A knowledge of electronics is becoming a mandatory part of any post graduate observer's background. This is immediately obvious if one considers the role this subject plays in any modern aircraft installation. To provide the student with an adequate theory background sixty hours are devoted to: fundamentals of electricity, vacuum tubes and amplifiers, communication systems, transmission lines, propagation and radar. In the past, observers arriving at CNS who have not previously studied electronics have experienced some difficulty with this subject. Personnel who are eligible for advanced training would, therefore,be well advised to prepare for the course by reading the RCAF Training Command manual "Electronic Theory for Observers". If time is not available to read the entire text, a thorough understanding of Chapters 2, 3, 4, and 9 should be ensured. In the future it is hoped to increase the time allotted for this subject to 70 hours.

Electronic Equipment.

The thirty-six hours devoted to Electronic Equipment are intended to permit a study of current air and ground electronic aids. Equipments discussed include: VOR, Consol, Tacan, Loran, Gee, Shoran, Decca, ILS, GCA, Sarah, APS-33, APS-42, APS-20E, APG-33 (AI radar), and finally, Doppler equipment and its inherent errors.

Electronic Counter Measures (ECM)

The subject of ECM is a recent addition to the SONI syllabus, and the eleven hours are intended as an introduction to the field. Topics include an analysis of principles, equipment. active and passive countermeasures, and communications jamming.

Meteorology

The meteorology syllabi for all post graduate courses has recently been completely revised. The present policy devotes twenty hours to a discussion of circulation patterns and cooling processes, examining their effect and methods of recognition. In addition, approximately fifteen minutes per day is devoted to a study of the current weather situation. Eight hours of flight planning exercises are also given in class. All of this training, which stresses the practical aspects of meteorology and its effect on flight planning, should result in the graduate having a sound knowledge of this subject, and most important, how he can apply his knowledge to himself and the forecaster.

Flying

During the course the student obtains approximately forty hours of flying which is spent as follows:-

- Review and Radar Familiarization: 10 hours.
- Long Range Grid/Gyro and Single Heading: 20 hours. (10 hours day; and 10 hours night.)
- Air Assessment Flight (AOS): 10 hours (5 hours day; and 5 hours night).

The flying is carried out, where possible using the APS-33 radar equipped Dakota, while the air assessment exercise is flown with one of the AOS courses. Twenty hours are also allotted for briefing and post-flight analysis.

Instructor Training

In addition to the eighty hours of instructor training given at SIT the student receives fifty seven hours at CNS. Time is devoted to organization of appropriate units, service writing, three-prong observer training, and practice lecture hours.

Assessment

A total of 1,150 marks are allocated in the syllabus, with a relative weighting being based on the length and complexity of the subject. Flying is allotted 100 of these marks with the student being assessed on the long range flights. No mark is given in instructor training, but an assessment of the student's capabilities is included in the narrative of the training assessment (PT4).

Conclusion

The SONI course is possibly one of the most important steps in the career of any RCAF Observer/Nav.The course is revised each year to ensure that it is current and useful to the potential instructor or staff officer, and a valuable background experience for the squadron navigator. The importance of the course should encourage eligible personnel to ensure that they are prepared for it, through reading the recommended references in Mathematics and Electronic Theory. With adequate preparation the course can be a vital and useful step forward for personnel who are prepared to apply themselves.

RADAR SCOPE INTERPRETATION

By Captain CE Evans, USAF
Central Navigation School

The increasing use of radar in RCAF aircraft is posing a hitherto little known problem to the untrained operator. This problem is the interpretation of the radar scope presentation. To the uninitiated a radar picture often appears as a jumbled mass of returns and, at times, even the trained operator may encounter this confusing experience. Therefore, it is to the advantage of the enterprising observer to learn what changes he can expect in his radar picture so that he may anticipate them and intelligently interpret the information presented to him.

There are many factors that affect scope appearance; distorting the radar picture in various ways. Many of these are known and measurable but others are still an unknown quantity. Fortunately, however, unceasing research and experimentation continually adds to our knowledge of this subject.

The factors which distort the radar picture fall into two categories. These are:

- Equipment characteristics, which are the inherent or design characteristics of the set itself, and
- Target characteristics, such as shape, size, location and structural content of the target.

This article, the first of two, will consider equipment characteristics, while the concluding article dealing with target characteristics will appear in the July issue of the OBSERVER.

When considering the inherent errors of the equipment we are in luck. These errors are measurable and we can accurately predict what return a particular ground object will give. The specific errors that we will consider in this category are Beam Width error, (BWE) Pulse Length error (PLE) and Spot Size error (SSE).

Beam Width Error

The width of a beam of radar energy is measured from its center point (maximum power) to its half power point (Figure 1). As an example, let us consider the APS-33 radar set which has a beam width of 3.6°. With this set, the beam will subtend an arc of approximately two miles at 30 miles range. Since the return will be painted from the time the leading edge of the beam strikes the target, the appearance

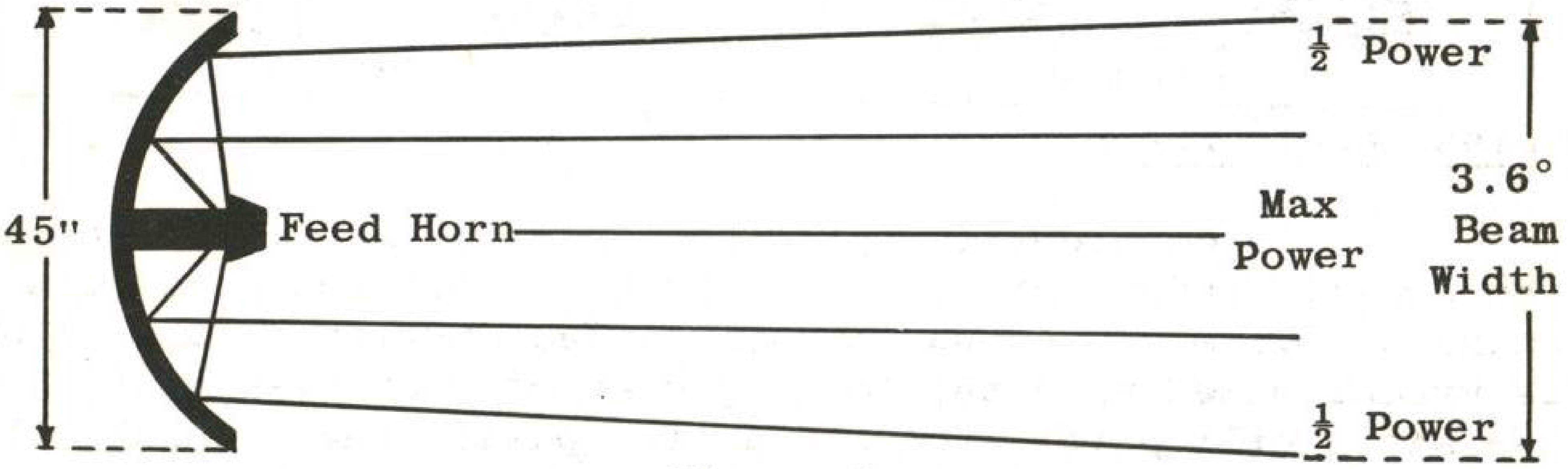


Figure 1

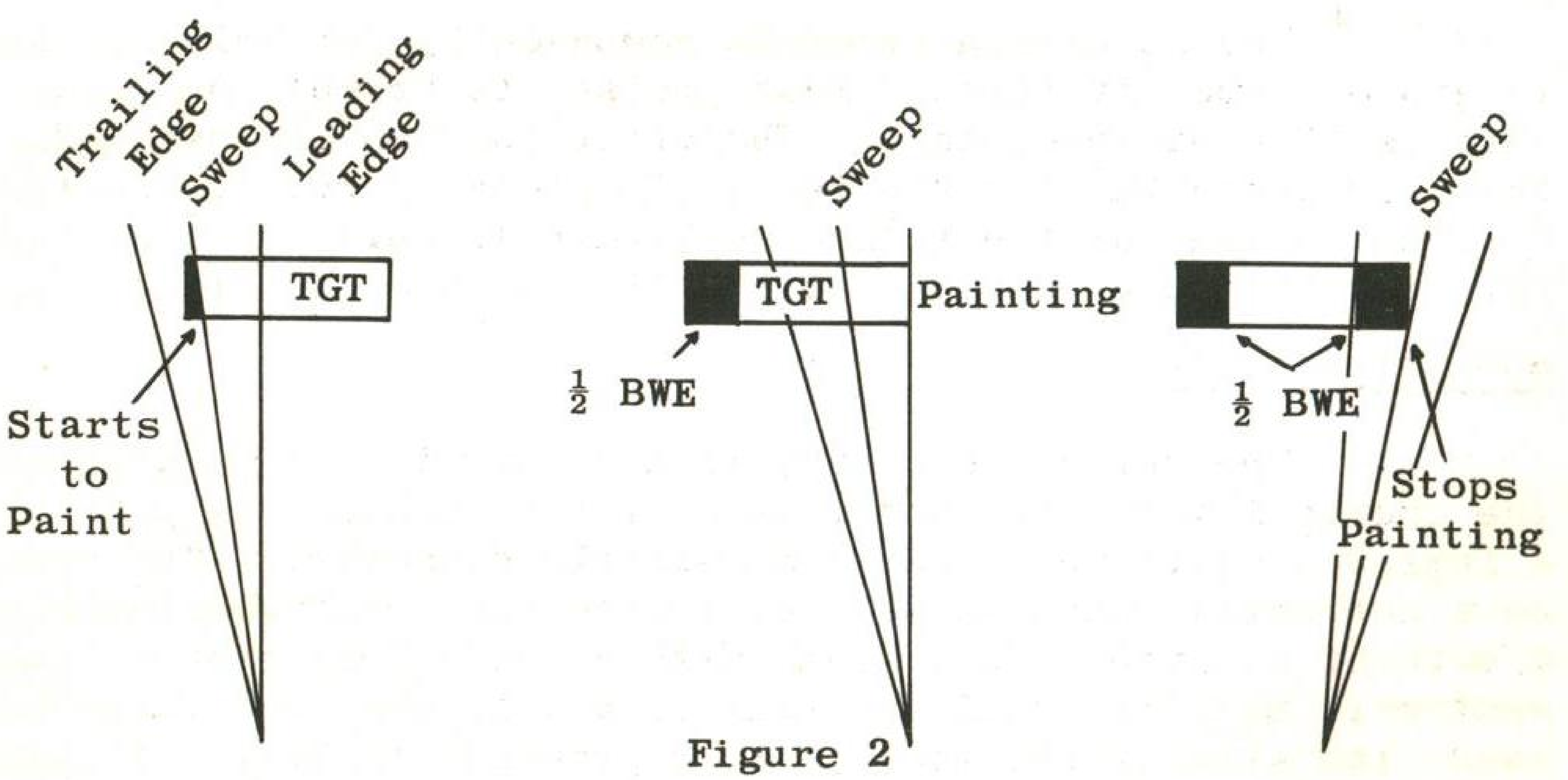


Figure 2

of all reflected returns will be increased by 3.6° in the azimuth direction (Figure 2).

Beam Width error will, of course vary with range to the target; however, if we use a one mile error at 15 miles the following formula results which gives the error in feet.

BWE = 1/15 x Range to Target x 6080, or

BWE = 405 x Range to Target

Half of the total Beam Width error is applied to each side of the return in the azimuth direction (Figure 3).

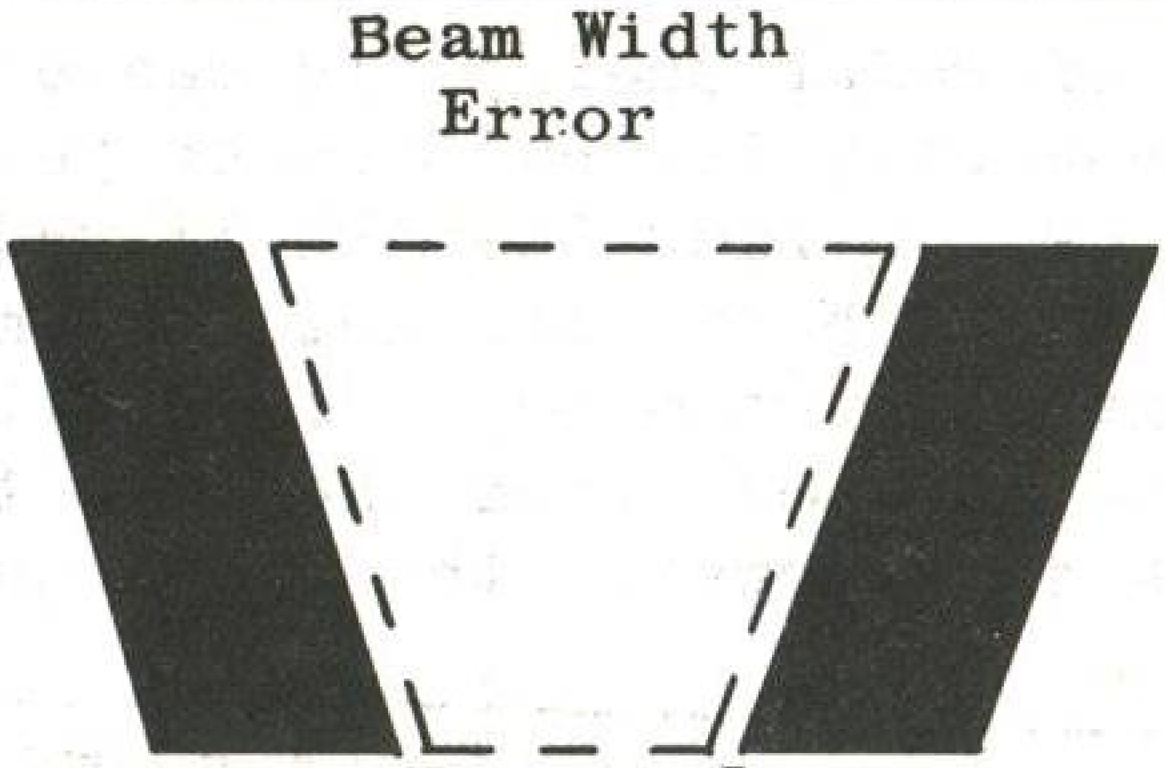


Figure 3

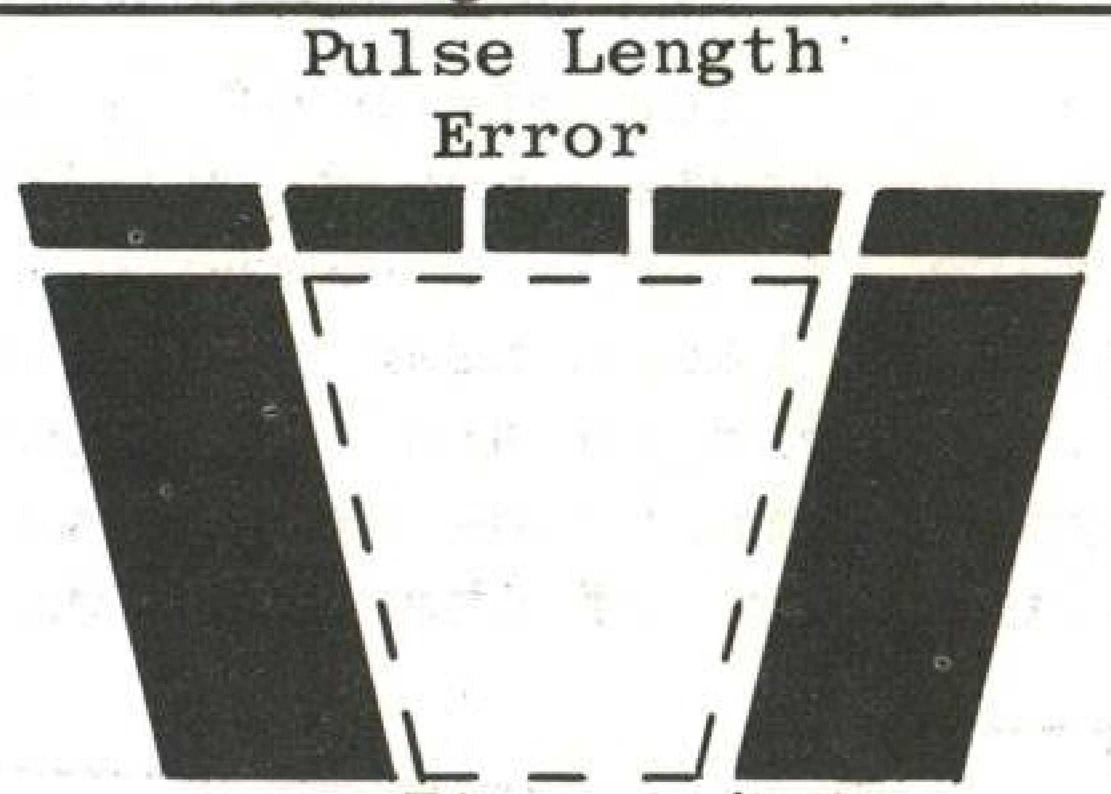


Figure 4

<u>Pulse Length Error</u>

In considering Pulse Length error let us again use the APS-33 radar set as an example. This set transmits a pulse of 0.5 microseconds duration. The display of the sweep is synchronized with the leading edge of the pulse; therefore the sweep will paint for the entire pulse length which will extend the return by the length of the pulse in the range direction.

Pulse Length error is computed by determining the length of time it takes a radar pulse to travel one mile. This is 12.4 microseconds. The error for 0.5 microseconds, then, is approximately 245 feet. The total error is applied to the far side of the reflected return. In this instance the return will appear similar to the illustration in Figure 4.

<u>Spot Size Error</u>

The reflected energy from a target is presented on the chemically-coated inner face of the cathode ray tube as a luminous spot which has a measurable diameter. The spot on a correctly tuned scope has a diameter of approximately 1/60th of an inch. On a scope with a 2 1/4 inch radius, the spot will be 1/135th of the radius, and at whatever range is used the size of the spot will represent 1/135th of that range. Therefore, the variable in this case is the range on the scope. The following formula gives the error in feet:

SSE = 1/135 x Range on Scope x 6080, or
SSE = 45' x Range on Scope

The error is applied in all directions by one-half the diameter of the spot (or half the Spot Size error). Adding this to the other errors, our final predicted return will appear similar to the illustration in Figure 5.

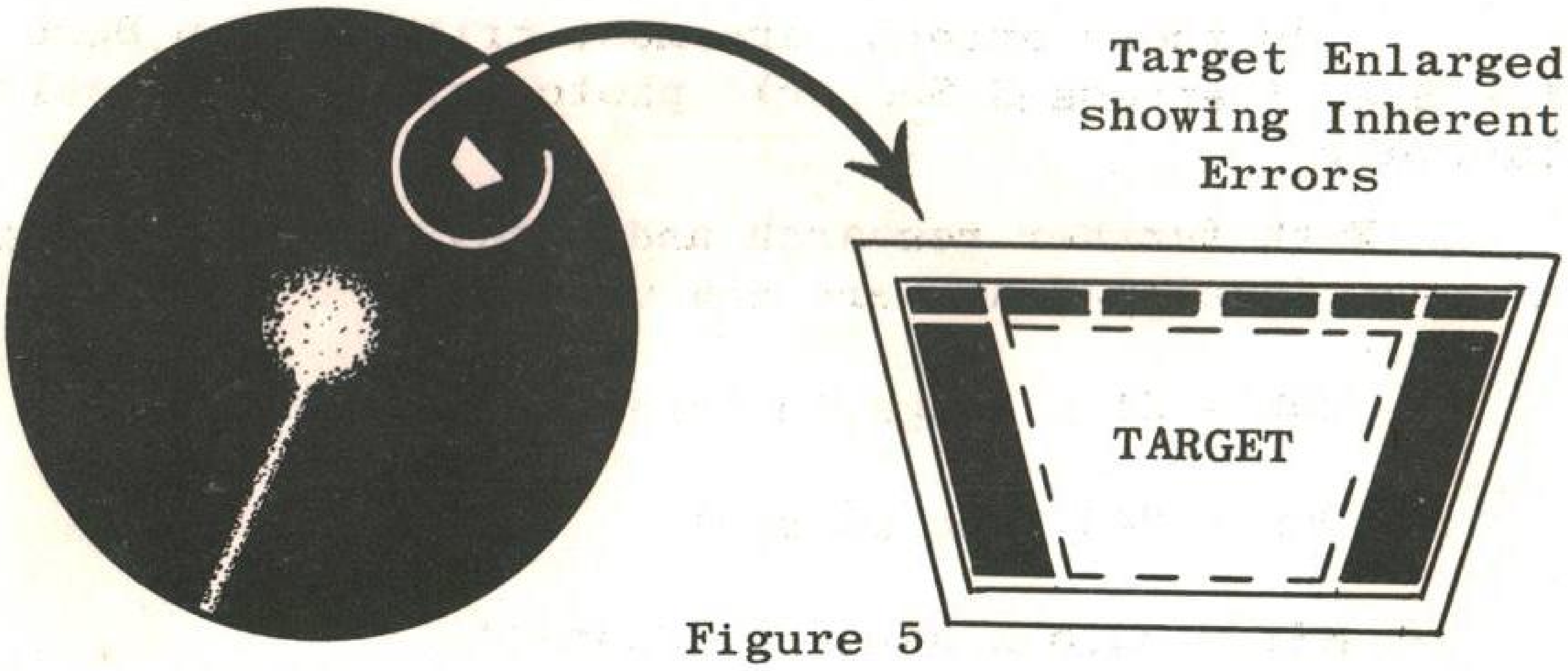


Figure 5

Miscellany

The following points should also be noted when considering inherent equipment errors.

- The effect of radar resolution errors on non-reflecting targets (areas of no return) such as lakes rivers, sand, etc., is to DECREASE their apparent size. This is caused by errors from adjoining areas.
- The use of other types of scopes, i.e., B-Scope, Offset Sector, etc. will change the above formulae accordingly.
- The following formulae may also be of interest:

Total Azimuth Error = SSE + PLE
Total Range Error = SSE + BWE

Latest Developments

Soon after the above formulae were developed, it became apparent to airborne operators that, in many cases, they were not reliable. As practical experience proved, the predicted errors were only correct when high gain settings were used. With low gain settings, it seemed that the errors were appreciably less than what the formulae predicted. In 1955, a group of navigators at Mather Air Force Base, near Sacramento, California, set out to evaluate the formulae by actual tests. Under a project approved by the USAF Research Center at Wright-Patterson Air Force Base, Dayton, Ohio, they flew 700 individual photographed runs on a predetermined and measured target area. Radar scope photographs of these runs were studied and analyzed. It was discovered that the errors were in some cases only one-third of the predicted ones.

As these errors are most critical on Bomb Runs, Sector Scan (Depressed Sector) photographs were dealt with exclusively.

With further research and study, the following formulae were developed and are now used:

BWE = 51 x Range to Target

PLE = 245' (no change)

SSE = 22.5 x Range on Scope

Figure 6 illustrates the results of the tests: The target size is superimposed on the measured return size equal to the average of all runs made. The dotted line indicates the return size with the high gain errors applied.

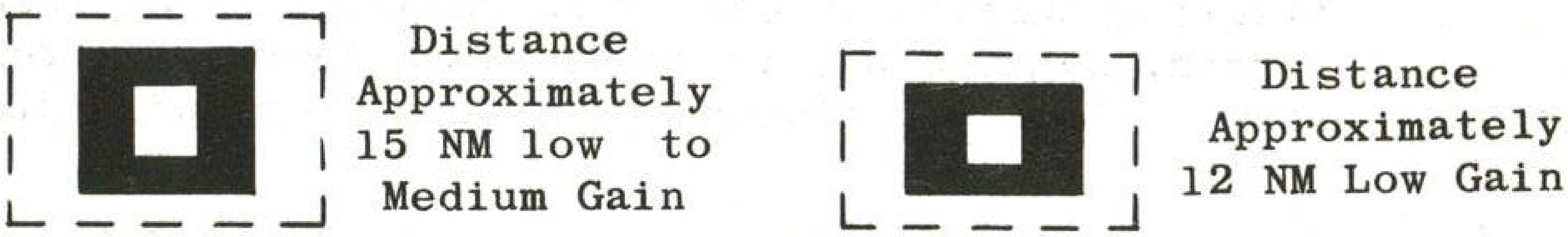


Figure 6

Summary

To sort out the jumble of radar returns, knowledge of the set (design characteristics) and knowledge of the target area and operator technique are the three most important aspects. While in flight, the radar operator is not going to have all the time he wants to compute and apply all errors. However, in pre-flight prediction study, he will have time to evaluate the errors and when in the air increase his practical radar scope interpretation ability.

In the next issue of the OBSERVER the second phase of this problem will be discussed; i.e., Target Characteristics such as, target size, target shape, target location and other factors.

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F/L H Hibbard F/L RE Burn F/O JLRD Fillion F/O HEC Shergold F/L SR Kerr F/O HJ Graham F/O DR Stewart

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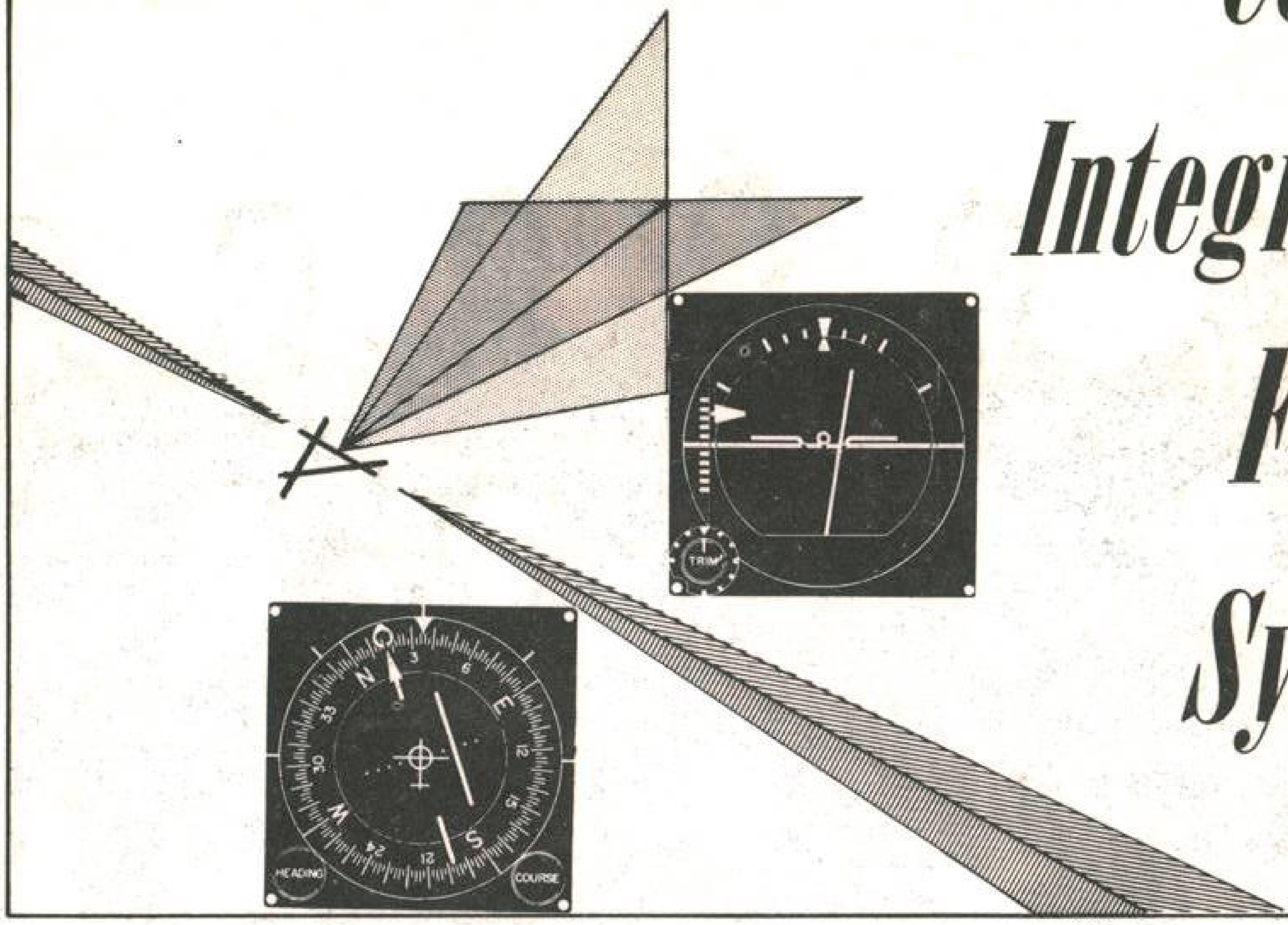
F/O RD Zimmer F/O JEHP Roy F/L MS Slezak (Course Director) F/O MR Hunter F/O JC Lynch

The Pilot's Instruments

Collins Integrated Flight System



The Collins Integrated Flight System is the fifth in our series on the pilot's instruments. The Collins System, like the other systems we have discussed, was designed to solve the problems inherent in conventional instrument systems with particular emphasis on instruments for use in high speed aircraft operating in dense traffic conditions.

In the Collins system two basic instruments are used to display basic attitude; navigation situation; and flight director information. These displays are a "forward view" instrument and a "plan view" instrument. Both presentations are of the symbolic pictorial type, combining the available data in a logical, unambiguous manner, so as to provide additional valuable information by their interrelationship.

An ILS approach and landing under instrument conditions continues to be a highly critical flight operation. It may be assumed that, for some time, the pilot will continue to make landings manually with visual guidance. It is essential, therefore, that he be properly prepared for the transition from instruments during the approach to visual contact after breakout. This requires the pilot to form an accurate mental picture of the complete situation. The Collins instruments are designed to simplify the formation of such mental pictures. The presentations prove equally effective for all phases of flight, including: take-off, climb out, enroute navigation, and terminal area manoeuvres.

OPERATION

Forward View Display

The "forward view" instrument is the Collins Flight Director Horizon or Approach Horizon (Figure 1). It presents a pictorial display of: pitch attitude, by position of the aircraft symbol (1) against the Horizon Bar (2); bank attitude, by position of the Horizon Bar and Bank Angle Indicator (3); relative position of glide slope, by position of the Glide Slope Pointer (4) with respect to the Glide Slope Scale (5); and Flight Director steering information by means of the Steering Pointer (6).

Basic attitude information is displayed on the Horizon in the conventional manner by means of the aircraft symbol and the Horizon Bar. Sensing is identical to that of the standard artificial horizon. A Manual Pitch Trim Knob (7) is provided for adjustment of the pitch indication to match the trim of the aircraft. Experience has shown that a constant display of basic attitude information on the Flight Director instrument is highly desirable, since the pilot must have this information to maintain proper orientation both in manual and automatic flight.

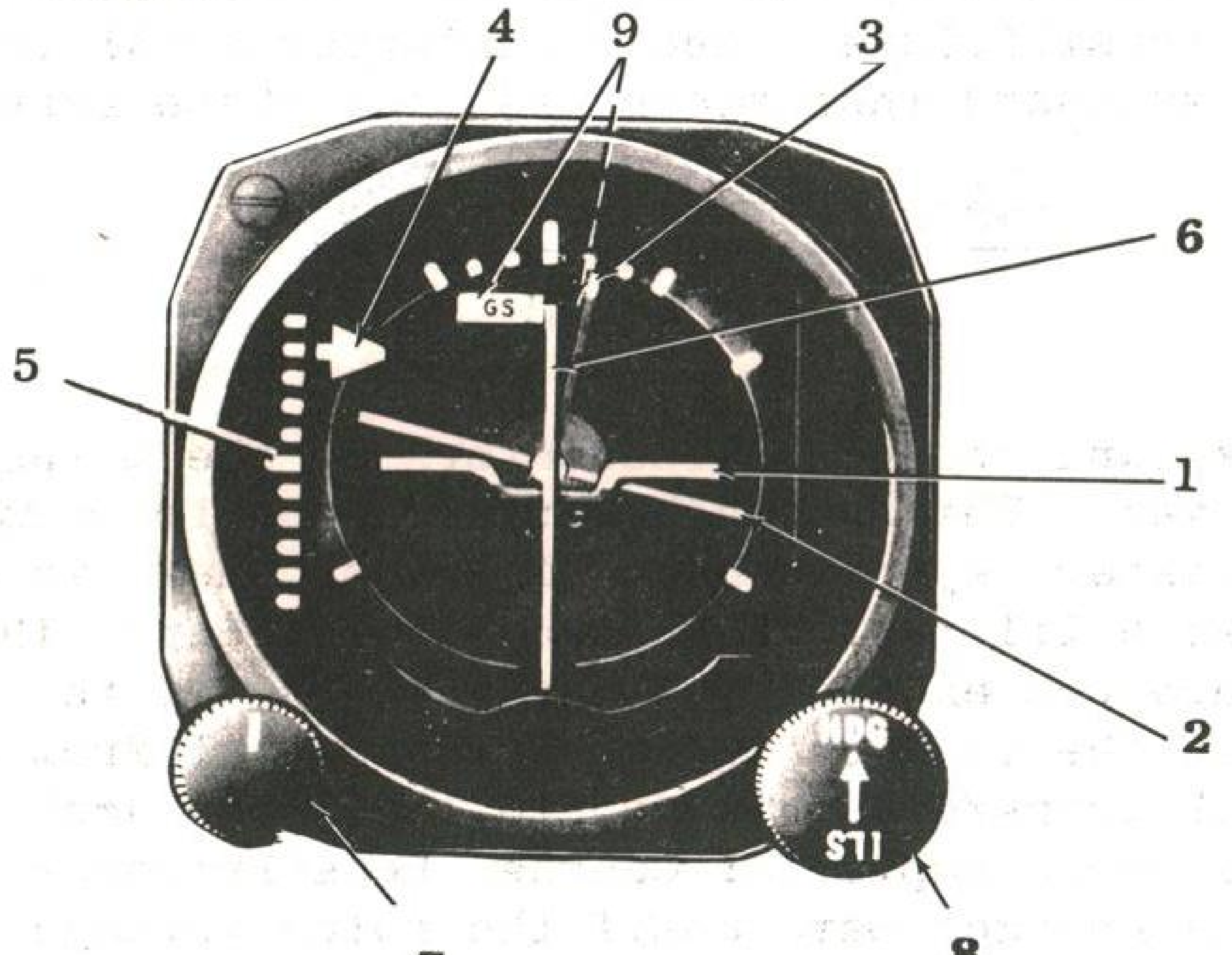


Figure 1 Collins Flight Director Horizon

An optional HDG-ILS Selector Switch Knob(8) is provided for switching the Flight Director mode of operation between the navigation mode and the ILS mode. Other optional function selector arrangements can be provided to meet customer requirements.

In addition, the Horizon provides warning flags(9) to indicate the functioning of the glide slope receiver, localizer/VOR receiver, vertical gyro operation and flight director computer operation.

Signals and Indications

The Flight Director Horizon and Course Indicator instruments are designed to operate from standard signal inputs wherever such standards have been established, and to provide standard indications similar to previous instrument designs integrated into a pictorial display presentation.

Indications of VOR or localizer deviation on the Course Indicator, and glide slope deviation on the Horizon are provided by meter movements operating directly from the standard d-c signal outputs of the navigation and glide slope receivers. Standard "5-dot" displacement calibration is used on each.

"TO-FROM" indication on the Course Indicator, and glide slope and localizer/VOR warning flags on the Horizon are similarly operated by d-c meter mechanisms from the standard signals provided by the respective receivers. All indicators have sensitivities and resistances equal to those of the previous standard indicators used for these services.

INSTRUMENTATION CIRCUITS

Attitude

The bank and pitch indicators in the 4-inch Horizon are servo driven. The Approach Horizon contains a high impedance, bank-repeater, synchro control transformer in which the rotor turns at a 1:1 ratio with the Horizon Bar. The stators of this synchro are excited by the stators of the bank-data transmitter in the vertical gyro. The signal from the rotor of the control transformer is fed to the servo amplifier. The output of the servo amplifier causes the servomotor to operate and drive the Horizon Bar until the rotor voltage is zero. The motor assembly includes a rate generator connected to the input of the amplifier so that proper servo damping is obtained. The Bank Horizon Bar has 360° freedom.

The pitch servo circuit is similar to the bank circuit. The Approach Horizon contains a synchro control transformer in which the rotor is connected to the Pitch Bar. The stators of this synchro are excited by the pitch-data transmitter located in the vertical gyro. A signal on the rotor is fed to the input to the pitch servo amplifier. The output of the servo amplifier causes the servomotor to operate and drive the Pitch Bar until the input signal to the servo amplifier is zero. Rate generator damping is provided as in the roll axis.

A pitch-trim signal is applied to the input of the pitch servo amplifier to adjust the Pitch Bar to zero for normal pitch attitudes in either the heading or ILS modes of operation. Servo amplifiers are of the transistor type having flag and redundant circuit failure protection. Loading on the vertical gyro data source is minimized by use of high impedance synchro control transformers. The bank and pitch circuits are compatible with the synchro transmitter outputs of the various remote vertical gyros now going into use.

The bank and pitch indicators in the 3-inch Approach Horizons are D/Arsonval meter movements. The 3-inch Horizons normally are used with the type 3 gyro which has potentiometer pick-offs. Attitude signals are derived from a simple resistive bridge circuit.

Proper combination of the presented data makes it possible to provide the pilot with additional cues and guidance. Vertical guidance of the aircraft is concerned with forward view indications, and both pitch attitude and vertical position are required. The Approach Horizon therefore is designed to present both vertical position (with respect to glide slope) and pitch attitude separately,but in such a manner that accurate flight director proportional control of pitch can be attained easily by visual combination of these signals to make good the desired flight path. Furthermore,by presenting both vertical position and attitude indications on this instrument, the transition from glide slope and steering attention during the early part of an ILS approach to attitude attention at the lower altitudes is greatly facilitated. This has proved to be preferable to a system whereby these signals are combined electrically and only their resultant is presented to the pilot on a null-type vertical guidance indicator.

In lateral control, computed signals are used for directing flight on specific headings or along radio paths. The Steering Needle combines the necessary signals for left-right bank commands. The corresponding navigation situation is presented by the Course Indicator.

Plan View Display

The "Plan view" instrument is the Collins Course Indicator (Figure 2). It presents a pictorial display of Magnetic Heading by a Moving Card(1) and Lubber Line (2); Desired Magnetic Heading (3); selected localizer or VOR course (4); deviation from localizer or VOR course(5); and TO-FROM information with regard to VOR station (6). A Course Selector Knob (7) and a Heading Selector Knob (8) are provided for setting course and heading respectively. A miniature airplane (9), etched on the instrument's glass, simulates the aircraft.

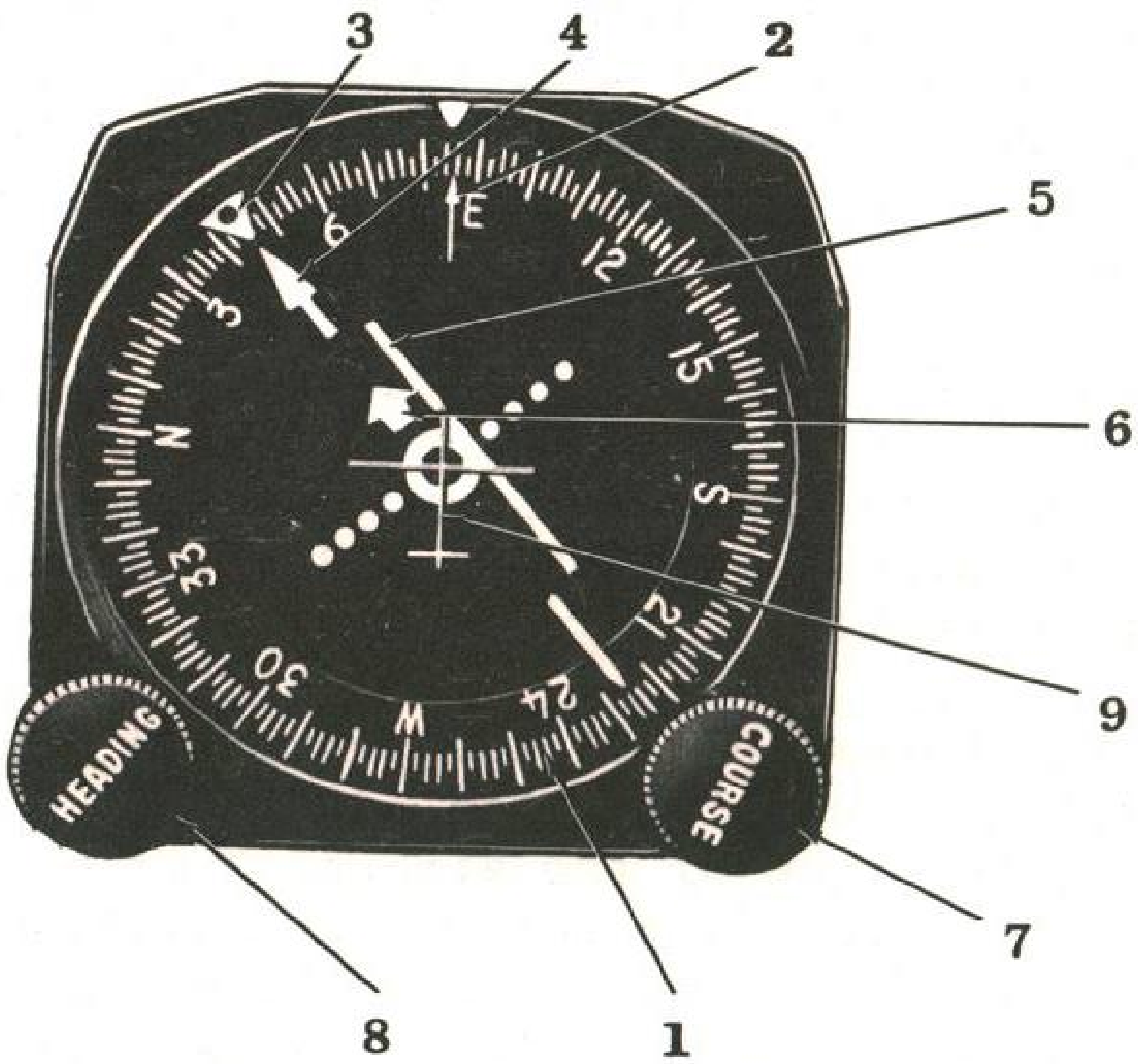


Figure 2 Collins Course Indicator

The display of the navigation situation as shown on the Course Indicator is completely pictorial, showing a "plan view" of the aircraft's position and heading with respect to the selected heading and course, with no ambiguity or reversed sensing at any time. When on VOR, the Course Bar shows relative direction and position (in terms of angular deviation measured at the station) of the selected course. The TO-FROM indicator (driven directly from the receiver) always shows the direction to the station, along the Course Line. When flying a localizer, the Course Pointer is set to the inbound localizer heading, and the Course Bar again shows relative direction and position (in terms of angular deviation measured at the transmitter) of the localizer. Whether flying inbound or outbound, on the front or back leg of the localizer, the display always gives a true picture of the situation. Since no TO-FROM signal is transmitted on localizer, the TO-FROM flag remains hidden.

The Course Selector Knob orients the course deviation display with respect to the compass card, and positions the rotors of the course synchro resolver, associated with the VOR navigation receiver. The Heading Selector Knob positions a Heading Index on the compass card, and positions the rotor of the heading error synchro, which provides a signal to the Flight Director Computer proportional to the sine of the difference between the selected heading and the actual heading of the aircraft.

Heading Circuits

Heading Repeating Servo. The Course Indicator supplies the pilot with heading information. The Azimuth Ring of the Course Indicator is servo driven in all models of the instrument. The Course Indicator contains a synchro repeater control transformer in which the rotor turns at a 1:1 ratio with the Azimuth Ring. Stators of this synchro are excited by stators of the heading data transmitter in the stabilized magnetic compass. The error signal from the rotor is fed to the input of the heading servo amplifier. The output of the servo amplifier causes the servomotor to operate and drive the Azimuth Ring until the rotor voltage is zero. The motor assembly includes a rate generator connected to the input of the servo amplifier so that proper servo damping is obtained. Servo loop and servo amplifier circuitry is the same for bank, pitch, and heading repeat functions.

Heading Selection Circuits. In addition to continuous heading information, heading-error signals are supplied from the Course Indicator. Selected heading for the heading mode is provided by rotating the Heading Selector Knob on the Course Indicator to a desired heading. The selected heading is displayed on the Azimuth Ring by the Heading Marker, which rides with the Azimuth Ring after being set. Deviation from the selected heading, shown by a difference between the Heading Marker and the Lubber Line, produces a heading error signal which is sent to the computer. The Course Indicator contains the selected heading synchro, the stators of which are excited from the stators of the heading data transmitter in the stabilized magnetic compass. The rotor voltage is zero when the aircraft is flying the heading selected. This synchro is positioned by the Course Knob. Deviation from selected course, shown by the difference between the Course Arrow and the Lubber Line, produces an error signal from this synchro.

Radio Position

Glide Slope Position. The Glide Slope Pointer is a short horizontal bar found at the left of the face of the Flight Director Horizon or Approach Horizon. It moves vertically, and is pivoted in such a fashion that it remains parallel to the pitch axis of the aircraft. The meter movement which operates the Glide Slope Pointer is connected directly to the glide slope receiver in the same standard manner as the horizontal pointer meter of any flight-path deviation indicator. There is no connection between this meter circuit and any other part of the steering indicator or computing equipment. The Glide Slope Pointer is responsive to a radio signal in proportion to the aircraft's deviation above or below the glide path.

VOR/LOC Deviation. The Course Bar is driven by a meter movement connected to the output of the navigation receiver. It is responsive to radio signals in proportion to displacement and direction from a selected radial or beam. The Course Bar provides both localizer service and VOR service without change of connection, functioning in the same standard manner as the vertical needle of a flight-path deviation indicator. A second meter movement in the Course Indicator provides TO-FROM arrow indication during flight on an omni-course. This meter movement is connected in conventional manner directly to the TO-FROM metering circuit of the navigation receiver. It gives service only when the navigation receiver is tuned to VOR channels. The meter movement operates an arrow pointer which protrudes from the reference mark of the Deviation Indicator (center section of the Course Indicator). The pointer shows which end of the Course Arrow points toward the omni-station. The TO-FROM arrow continues to operate correctly in case the heading repeater servo or directional compass is not operating.

Course Selection

The major function of the Course Indicator is pictorial display of the aircraft's position, relative to an omni-range course or localizer beam. This is accomplished by the comparison of the position and direction of the miniature airplane (etched on the cover glass) to the Course Bar in the center of the instrument. Setting of the Course Arrow, by rotating of the Course Selector Knob at the lower right of the instrument case, positions the rotor of a standard course selector resolver. Positioning of the rotor produces a 30-cycle reference voltage phase shift in the navigation receiver required for omni-course measurement. The selected omni-range or localizer course is read on the Azimuth Ring, at the head of the Course Arrow. A differential action allows the Course Arrow to be set in relation to the Azimuth Ring for omni-course or localizer beam selection,but also allows the Course Arrow to rotate with the Azimuth Ring during change of heading. This also makes it possible to use the information from the Course Bar and from the selected course and heading synchros in case of a repeater servo failure in the Course Indicator.

Flags

Attitude Flag. A gyro attitude warning is presented on the face of the Flight Director Horizon. (Approach Horizon) for protection in the event of gyro or attitude circuit malfunction. The flag circuit indicates when information from the vertical gyro is not reliable, when there is pitch or bank servo failure, or when power is off.

Heading Flag. A Heading Flag is presented on the face of the Course Indicator. The Flag circuit indicates when information from the compass is not reliable, when there is heading-repeater servo failure, or when power is off.

Radio Flags. Two Radio Flag Alarms are provided in the Approach Horizon. The GS Flag is connected directly to the glide slope receiver and operates in conventional fashion. The LOC Flag is also connected directly to the navigation receiver and provides the same service as similar warnings on conventional Flight Path Deviation Indicators.

A data flow diagram of the entire system is shown in Figure 3.

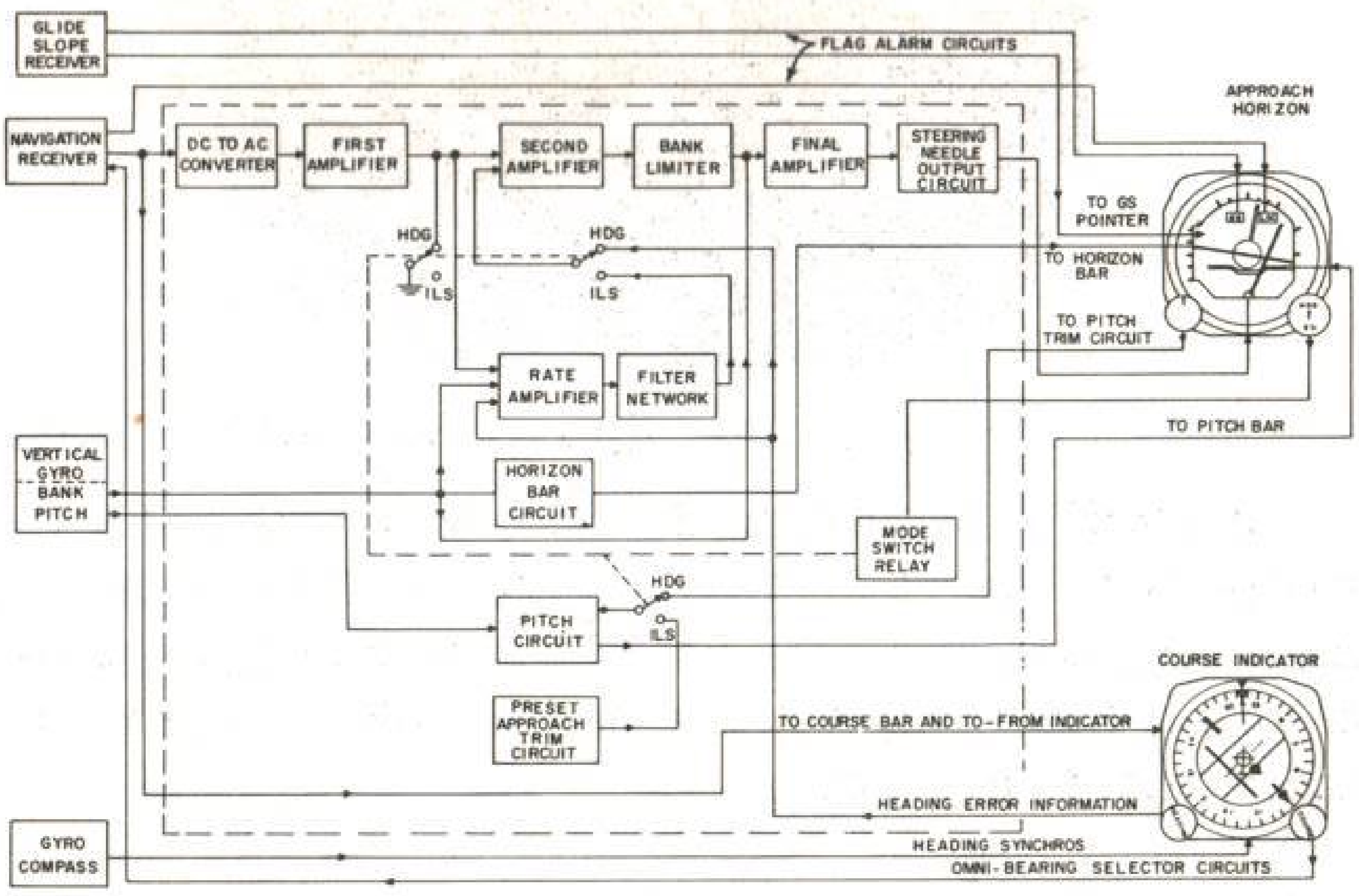


Figure 3 Data Flow Diagram

DISTANCE RADIO MAGNETIC INDICATOR

Requirements exist today, or will in the future, for a distance indicator of some form to be placed on the instrument panels of many aircraft. A distance indicator will be required for DME, for TACAN, or for any of the several radar or navigation computer systems which have been or are being developed.

Panel space on a modern aircraft is at a premium. The use of separate distance indicators for each such system, where more than one system is to be installed, would be undesirable. In fact, the addition of an instrument for the sole purpose of providing distance information to the present panel will be difficult in some cases.

The Collins Radio Company proposes a combined distance and radio magnetic indicator as a "common system" instrument for all distance indication service(Figure 4). This instrument, the Distance Radio Magnetic Indicator (DRMI) is offered as an optional accessory to the Collins Flight Director System. It is not directly connected with the Flight Director, and is not required for operation of that system.

Figure 4 Distance Radio Magnetic Indicator

The DRMI presents distance information in digital form, superimposed on the conventional RMI display consisting of a moving compass card to show heading, and two bearing pointers to show bearing to an ADF, VOR, TACAN, Computer Waypoint, or similar facility.

The DRMI is a standard 3-inch panel instrument, approximately 7-1/2" over-all in length,including an integral servo amplifier for the compass card drive. A miniature type connector is used, so that depth required behind the panel is approximately the same as required for a standard RMI with an AN-type connector.

The DRMI can replace the conventional RMI on the panel, thereby requiring no additional panel space. The integral servo amplifier of the DRMI makes it possible to replace an all-synchro type of RMI without requiring the addition of a separate amplifier. However, the integral amplifier can be omitted where an external amplifier is already provided to drive a servo type RMI.

Distance is displayed by three digits, providing 0 to 999 miles range, with the units dial divided into half mile increments for easy interpolation to the nearest 0.1 mile. Each dial carries the digits 0 to 9, inclusive, spaced at 36°. "Zero" indication occurs at electrical zero of the corresponding synchro.

The advantage of such individual synchro drives for each dial include:

- Instant transfer of distance indication when switched from one output to another.
- Compatibility with DME and TACAN distance systems and with dead-reckoning and course-line navigation computers.
- Multiple distance (as well as bearing) indications by parallel operation of up to three indicators.
- Flexibility of operating speed in "track" or "search" with instant "lock-on". Any operating range within the total limits can be used without modification of the indicator.

CONCLUSION

This is the Collins Integrated Flight System, a two indicator display presenting all relevent flight data in a concise and logical form. While the observer is not directly concerned with flight systems, the question of display of navigational data should be of interest to everyone, particularly as the Collins system is reported to be one of the systems being considered by the RCAF for the CC-106 turbo-propellor transport aircraft.

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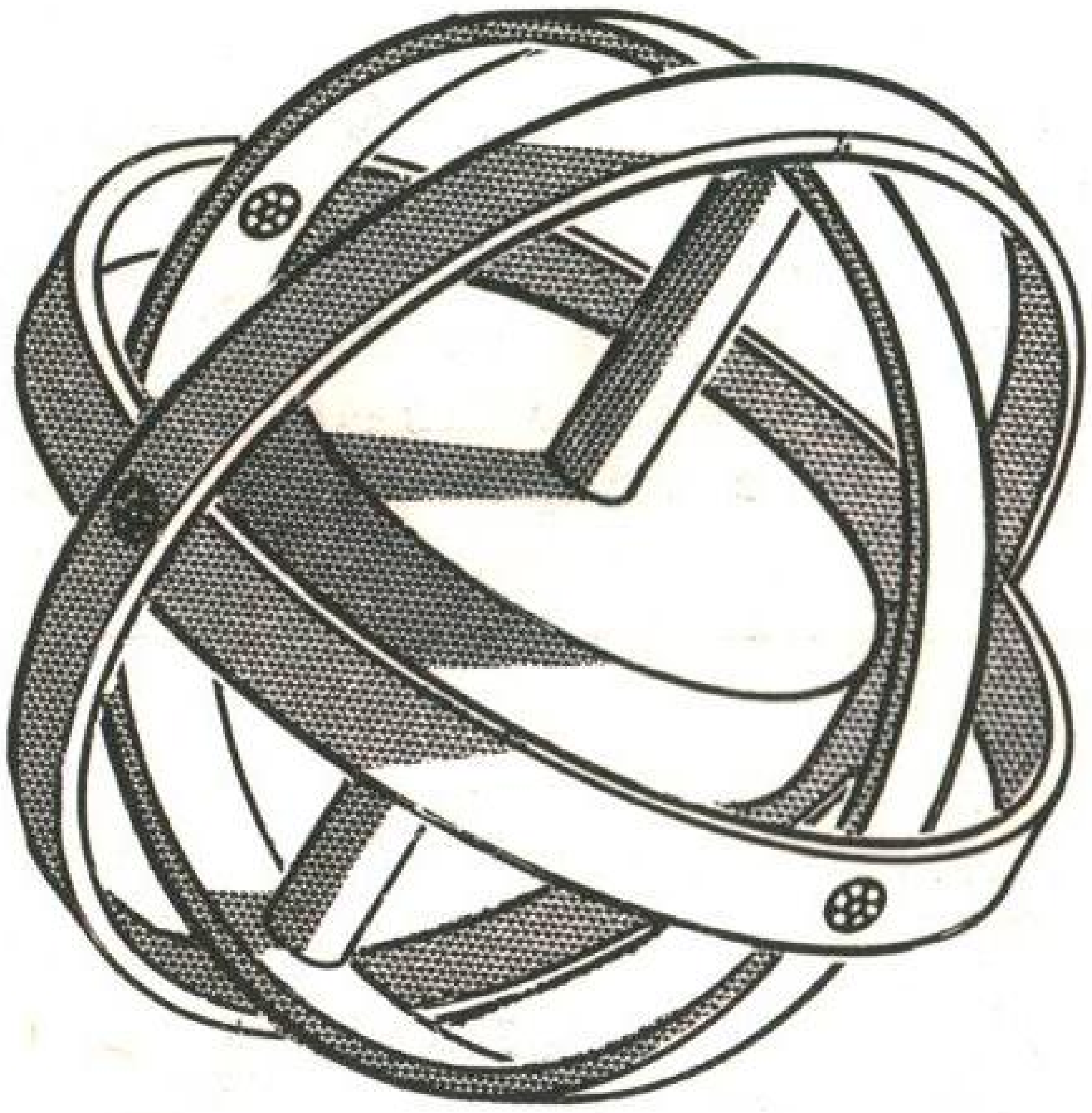
Back Row

F/O GF Thomas F/O RG Garnett F/O MG Mulroney
F/O AW Campbell F/O WD Lewis

Front Row

F/O FE Tuerk F/O JJJ Verreault F/O McLellan(Course Director)
F/O TE Dodd F/O BD Hillier



The Stable Platform

Several of the articles on integrated flight systems have stated that the system is capable of development and that it will accept inputs from a stable platform, or stable element. The stable platform is comparatively new, but it possesses advantages in several flight and guidance applications. This article should serve to introduce the observer to some of its types, methods of control, limitations, and future appearance.

The stabilized platform is any platform maintained horizontal with respect to a line drawn to the centre of the earth. Orientation of the platform is normally sensed gyrodynamically, but the gyros themselves need not be mounted on the platform.

The stable platform has many uses, some of which are as follows:

- A central heading/attitude source providing outputs of heading, pitch, and roll to a flight system and compass.
- A base for special instruments, such as a magnetometer being used to measure the strength of the horizontal component of the earth's magnetic field at altitude.
- A base for an automatic sextant, or astro tracker, enabling the celestial horizon to be determined.

A base for an acceleration sensing device to measure motion of a vehicle about different axes.

General Description.

The platform is mounted on pivots, or gimbals, so arranged to provide it with the degree of freedom demanded by the vehicle. In its simplest form it may be driven by servo motors, with pivots arranged to give it freedom in one plane, as shown in Fig. 1. The tilt stabilized antenna of a modern search radar is essentially a simple form of stable element.

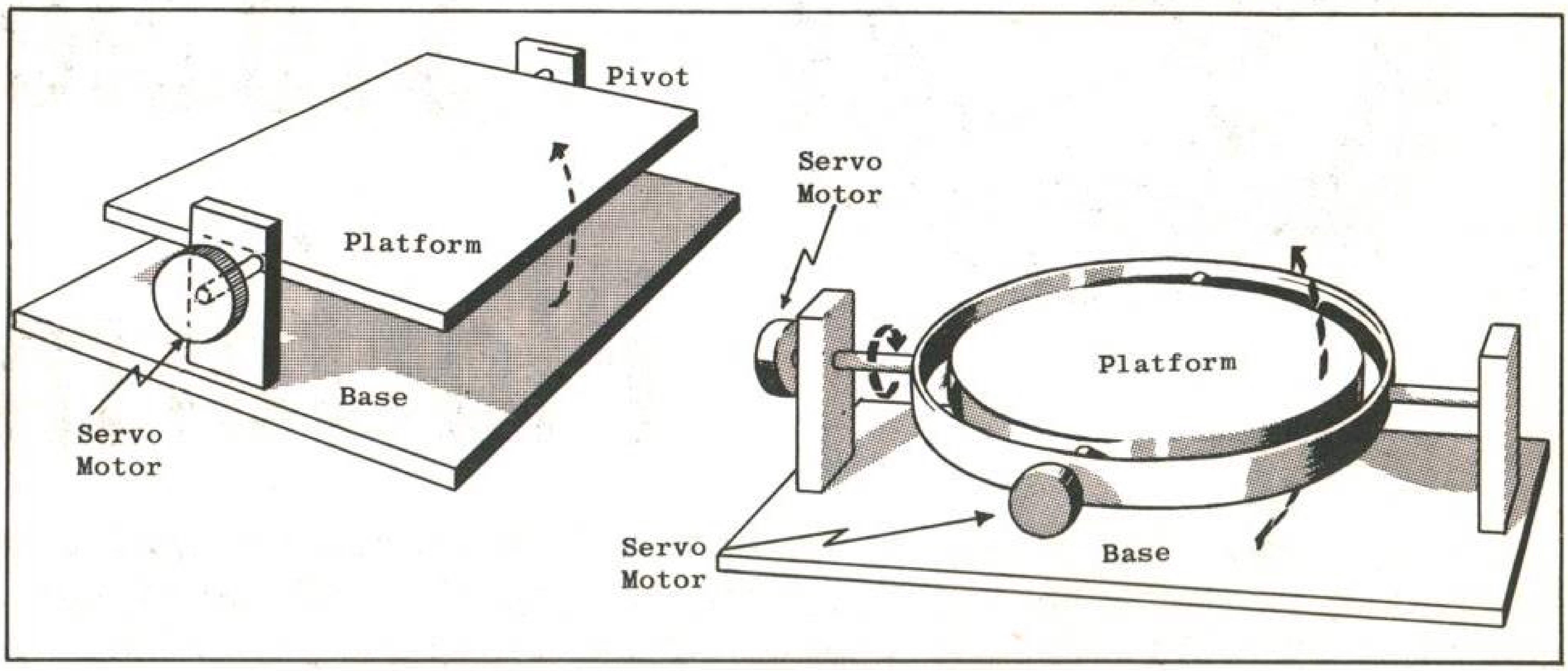


Figure 1 Figure 2

As the degree of freedom required of the device increases, so does the complexity of the gimballing and control required. An example of an arrangement giving limited freedom of movement in two planes is illustrated in Fig. 2.

Reference to Figure 2 indicates that the device turns with the base, hence to stabilize the device in azimuth (as would be required for an automatic sextant for example) requires that the platform be mounted on a central pivot. This results in more complexity, and a typical gimbal arrangement is illustrated in Fig. 3.

The same effect to that shown in the diagram can be obtained using gimbals that are full circles, but this is not essential.

The devices shown in the preceding paragraphs have illustrated increasing degrees of freedom, but to ensure complete freedom in all planes the problem of "gimbal lock" must be eliminated. To eliminate this problem an extra gimbal is required, similar to the roll correcting gimbal used to stabilize a directional gyro. A typical gimbal arrangement for this type of platform is shown in Fig. 4.

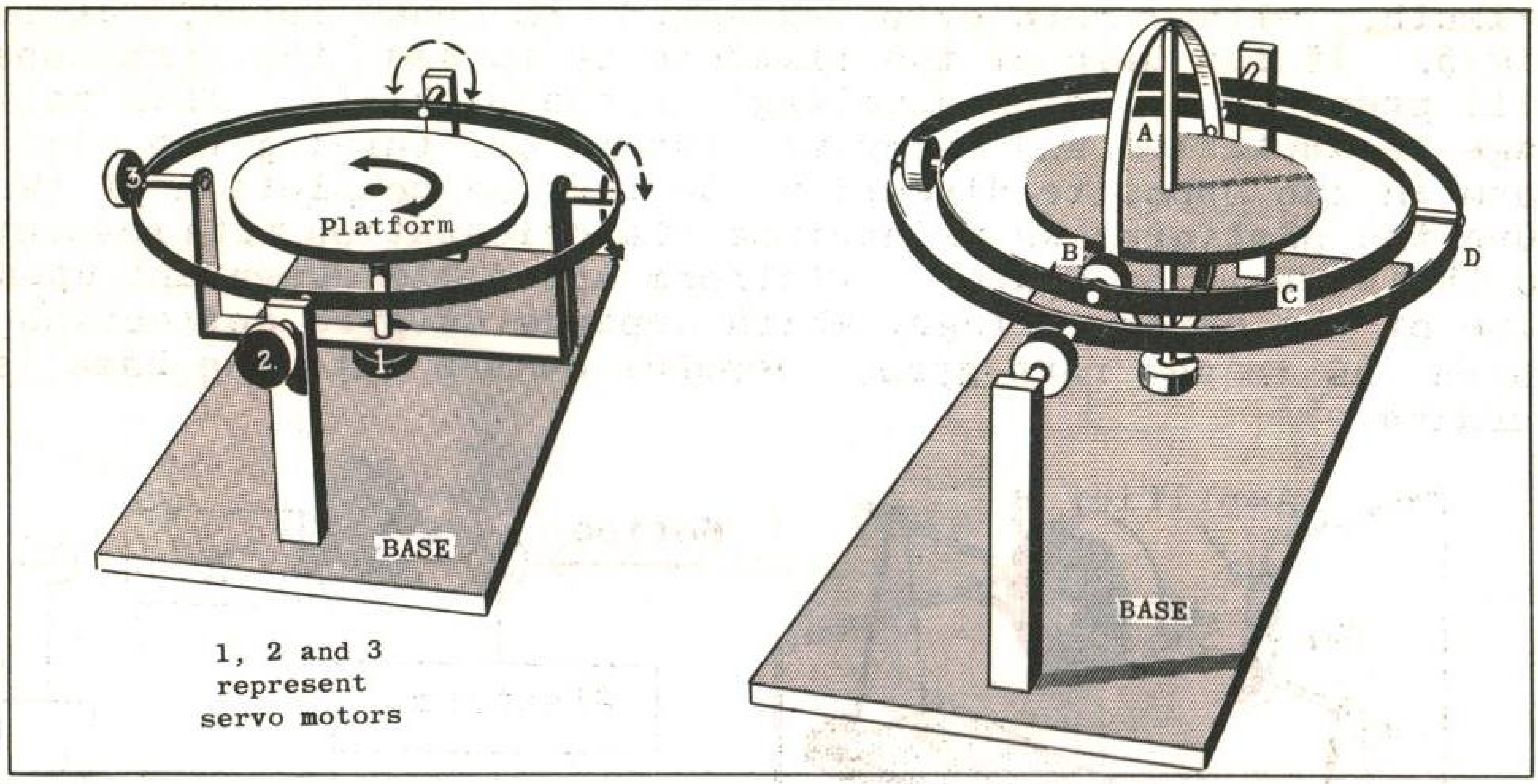


Figure 3 Figure 4

In the diagram, the four gimbals (from the platform out), are as follows:

(A) The central supporting shaft gives freedom in azimuth.

(B) The inner-roll gimbal, supporting the azimuth gimbal, allows freedom in the rolling plane.

(C) The pitch gimbal gives freedom in the pitching plane.

(D) The servo driven outer-roll, or follow roll, gimbal prevents "gimbal lock" when the vehicle rolls through ninety degrees.

The outer gimbal is secured to the case of the device, which represents the airframe of the vehicle.

The vehicle is now free to turn in any direction and the platform will remain in the earth horizontal. If, however, the platform is required to remain fixed with respect to some other position while the vehicle flies over the earth, for instance, position at take-off, at least one more gimbal must be added. However, this problem becomes rather involved and is beyond the scope of this introductory article.

Platform Control - Single Axis.

When considering control and sensing of a platform it is easier to consider a single degree of freedom system. For simplicity consider a platform, that is motor driven in azimuth, with a rate gyro arranged to sense turns, as in Fig 5. If the base of the platform is turned the gyroscope will precess, inducing a voltage in the pick-off. This voltage is amplified and energizes the motor, turning the platform in the opposite direction so that on completion of the turn the platform has maintained its orientation with respect to the earth, or space. Platform speed is dependant upon size of the error voltage, which depends on gyro deflection, which as in any rate gyro, depends on the rate the base is turning.

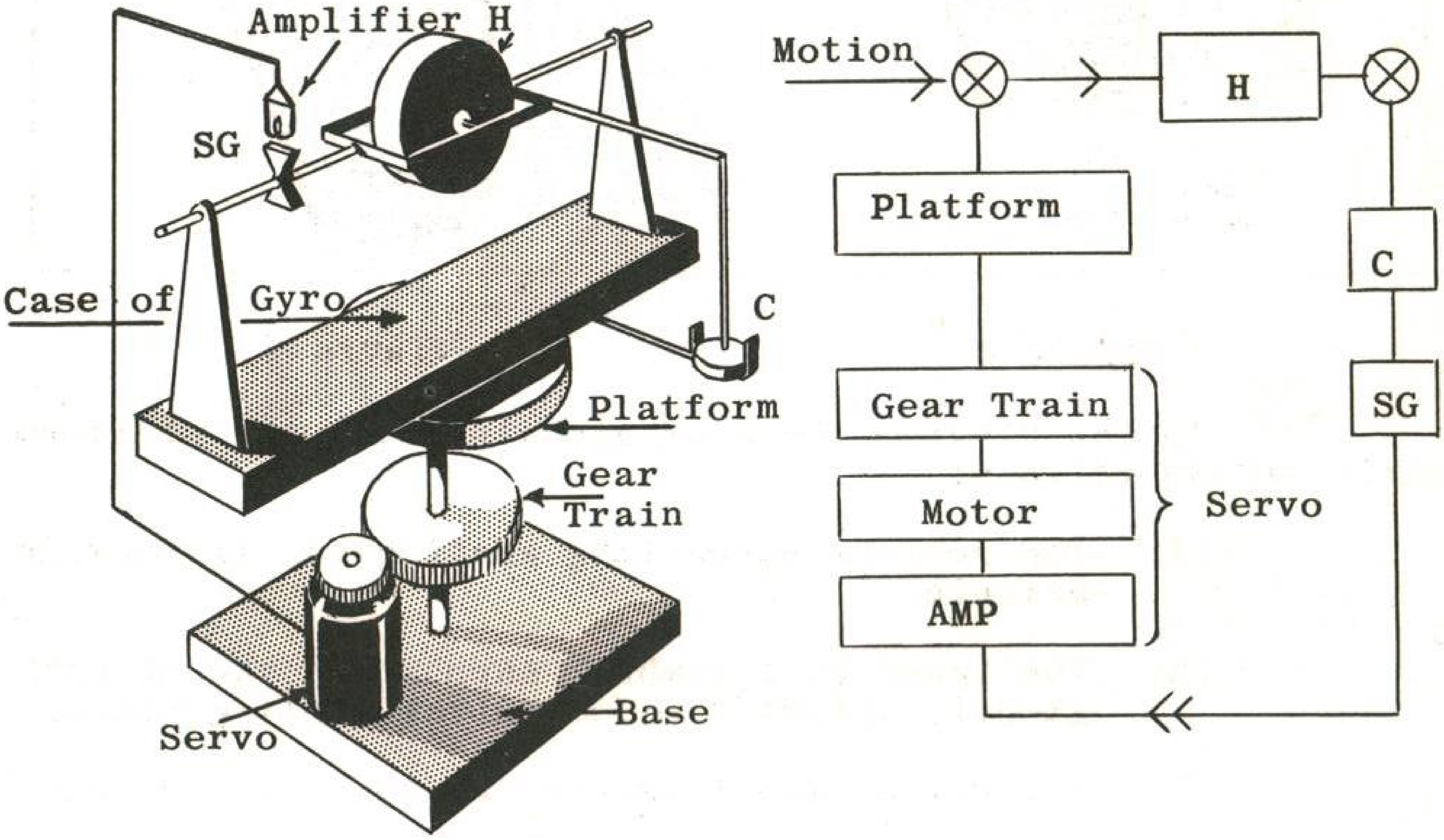


Figure 5

In the form illustrated above, the platform could be used as an attitude and direction transmitter, maintaining its orientation as the vehicle rotates about its axes. If however, it is required to use the device as an instrument base it must be torqued with change of position of the vehicle. If a torque motor is attached to the axis of the rate gyroscope, then, when the motor is energized the axis will precess. This will induce a voltage in the pick-off and the platform will be rotated. The rate of rotation is directly dependent on the voltage to the torque motor, and hence, is proportional to vehicular rotation. This technique could also be used to correct the azimuthal indication of the device for drift due to apparent wander, with the error voltage driving the platform and maintaining it with respect to true north. A block and schematic diagram of the complete system is illustrated in Fig. 6.

The rate of platform reaction is directly related to the formula:

$$\text{Rate of Rotation} = \frac{\text{Correcting Torque}}{\text{Angular Momentum of Gyroscope}}$$

(This formula is derived in the Appendix to this article.)

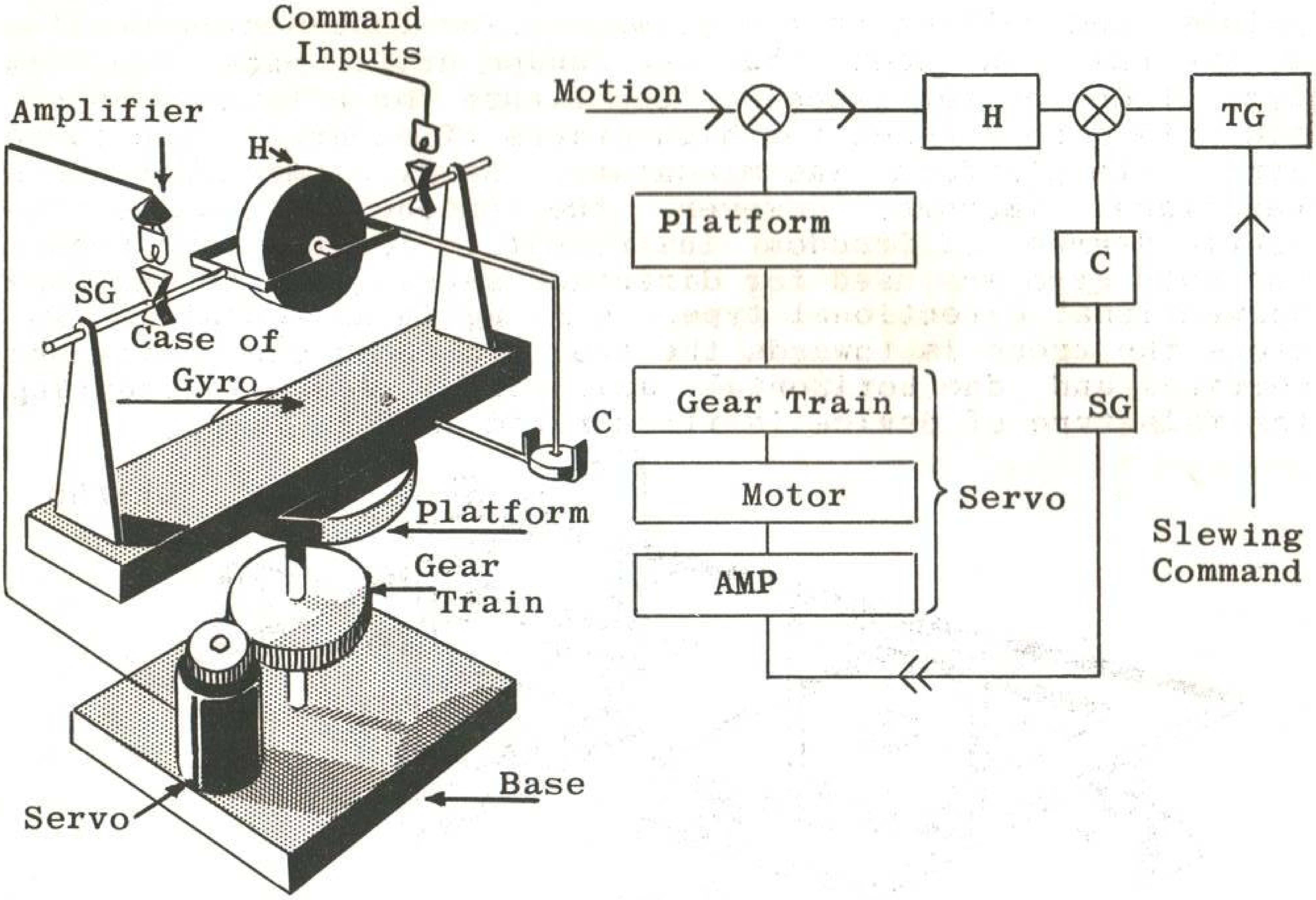


Figure 6

The effectiveness of the device will depend, however, upon the accuracy of the controlling gyroscope, the torque motors, servo motors, pick-offs, amplifiers, wiring, and other components used.

Platform Control Multiple Axes

Control of a rate gyro platform in three axes will require three units, each controlling its own motors and operating in an independent loop. The gyros will have to be arranged so that each senses its own plane, these being azimuth, pitch, and roll in the case of the platform being maintained in azimuth independent of the vehicles fore and aft axis, problems will exist in separating the pitch and roll axes of rotation. For example, if the axis of the platform and that of the vehicle coincide, the pitch and roll gyros sense the correct plane, but if the vehicle is turned through ninety degrees the axis of the platform is at right angles to that of the vehicle. To overcome this difficulty a resolver must be added between the gyros and their torque motors.

Platform Types - Two Gyro Platforms

The vertical axis gyroscope, sensing tilt in both the pitching and rolling planes, is especially suitable for control of the stabilized platform. It is this type of gyro that is used to stabilize a majority of search radars, autopilots, and roll-corrected compasses. The fundamental problem in the past has been that the random drift rate for this type of device far exceeded the figure for a liquid supported rate gyro, hence for high orders of accuracy the three gyro rate platform was mandatory. As gyro manufacturer's techniques improve, however, the tendency is to use the double degree of freedom instrument. For the same reason the rate gyro was used for direction sensing, rather than the conventional directional type. Here again as techniques improve the trend is towards the two gyro technique, using one vertical and one horizontal axis unit. A sample mounting for this type of device is illustrated in Fig. 7.

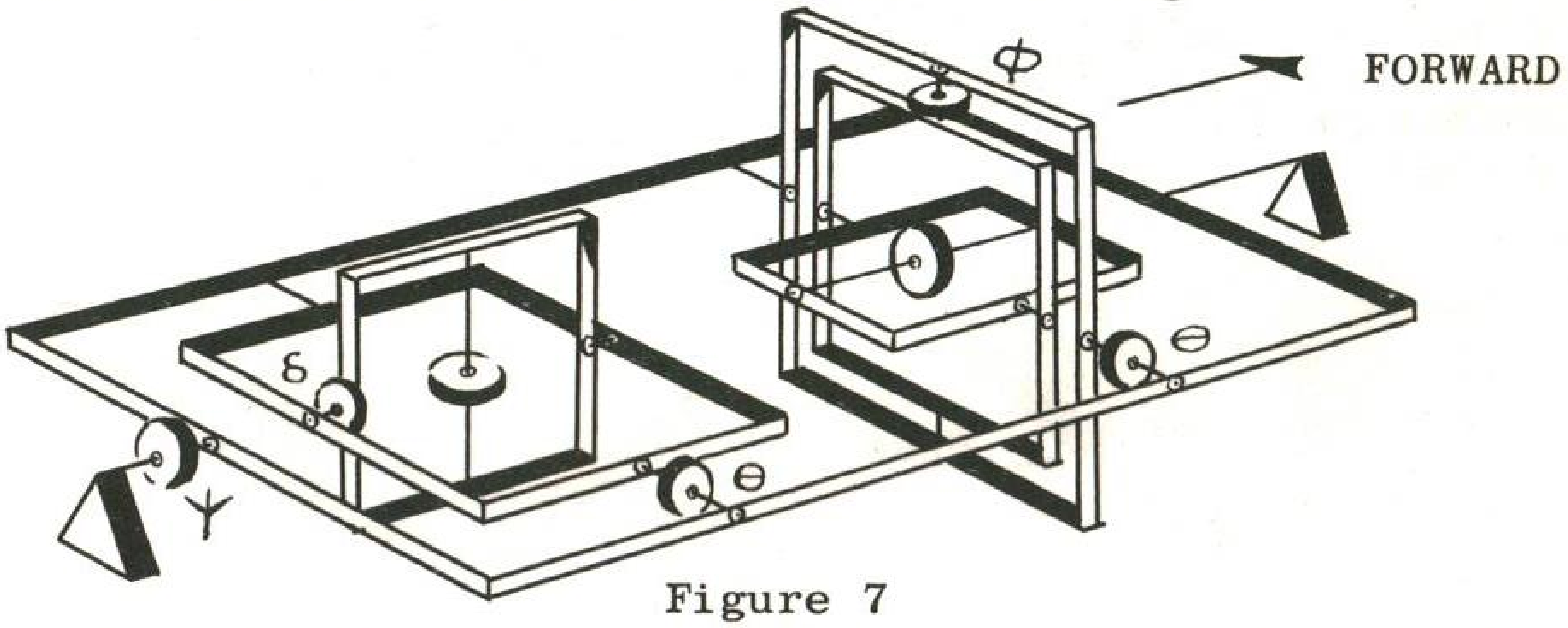


Figure 7
Two-Gyro Platform, Vertical Gyro-Directional Gyro Type

In October 1957 Sperry Rand announced a new two gyro platform using two horizontal axis, directional gyros rather than the horizontal/vertical combination. This device is reported to be very accurate but little information has been released to date.

Platform Limitations

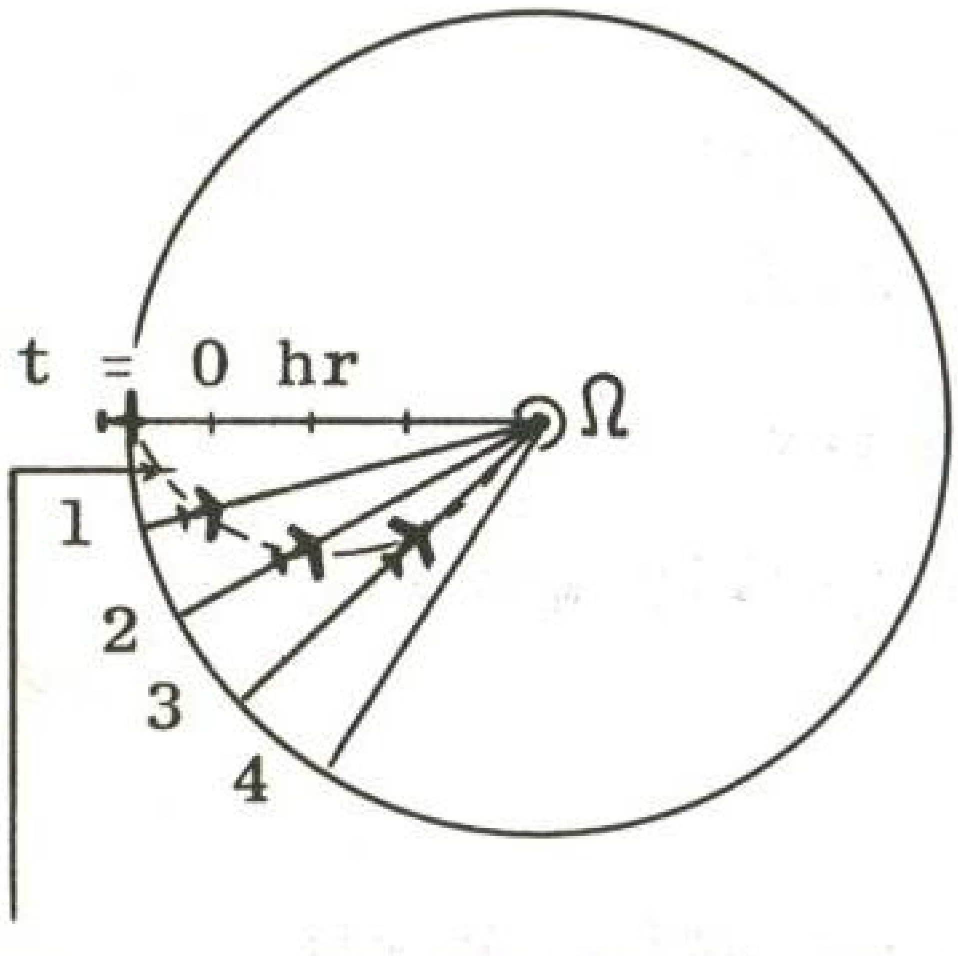
The elimination of random drift of the gyros is the basic problem with the stable platform. To ensure temperature effects are minimized the units must be set in a hermetically sealed case, minimizing movement of the centre of gravity. Other problems are, ensuring light weight with structural strength, obtaining dynamic balance of the platform and its associated gimbals, and having suitable components such as transmitters, motors and resolvers.

In addition to real wander the platform will react in the same way as a vertical and horizontal axis gyro with respect to apparent wander, due to both earth and vehicular rotations. The effect of vehicular rotation on the directional gyro was covered in a previous issue*, while the effect in the vertical plane can be derived in a similar manner.

In addition to real and apparent wander the platform will be subject to the effects of coriolis and oblateness. Coriolis affects the platform in the same way it deflects the bubble of the sextant, resulting in an incorrect vertical. Coriolis effect exists because the earth is rotating and a vehicle moving over the earth flies a curved track in space as the earth turns towards the east, this is illustrated in Fig. 8. Oblateness, on the other hand, results in a difference between the true and gravity vertical. This is because the earth is not a perfect sphere but an oblate spheroid. Because of oblateness the gravity vertical and true vertical only coincide at the equator and poles, with the maximum error occurring at 45° latitude. This only amounts to 11 minutes of arc, but is significant in systems requiring a high degree of accuracy. The effect is illustrated in Fig. 9.

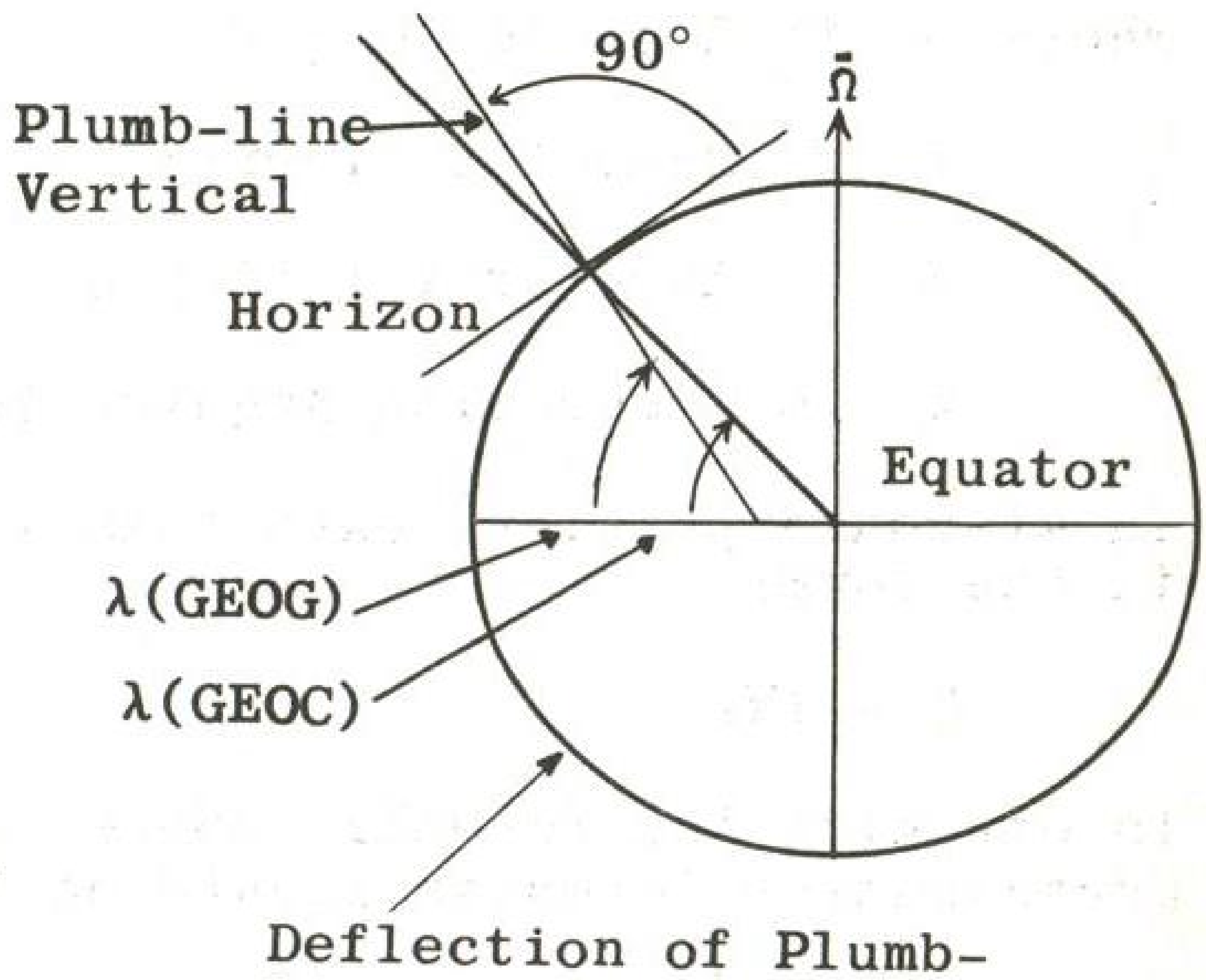
* *

* "Meridian Convergency and Gyro Drift" by F/L PRW Webb, RCAF Observer Oct 57. P145.



Deflection of flight path in space due to earth rotation gives rise to coriolis acceleration

Figure 8



Deflection of Plumb-line vertical due to oblateness and centripetal acceleration of earth

Figure 9

Conclusion.

This discussion of the stabilized platform has only been in general terms because of the various techniques that may be employed by individual manufacturers. The principal points to note are the different types of platform possible, the limitations of the platform, and the problems associated with its production. The platform itself is not new, it is only an extension of conventional gyro techniques, arranged to achieve the end result required.

* *

APPENDIX

$$\text{Rate of Precession} = \frac{\text{Correcting Torque}}{\text{Angular Momentum}} \qquad (1)$$

or

$$w = \frac{L}{IW} \qquad (2)$$

where L is Applied Torque

I is Moment of Inertia of the Gyro

W is Angular Velocity of the Gyro

w is Precession Angular Velocity

In standard physics texts this is normally given in the form:

$$L = IWw$$

In deriving the formulae above the following basic gyrodynamics formulae should be rememberd:

$$I = Mr^2 \qquad (3)$$

and $$W = Vr \qquad (4)$$

where I = Moment of Inertia
M = Mass of gyro
r = Radius of gyration
W = Angular velocity of gyro
V = Linear velocity of gyro

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