

RESTRICTED

THE RCAF  
OBSERVER



Vol 5 No 3

July 1959

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#500

# The RCAF OBSERVER

Incorporating the RCAF Navigation Bulletin

Founded 1949



It was announced recently that Wing Commander KR Greenaway, CD, will succeed Wing Commander WF Davy, CD, as Officer Commanding Central Navigation School in August, 1959.

W/C Greenaway is a well-known figure to observers in the RCAF, and to navigators the world over, for his many contributions in the aviation field. Outstanding among these contributions is his work in arctic aerial navigation.

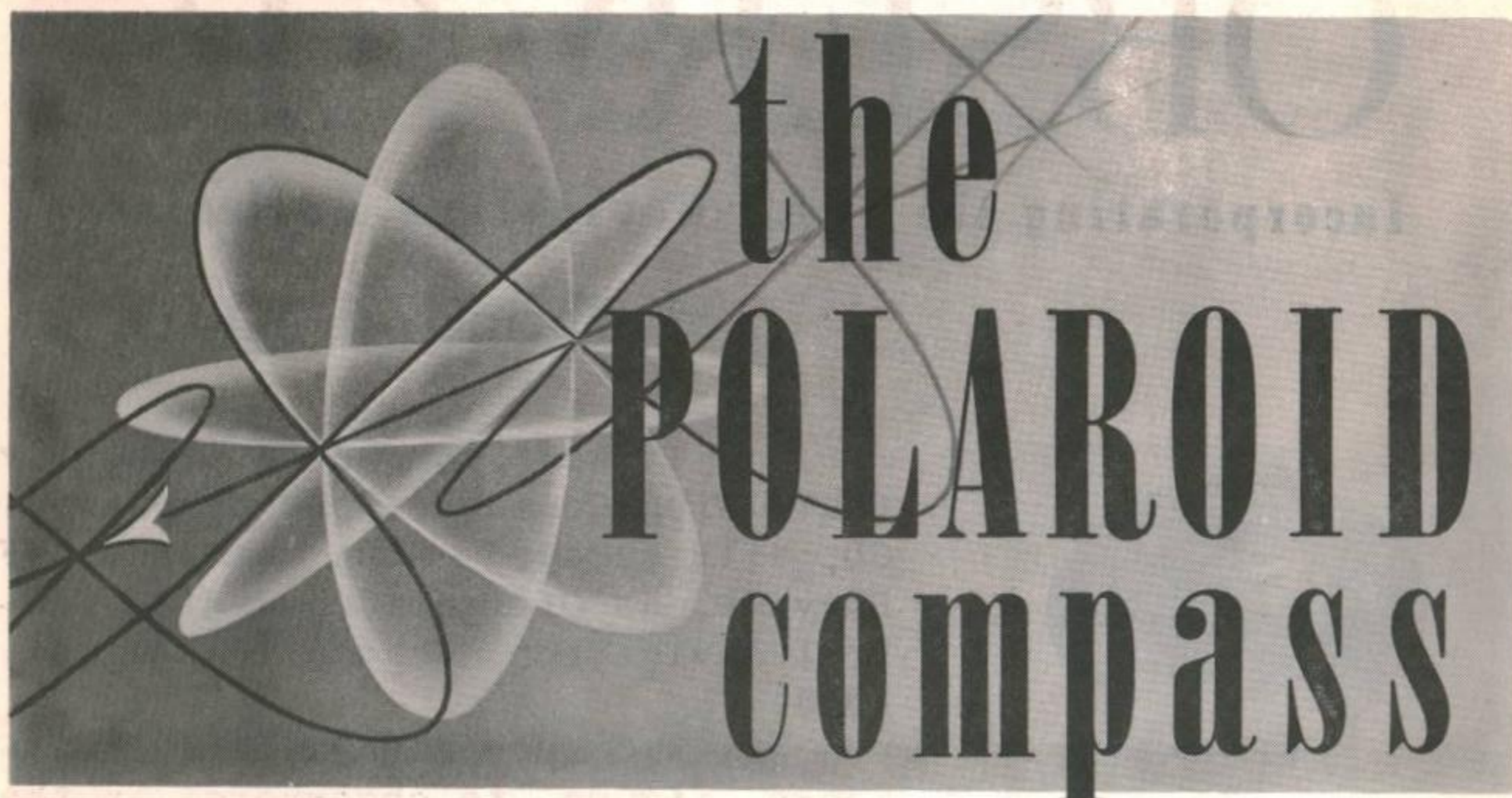
W/C Greenaway joined the RCAF in 1940, and served until 1945 as an instructor in both the wireless operator and navigator-wireless

operator trades. During the next three years, he was an instructor with Central Navigation School, and also served on detached duty with the United States Air Force, and the United States Navy.

In 1948, W/C Greenaway was seconded to the Defence Research Board. During this tour of duty, he wrote the book "Arctic Air Navigation", which is used as a text book by the RCAF, and as a reference manual by the USAF and Royal Air Force. He also designed the RCAF Twilight Computer, which is used by the RCAF and RAF for high-latitude flights.

In recognition of his outstanding work in the furtherance of aviation, W/C Greenaway has received several awards. In 1953, he was named the winner of the McKee Trans-Canada Trophy for 1952. He also won the Thurlow Award from the United States Institute of Navigation in 1952.

From 1954 until 1956, W/C Greenaway was on exchange transfer with Strategic Air Command of the USAF. Since then, he has been with the Directorate of Air Plans and Programmes at Air Force Headquarters in Ottawa.



The problem of obtaining a celestial heading reference during twilight conditions has plagued navigators for many years. This is particularly true of Arctic areas, where twilight periods can be very long and where no other source of heading reference is reliable. The advent of the jet transport, which can pace the sun and thus remain in twilight for an entire east-west flight, has increased the need for a device which will determine the correct heading at any time.

The Kollsman Sky Light Compass will determine the true heading of an aircraft when the sun is below the horizon, low on the horizon, or completely obscured by a partial overcast. This instrument, then, more than fulfills the requirement for a universal heading reference. For this reason the RCAF has purchased the Sky Light Compass, and it will soon be in use in Air Transport Command.

This article will describe the theory of the polarization of light, which is the principle used by the Sky Light Compass, and describe the construction and operation of the instrument.

### THEORY

#### Polarization of Light

Light is transmitted by waves, in much the same manner as a radio signal. These waves are transverse electromagnetic waves of a much higher frequency than radio waves. A transverse wave vibrates in planes perpendicular to the direction of propagation (Figure 1). In the case of

electromagnetic waves, there are two distinct vibrations, electrostatic and magnetic, which are perpendicular to one another. However, it has been proven that only electrostatic vibrations exhibit the properties which produce polarization of light, so the magnetic component may be ignored, and any future reference to vibrations will be to the electrostatic component.

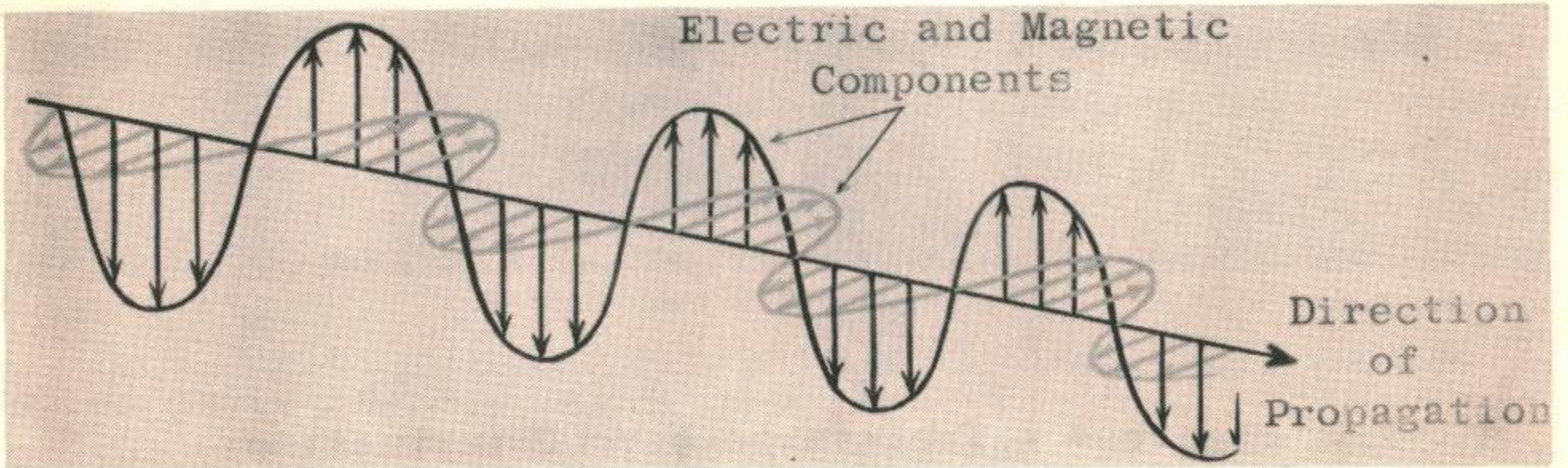


Figure 1 - Transverse Electromagnetic Wave

A ray of ordinary light has an infinite number of planes of vibration, rather than only two as depicted in Figure 1, and would appear as an envelope of these planes (Figure 2).

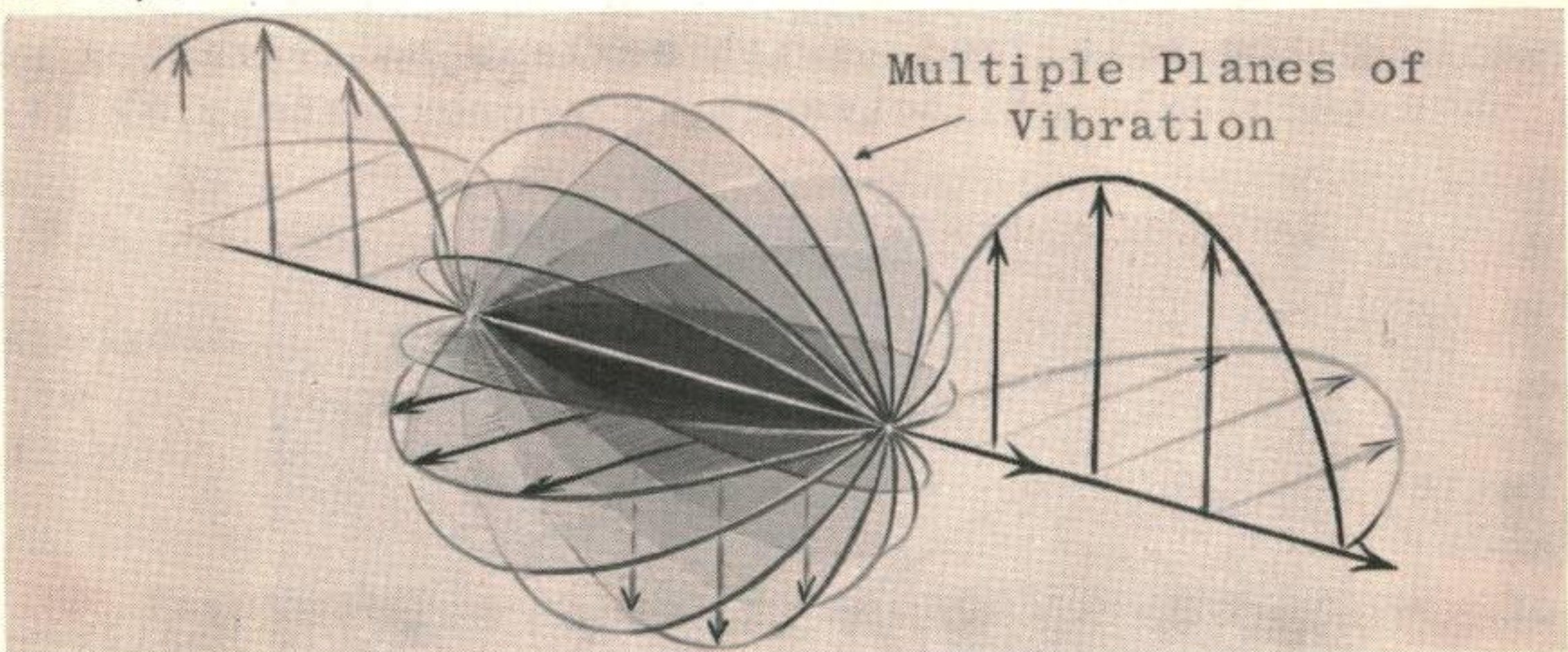


Figure 2 - Vibration in Ray of Ordinary Light

If the vibrations in a ray of ordinary light are eliminated except in a single plane (Figure 3), then the light is said to be plane-polarized.

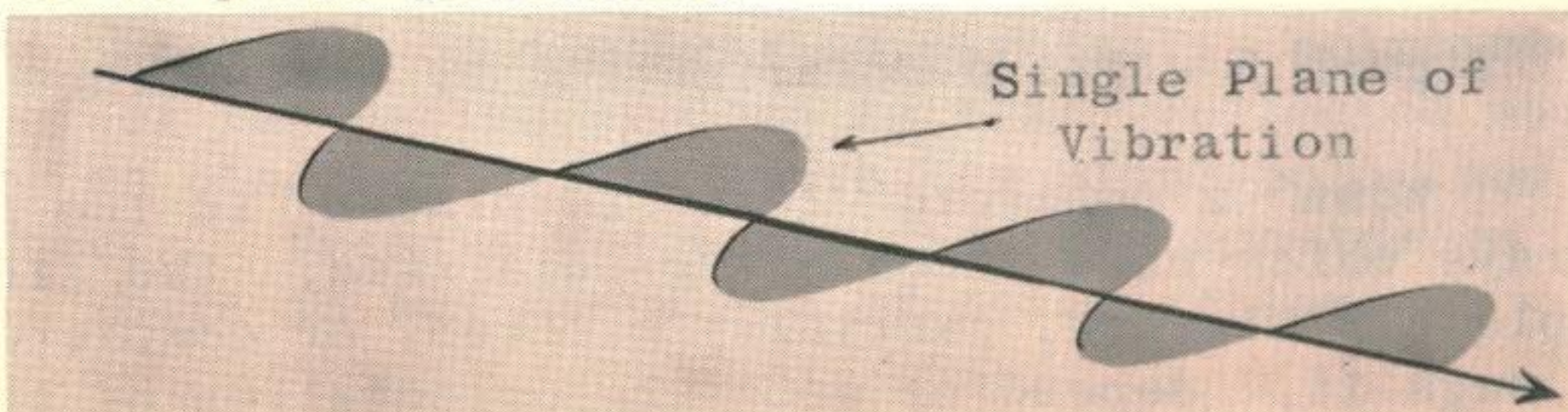


Figure 3 - Plane-Polarized Light Ray

The plane-polarization of light can be accomplished by reflecting rays from some object, by the passage of light rays through some refracting medium, or by passing light through a polaroid lens. One analogy which is particularly applicable to the polaroid lens is shown in Figure 4. A rope which

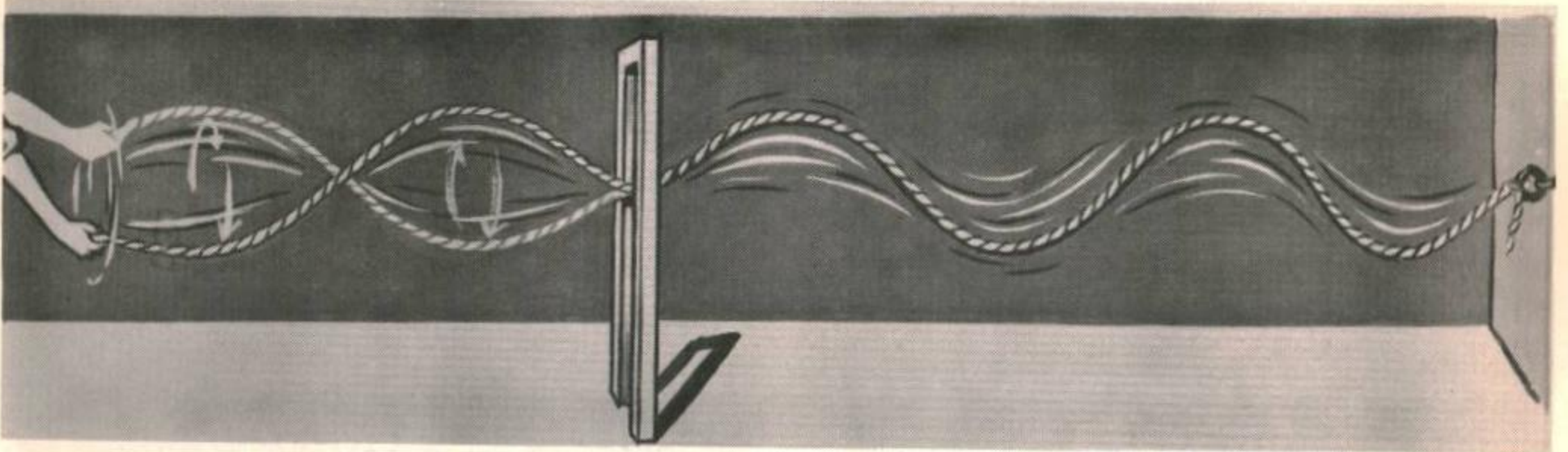


Figure 4 - Transverse Wave Polarization

is anchored at one end is rotated through a circle, setting up full transverse waves. If a vertical gate or slot is introduced, the vibration of the rope is restricted to the plane of the slot, and the wave is plane-polarized.

A light ray which is reflected from an unsilvered mirror is plane-polarized, with maximum polarization occurring when the angle of incidence is approximately  $57^\circ$  (Figure 5).

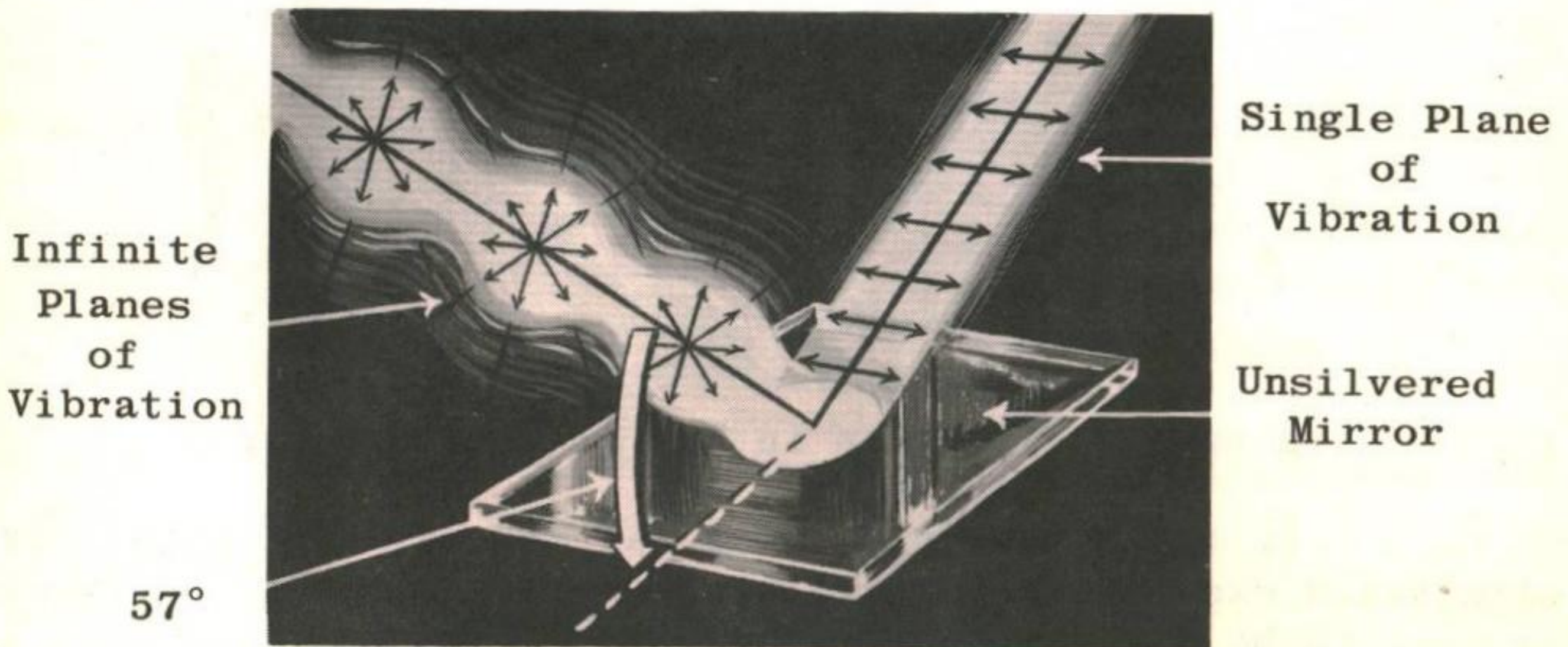


Figure 5 - Plane-Polarization by Reflection

When a polaroid lens is placed in the path of light rays which have been plane-polarized, the light will be completely blocked, partially blocked, or completely passed through it, depending upon the orientation of the lens'

axis with the plane of polarization of the light rays. The rope analogy can again be used (Figure 6). A second vertical

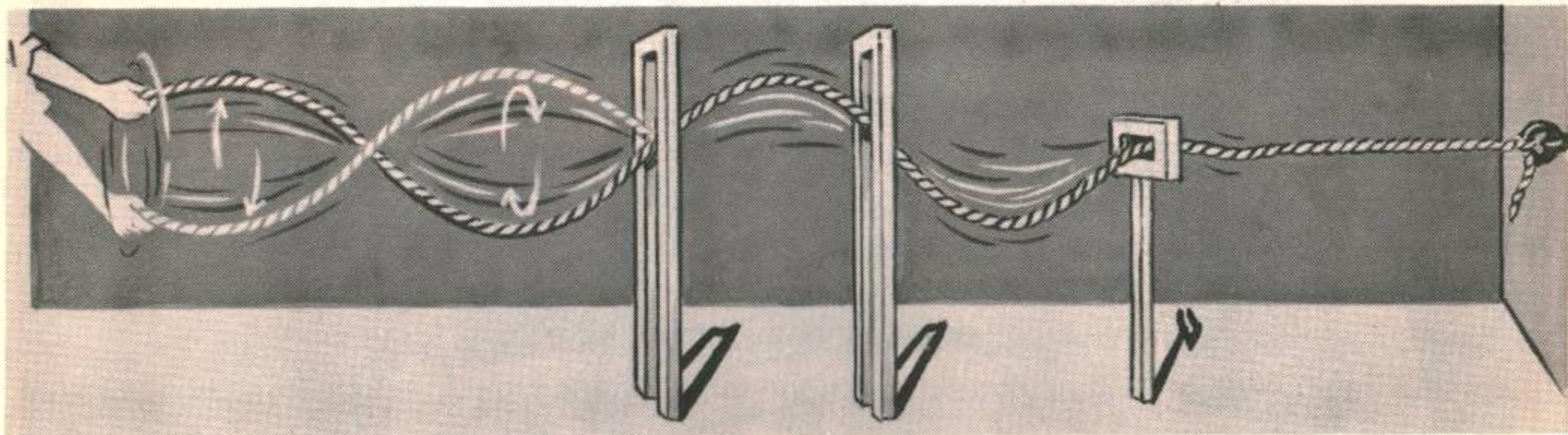


Figure 6 - Polaroid Effect on Polarized Waves

slot or gate, corresponding to a polaroid lens, will not affect the plane-polarized wave motion, and the wave continues through it. This situation is similar to the complete transmission of light through two polaroid lenses whose axes of polarization are parallel. However, a second slot, this time perpendicular to the first, will completely damp out any wave motion of the rope. This situation illustrates the complete blocking of light rays through two polaroid lenses whose axes of polarization are perpendicular to one another. At any other orientation of the lenses' axes of polarization, light will pass through in varying intensity (Figure 7).

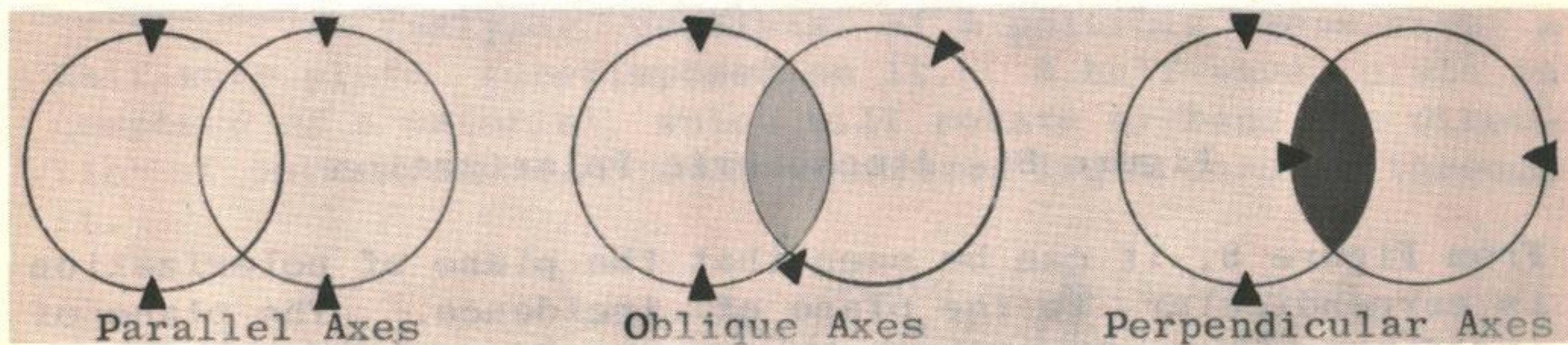


Figure 7 - Polaroid Lens Light Transmission

### Atmospheric Polarization

When sunlight enters the earth's atmosphere, it encounters vast numbers of tiny particles of matter, and is successively reflected from them. In being reflected from a particle, each ray of sunlight is partially polarized. The net effect of the entire process is that reflected sunlight reaching an observer on the earth is plane-polarized to a large extent. Because the sun's rays are considered to be parallel, there is but one plane of polarization.

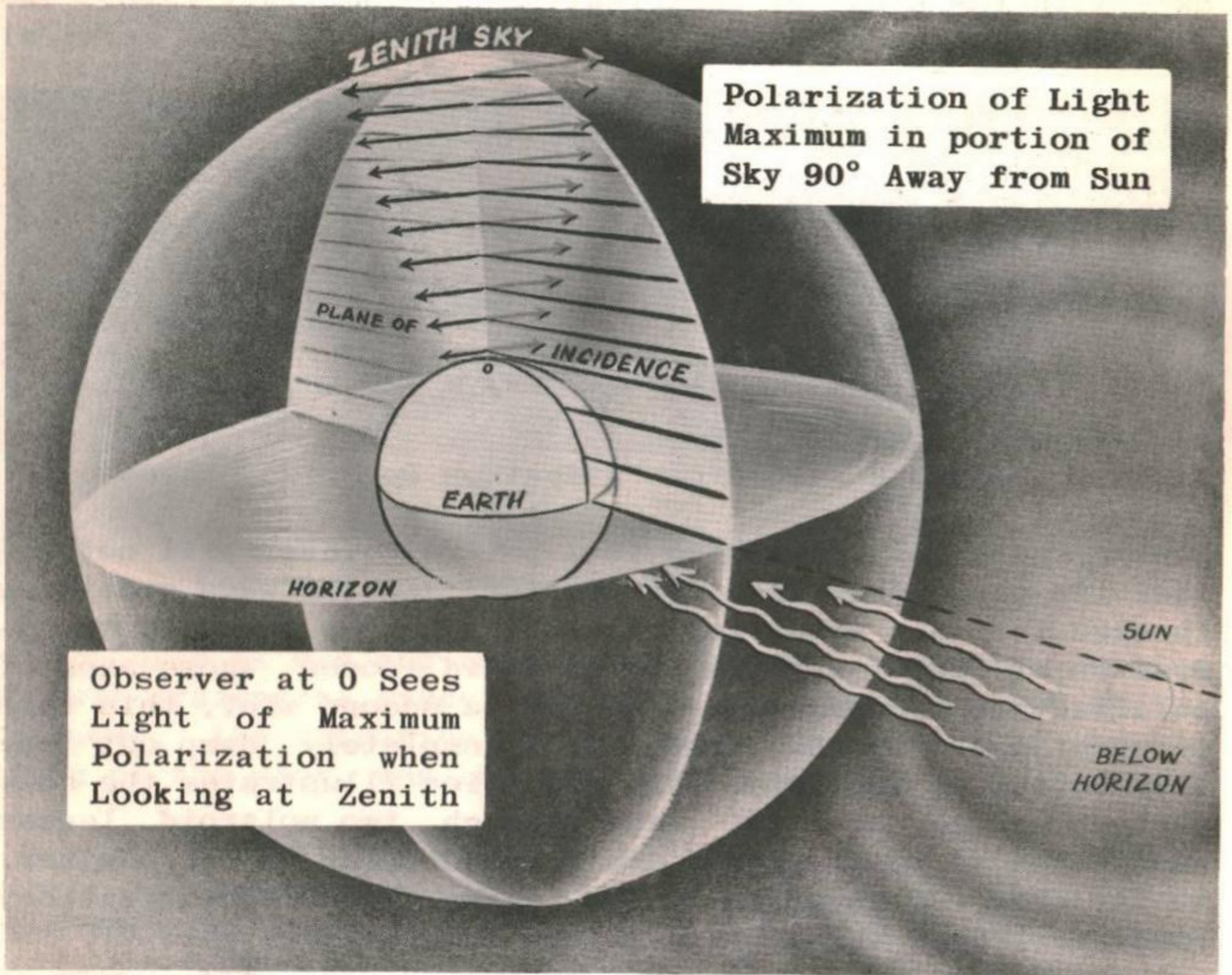


Figure 8 - Atmospheric Polarization

From Figure 8, it can be seen that the plane of polarization is perpendicular to the plane of incidence. The plane of incidence is a plane through the center of the celestial sphere, drawn parallel to the direction of propagation of the sun's rays. Figure 8 also indicates that maximum polarization for an observer at "0" occurs on the perpendicular from the sun's rays, or in that portion of the sky  $90^\circ$  removed from the sun. It is interesting to note that during twilight periods, with the sun just below the horizon, maximum polarization thus will occur very near to the observer's zenith. The degree of polarization diminishes with departure from the zenith towards the observer's horizon, reaching a minimum when the observer faces the sun.

AZIMUTH DETERMINATIONGeneral

If an observer viewed his zenith through a polaroid lens with the sun low on the horizon, he could determine the direction of the sun's azimuth by rotating the lens to obtain either maximum or minimum transmission of light through the lens. In the case of maximum transmission, the lens' polarization axis would indicate a direction  $90^\circ$  to the azimuth, while minimum transmission would indicate the azimuth. In both cases, however, there is a  $180^\circ$  ambiguity, and the observer would have to know the approximate direction of the sun's azimuth to resolve this problem.

Unfortunately, a simple device containing a rotatable polaroid lens cannot be used, because the human eye cannot judge maximum and minimum light intensities with sufficient accuracy. However, the eye can determine the existence or absence on the lens of a pattern, which is either lighter or darker than the remainder of the lens, with acceptable accuracy. Such an arrangement, called an analyzer, is used in the Kollsman Polarized Sky Light Compass.

Analyzer

An analyzer consists of a polaroid lens with a half-wave plate superimposed on it. A half-wave plate is composed of a material which will rotate or bend the direction of polarization of plane-polarized light passing through it.

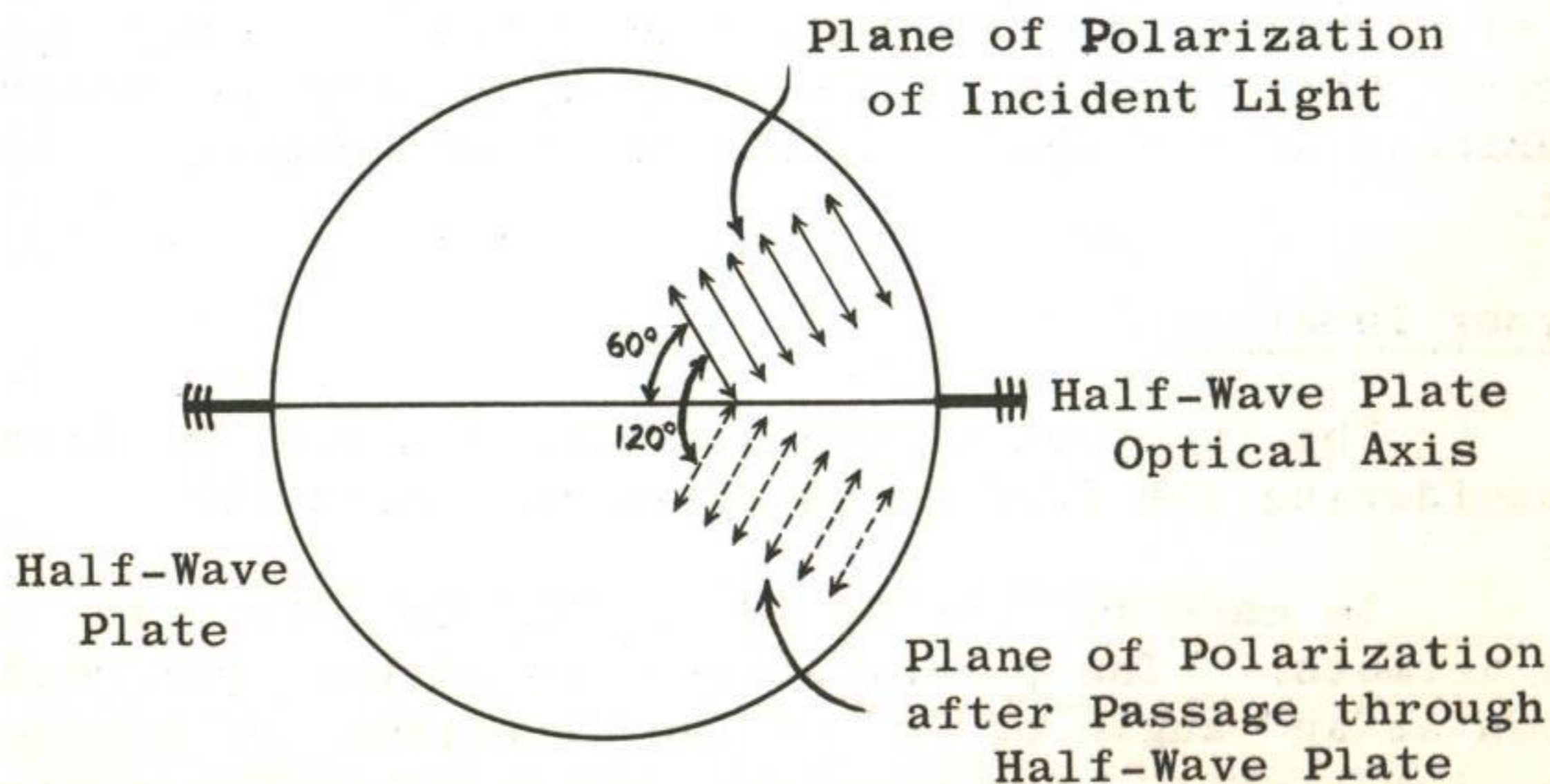


Figure 9 - Half-wave Plate Action

The amount of rotation is equal to twice the angle between the plane of polarization of the incident light and the optical axis of the half-wave plate. In effect, a mirror image of the plane of polarization of the incident light is formed on the opposite side of the plate's axis (Figure 9). It is obvious that no rotation will occur in two cases: when the plane of polarization is at right angles, or parallel to the optical axis of the half-wave plate.

The half-wave plate is fixed to the polaroid lens with the polarizing axis of the lens forming an angle of  $30^\circ$  with the optical axis of the half-wave plate (Figure 10).

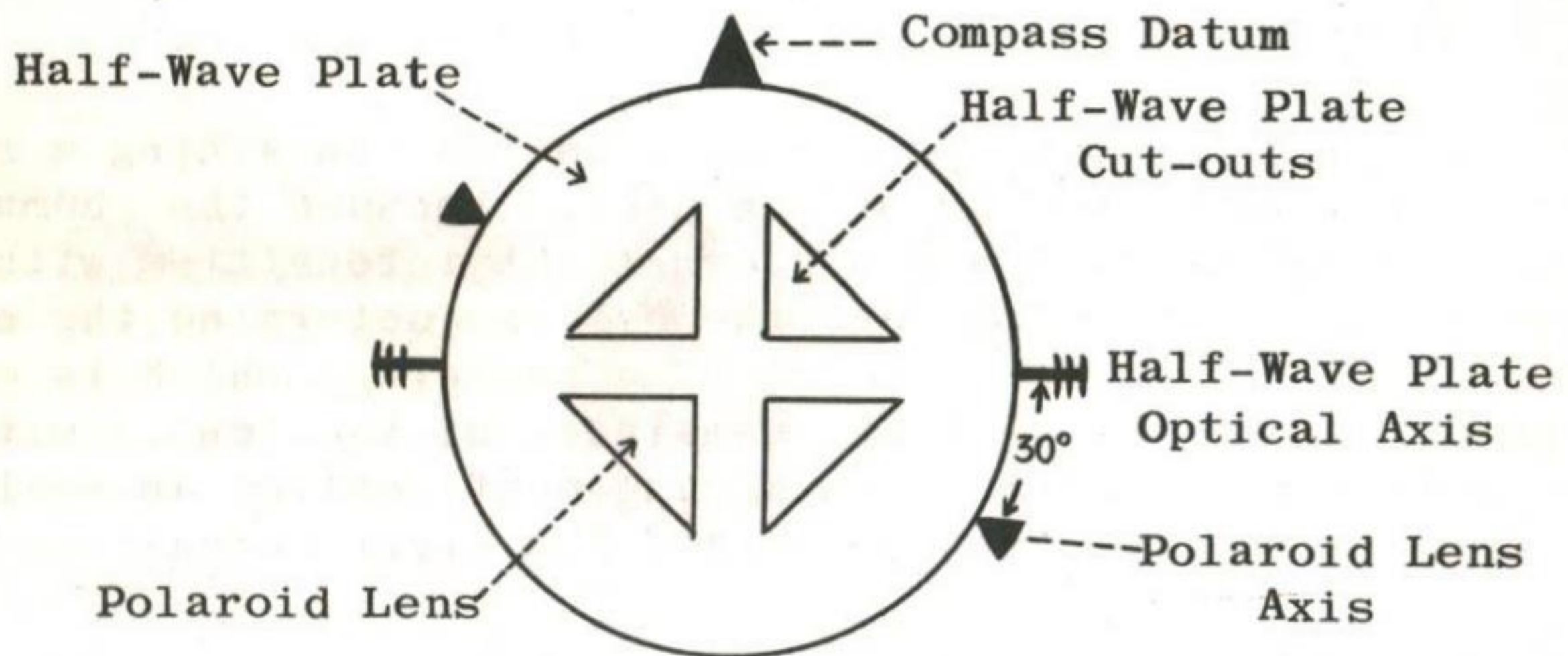


Figure 10 - Analyzer

The datum is  $90^\circ$  removed from the optical axis of the half-wave plate. In the half-wave plate overlay there are four triangular cut-outs which allow the plane-polarized incident light to reach the polaroid lens unaffected. This combination of a half-wave plate and a polaroid lens will provide patterns which enable an observer to determine accurately the azimuth of the sun, and thus the true heading of an aircraft.

### Analyzer Function

The function of the analyzer can best be described by considering the four cases shown in Figure 11.

In case 1, the datum is  $30^\circ$  to the left of the sun's azimuth. The polarization axis of the polaroid lens is then at an angle of  $90^\circ$  to the direction of propagation of the sun's rays, and thus the plane of polarization is parallel to the polaroid lens' axis. This means that the

incident light passing through the cut-outs directly to the polaroid lens will be completely transmitted, and the cut-

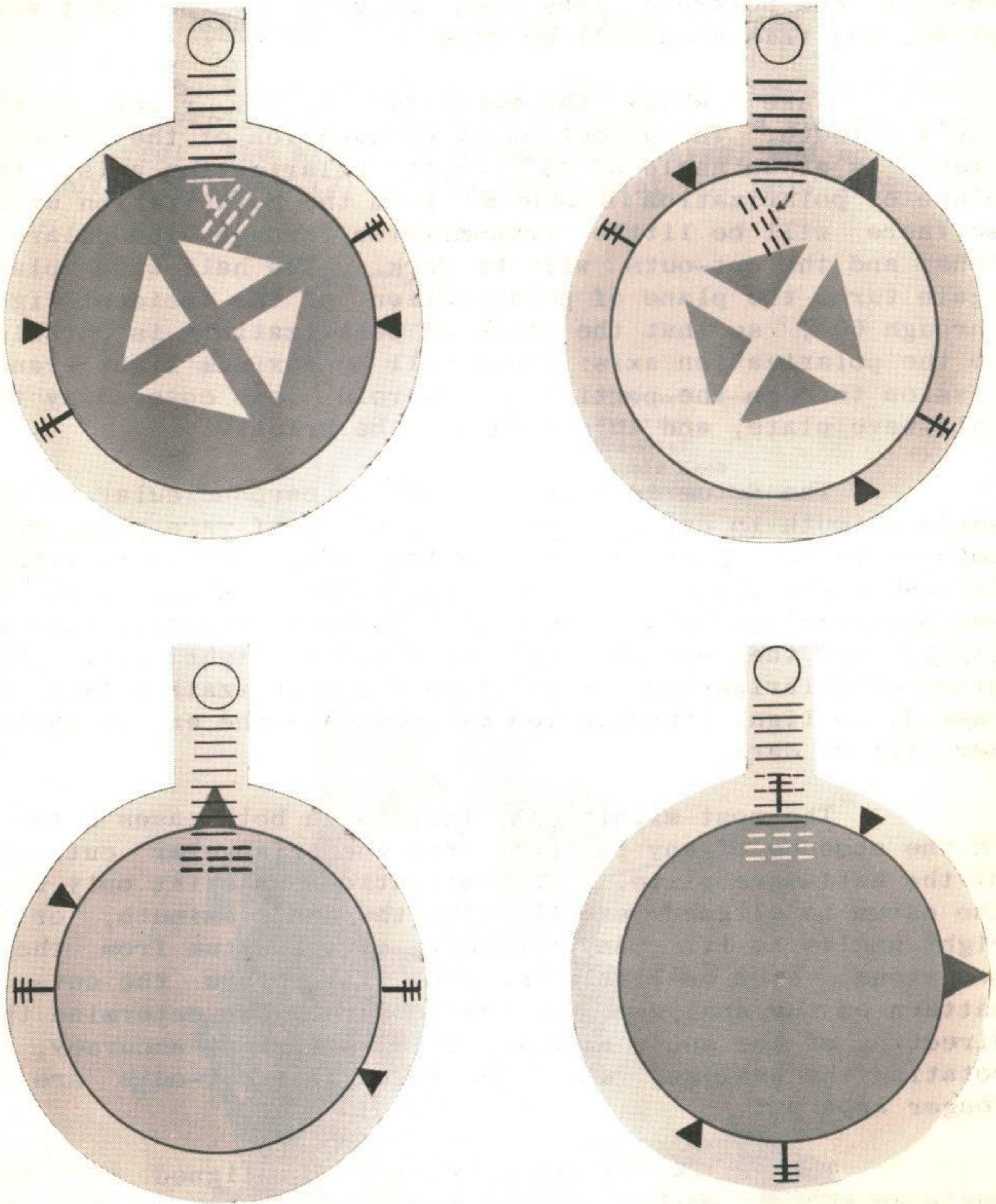


Figure 11 - Analyzer Function

outs will be bright. The plane of polarization of the incident light makes an angle of  $30^\circ$  with the half-wave plate optical axis. The plane of polarization is thus rotated  $60^\circ$  as the incident light passes through the half-wave plate, so

the plane of polarization is at an angle of  $60^\circ$  to the lens' axis. Therefore there will be poor transmission of light through the polaroid lens area covered by the half-wave plate, and this area will be dark.

Case 2 shows the datum  $30^\circ$  to the right of the sun's azimuth. The direction of propagation of the incident light is at an angle of  $30^\circ$  to the polarization axis, the plane of polarization is thus  $60^\circ$  from the polarization axis, so there will be little transmission through the polaroid lens and the cut-outs will be dark. The half-wave plate again turns the plane of polarization of the incident light through  $60^\circ$ , so that the plane of polarization is parallel to the polarization axis: there will be maximum light transmission through the portion of polaroid lens covered by the half-wave plate, and this area will be bright.

The datum is aligned with or perpendicular to the sun's azimuth in cases 3 and 4, so the half-wave plate will not rotate the plane of polarization of the incident light. In case 3 the plane of polarization is at an angle of  $30^\circ$  to the polarization axis, there will be good transmission of light, and the entire analyzer will be light grey. The plane of polarization is  $60^\circ$  from the polarization axis in case 4, so light transmission is poor, and the entire analyzer will be dark.

The most significant feature in both cases 3 and 4 is the absence of any pattern from the triangular cut-outs of the half-wave plate. This situation can exist only when the datum is aligned exactly with the sun's azimuth, or at right angles to it. Any movement of the datum from these positions, even as little as  $\frac{1}{2}^\circ$ , will reform the cut-out pattern on the analyzer. Thus the observer can determine the direction of the sun's azimuth, with sufficient accuracy, by rotating the analyzer until the triangular cut-outs are no longer apparent.

The datum of the analyzer is aligned with the sun's azimuth in case 3, called the "light-match point". If, however, the datum were reversed  $180^\circ$ , a light-match point would be found again. Thus the  $180^\circ$  ambiguity remains, but the problem can normally be resolved by observation of the horizon, or by the knowledge of the aircraft's approximate true heading. In the event of the dark-match point (case 4) being used, the observer must allow for the  $90^\circ$  displacement

of the analyzer datum, and must realize that a  $180^\circ$  ambiguity is possible again.

KOLLSMAN POLARIZED SKY LIGHT COMPASS

The Kollsman Polarized Sky Light Compass closely resembles a Kollsman periscopic sextant with a shorter periscope barrel, the altitude mechanism missing, and no averaging device (Figure 12). The instrument not only looks like

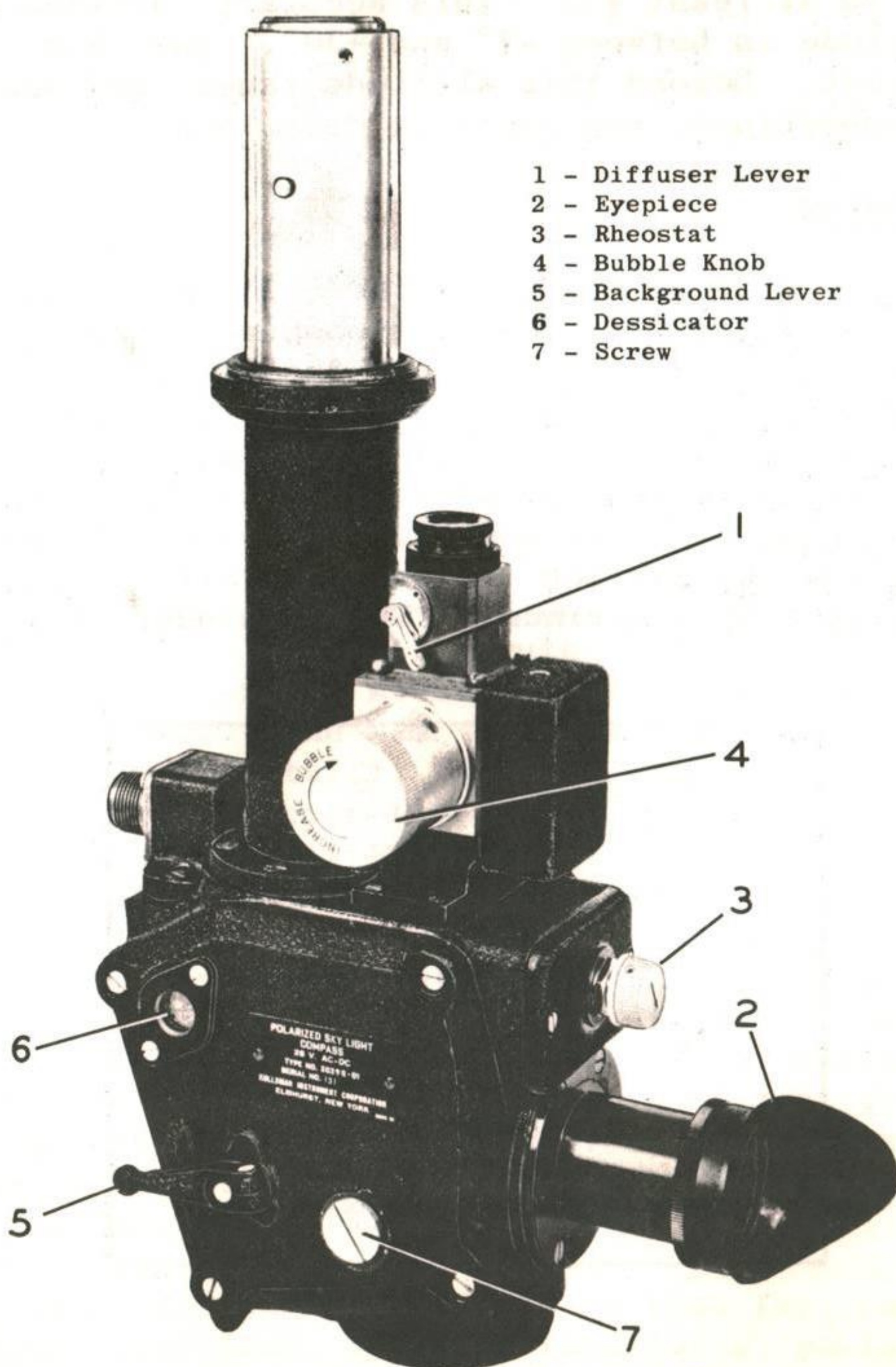


Figure 12 - Kollsman Polarized Sky Light Compass

the periscopic sextant: it also uses the sextant mount. The rheostat control, bubble chamber, bubble control, and heading-scale optical system are identical. The one control not found on the periscopic sextant is the background lever, which introduces a dark background in the lower portion of the field of view to improve the heading-scale definition.

### Accuracy

The Sky Light Compass is capable of heading determination to at least  $\frac{1}{2}^{\circ}$ . This accuracy applies when the sun's altitude is between  $-7^{\circ}$  and  $+30^{\circ}$ , and when there is a thin overcast. Beyond this altitude range, and with thicker overcast conditions, the accuracy decreases.

### Optical System

The optical system of the Sky Light Compass is illustrated in Figure 13. The main component, the analyzer, is mounted horizontally on the top of the periscope barrel. As previously mentioned, the barrel is quite short, and when the instrument is fully inserted in the mount the top of the barrel is three-eighths of an inch below the exterior surface of the mount. This positioning leaves the analyzer in a well, below the surface of the aircraft, thus reducing direct sunlight to a minimum. The remainder of the optical

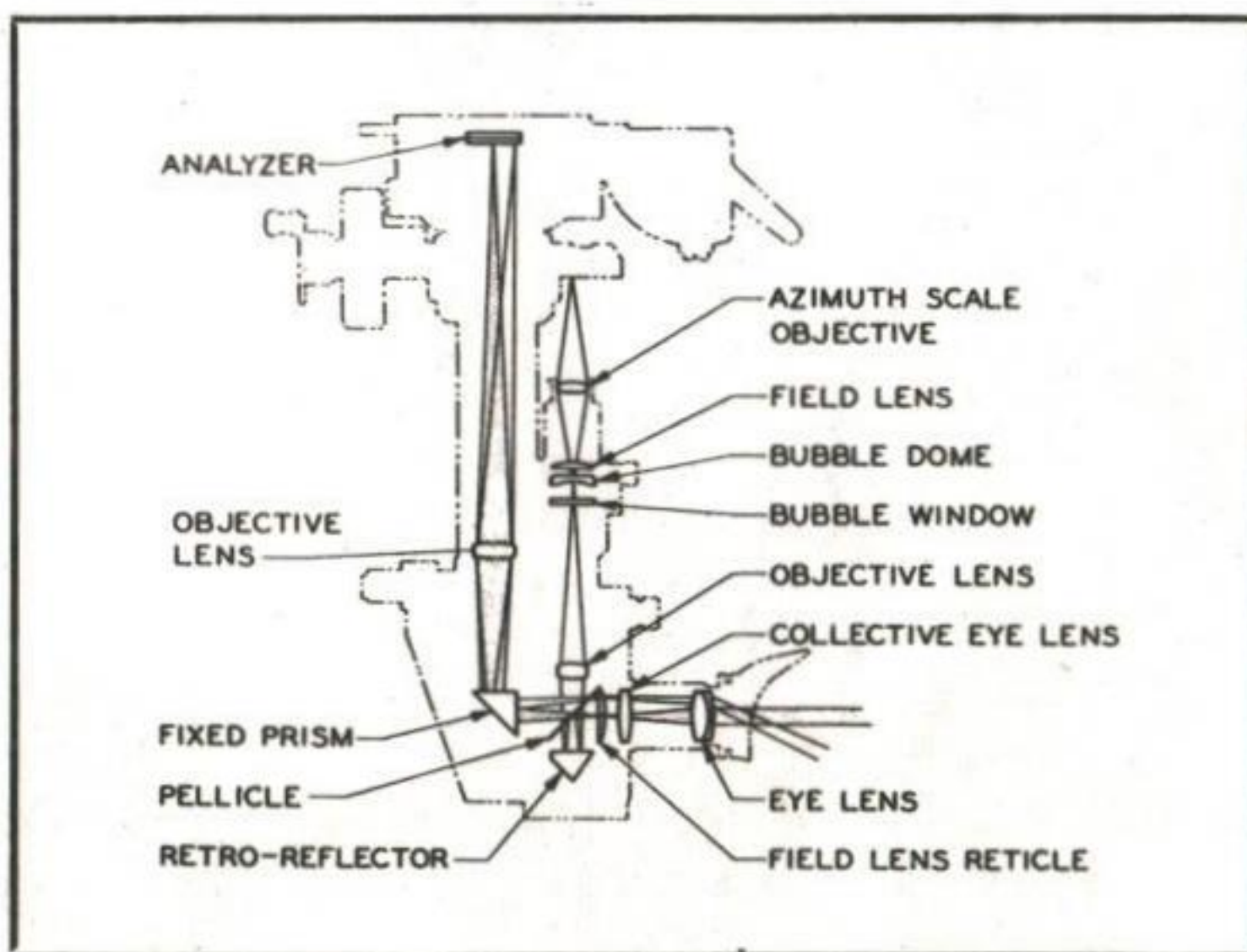


Figure 13 - Lens System

system is almost identical to the periscopic sextant.

SKY LIGHT COMPASS OPERATIONPre-Flight Check

Prior to take-off, the instrument should be checked to ensure that it will function properly. The following checks are identical to those for a periscopic sextant:

- Bubble System
- Diffuser
- Mount
- Electrical System

There are two additional precautions that should be taken. The background lever, when depressed, should provide a dark area in the lower portion of the field of view. Also, if the sun is above the horizon but its altitude is less than  $30^\circ$ , the Sky Light Compass heading determination can be checked against that of a periscopic sextant.

In-Flight Use

To obtain a true heading reading with the Sky Light Compass, the correct azimuth is computed and set on the azimuth scale of the mount in the normal manner. A bubble is formed (about the same size as for a sight on the sun with a periscopic sextant), and the compass inserted in the mount. If the bubble cannot be seen, the rheostat is adjusted until the bubble is visible. The true heading scale should be visible when the diffuser lever is in the "out" position. If it is not readable, the background lever is depressed. The compass is rotated until the approximate true heading is indicated. The compass is slowly rotated about this reading until the pattern of triangular cut-outs disappears, and the entire field of view is a light grey. Then, with the bubble centered over the vertical cross-hair, the true heading is noted. This procedure is repeated several times to ensure an accurate reading.

A point worthy of note is that the centering of the bubble is far less critical than for a periscopic sextant reading. The main object is to align the lateral axis of the analyzer with the observer's celestial horizon, which

is accomplished by placing the bubble over the vertical cross-hair. Even this requirement is not overly critical, and acceptable results can be obtained without any bubble at all, if the instrument is held approximately vertical to the aircraft's axes. Thus a completely unserviceable bubble system does not destroy the effectiveness of the compass.

If for some reason the observer wishes to use the dark-match point, he must remember to add or subtract  $90^\circ$ , depending upon which of the two dark-match points is used.

### Alignment

The Sky Light Compass can be aligned using several different methods. The obvious one, comparison with results from a periscopic sextant, probably will be the most common. Other methods are described in the manufacturer's instructions.

### CONCLUSION

The Kollsman Sky Light Compass is a most welcome addition to the stock of navigational equipment. Although it does not solve the problem of providing a heading reference in heavy overcast conditions, in conjunction with a periscopic sextant it meets all other requirements. Its introduction into operational use in the RCAF will be of inestimable assistance to observers, who will be able to venture into the far north with considerably more confidence than of old.

# 36 SONI

9 Mar 59 - 19 Jun 59



Back Row

F/O RW Hounsell, F/O PL Rhodes, F/O A Corazza, F/O JF Peckitt

Front Row

F/O JG Lafreniere, F/O RL MacNeil, F/L JW Rodger (Course Director), F/O JA Young

# B-52 nav



by

Flight Lieutenant DJ Connolly  
USAF Academy  
Colorado Springs

As you leave the crew bus and walk towards the B-52, it gives the impression not only of gigantic size but also of tremendous weight. It appears ready to sink into the concrete. The wings droop, their top surfaces wrinkled; the fuselage is buckled about the wing roots. The absence of root fairings on both wing and tail gives the illusion that these surfaces are butt-jointed to the box-like fuselage. Paradoxically, this airplane is a sprightly and graceful thing in the air; a true characterization of Beauty and the Beast.

If the airframe looks "beat" as it sprawls across the tarmac, it has a right to, for it can carry in fuel alone some 40,000 gallons. The two outboard drop-tanks weigh 20,000 pounds each when filled, and are 40 feet long. The gross weight of the aircraft is well over 400,000 pounds.

The weight figures are impressive, but so is the rate at which the fuel burns off. During touch-and-go landings, the B-52 burns 2-3,000 pounds on each circuit. On a GCA, 5,000 pounds is used. Compare this with a North Star which would consume approximately 400 pounds of gasoline on a similar approach.

Launching is an event. A full preflight check is carried out the day before the flight, and it takes about 3 hours to complete. The pilot's check list is about 50 pages

long, and it does not include checks of the navigation, bombing, and ECM equipment. Prior to the flight, a shorter check is performed, but even this seems exhaustive when compared with the routine used for conventional aircraft. Those navigators used to a desultory check of the radio compass and driftmeter in their aircraft would be abashed by the work involved in a pre-flight check of the navigation compartment of the B-52. It takes a full hour and a half, and nothing is left unchecked. The aircraft takes off with its navigation and bombing system in full operation.

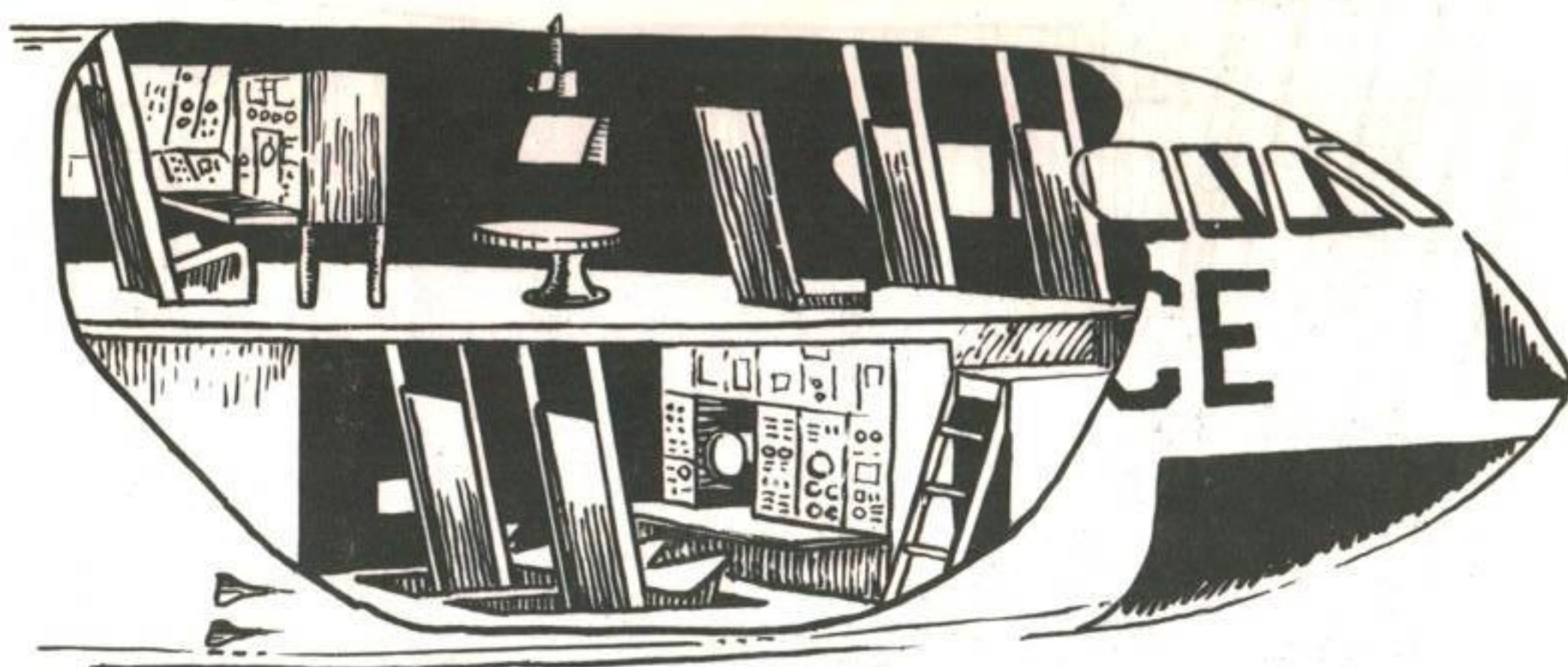


Figure 1 - B-52 Crew Compartment

Inside, the crew compartment is remarkably roomy, especially when compared with such other heavyweights as the B-47, the Victor, and the Vulcan. The regular crew consists of six: two pilots, a navigator, a radar/bombardier, an ECM operator, and a tail gunner. The layout of these stations is shown in Figure 1. The tail gunner sits alone in a separate pressure compartment. The two navigators also sit in relative isolation, side by side on the lower deck. They ride in downward-ejection seats. Pilot and co-pilot sit side by side with an extra "jump" seat between and slightly aft of them. This is for an additional crew member, such as an instructor; no flight engineer is carried. The ECM operator sits about 15 feet aft of the pilots on the top deck. The space between him and the pilots is open, occupied only by an astro stool and a bunk. The last-mentioned three crew members mount standard ejection seats.

A ladder connects the two decks, but crew movement is kept to a minimum with everyone strapped in and connected to oxygen and interphone.

The navigation equipment in this aircraft probably

represents the ultimate in currently-operational, radar-GPI systems. The major elements, all integrated into one package, are a search radar, a bombing computer, a ground position indicator, and Doppler equipment.

The search radar features good definition at all ranges, azimuth stabilization, and a 10" display. A 5" repeater scope is located in front of the navigator. Because of the chin-mounted antenna, a sector to the rear of the air-



Figure 2 - B-52 Navigation Compartment

craft is obscured. Radar fixing is accomplished by placing a set of electronic cross hairs (see Figure 2) on an identifiable return, setting its co-ordinates into the GPI counters and pushing a button. This automatically resets the GPI to the correct position of the aircraft. The same crosshairs are used as a bombsight. Their position is controlled by a small control column with which the radar/bombardier may also steer the aircraft. With the ballistics computer work-

ing, bomb release is automatic. The bombardier runs in on the correct track simply by maintaining the crosshairs on the target or the offset aiming point. The crosshairs are stabilized on the target by means of the GPI computer, which drives them at the calculated G/S and track angle. Hence, any tendency for them to drift from the target is caused by an error in the GPI wind. As the operator corrects for any apparent wandering of the crosshairs, he automatically establishes the correct wind. This tracking technique is not restricted to bombing: at any time an accurate wind may be found by this method.

To further enhance this feature, all new models are equipped with Doppler, from which G/S and track are ingested continuously into the GPI.

When fed with this diet of fresh winds or Doppler data, the GPI is, as might be expected, very accurate. It continuously displays the co-ordinates of present position, the course to steer, and distance to destination. This virtually obviates the need for manual airplot or trackplot.

What do the navigators do in the face of all this automaticity? They work constantly. A typical six-hour practice mission might include a three-hour all-astro leg, 3 or 4 practice bomb runs, each involving a dog-leg approach to the target, and a tanker rendezvous and refuelling. All this is guaranteed to keep anyone busy, Doppler or no Doppler.

Astro technique has been refined to the status of an art in SAC. All fixes are precomputed and all possible corrections are taken into account, even wander from heading or rhumbline correction. The annual bombing and navigation competitions can take much credit for this very professional use of astro navigation. In the B-52 the navigator is the brains behind celestial navigation, but the ECM operator upstairs takes all the sights. A standard Kollsman periscopic sextant is carried. In newer models of the B-52, an automatic astro tracker will be used. This supplies continuous azimuth and intercept information for any selected star. This data must then be plotted using the GPI present position as the assumed position.

The crews that man these aircraft are highly trained. Most are veterans of B-36 and B-47 operations. Crews are of necessity rarely broken up, and in fact are so close-

ly knit that overall high performance can earn each member a spot promotion. Conversely, an individual's ineptness (poor bombing score, weak instrument flying) can demote them all, much more quickly, to their substantive ranks.

The onus in B-52 operations is on accomplishment of the mission. A crew that aborts must explain why: a board of officers considers each case. In-flight malfunction of equipment is not necessarily an excuse. If the broken part could have been repaired or replaced, and was not, heads will roll. To this end crew members are taught much about in-flight maintenance. The radar man, for example, studies his equipment for many months in ground school before using it in the aircraft. A part of his navigation kit is a bagful of spare amplifiers, tubes, and circuit sub-assemblies. A repair manual of encyclopaedic dimensions becomes his bible.

If any failure occurs during pre-flight or run-up, a radio-dispatched maintenance truck is always within hailing distance.

The success of this SAC system of maintenance and training is dramatically demonstrated at the bombing competitions which are close simulations of combat missions. With some 80 bombers flying half-a-dozen missions each, aborts are almost unknown, and even a five-minute delay in take-off is considered a failure.

This is professional flying as all military flying should be, but unfortunately is not. B-52s are very costly and hard to come by, and inefficiency cannot be tolerated. To do so would be criminal: so much depends on them. As Marshall of the RAF, Sir John Slessor, states: "...The days are past when the number of bombs available was a severely limiting factor. The crux now is to retain our ability to put those bombs where we want to, if and when we have to, and we should give highest priority to the scientific techniques of navigation and bomb-aiming...". And crew training, and maintenance!

# 22 SORI

9 Mar 59 - 19 Jun 59



Back Row

F/O GH Keil, F/O CY Cave, F/O RF Chapman

Front Row

F/L WH Stockdale, F/L LJ Rushcall (Course Director)

# missile



by

Flight Lieutenant GR Hunn  
410 (AW) Sqn

The surface-to-air missile was the second category to which the Germans paid considerable attention during World War II, probably to counter the ever-increasing allied bomber offensive. The Allied Air Forces, as far as is known, had no surface-to-air missiles operational during the war years, and it is only comparatively recently that the United States and England have entered this field in earnest.

The Germans had a total of five surface-to-air missiles at the close of World War II:

- Schmetterling (HS-117)
- Wasserfall
- Enzian
- Rheintochter I
- Rheintochter III

All of these weapons were designed to use a common radio command guidance system. This common system, with minor modifications, was used throughout. A summary of the performance of these missiles, and the guidance system used, is shown in Table 1.

	Schmetterling (HS-117)	Wasserfall	Enzian	Rheintochter I	Rheintochter III
Speed	540 mph	Supersonic	560 mph	Not Known	Supersonic
Max Alt	35,000 ft	65,000 ft	48,000 ft	Not known	Not Known
Range	10 mi: Low Alt Targets	30 mi	16 mi	18,000 yds	Not Known
Warhead	55 lbs	200 lbs	1,000 lbs	Not Known	Not Known
Warhead Detonation	Proximity Fuse	Radio/ Infra-red Proximity	Not Known (Probably Radio)	Not Known	Not Known
Guidance System	Burgund System	Elsass System	Burgund System	Elsass System	Elsass System
Remarks		Modification of V-2		Poor Performance: not produced	Modified Version: new pro- pulsion unit. Not produced.

Table 1 - German Missile Characteristics

Burgund Command Guidance System

The common unit that all five missiles developed by the Germans were to use was the Burgund radio command guidance system. The system was essentially the same as that used for surface-to-surface and air-to-surface missiles discussed in the previous articles of this series\*. The components of the Burgund system (Figure 1) were:

- A director in which missile and target-tracker operators were seated.
- A computer and power-supply trailer.
- The KEHL radio transmitter.
- Missile launcher.
- The missile, with the STRASSBURG receiver.

\* RCAF OBSERVER Jan and Apr 59

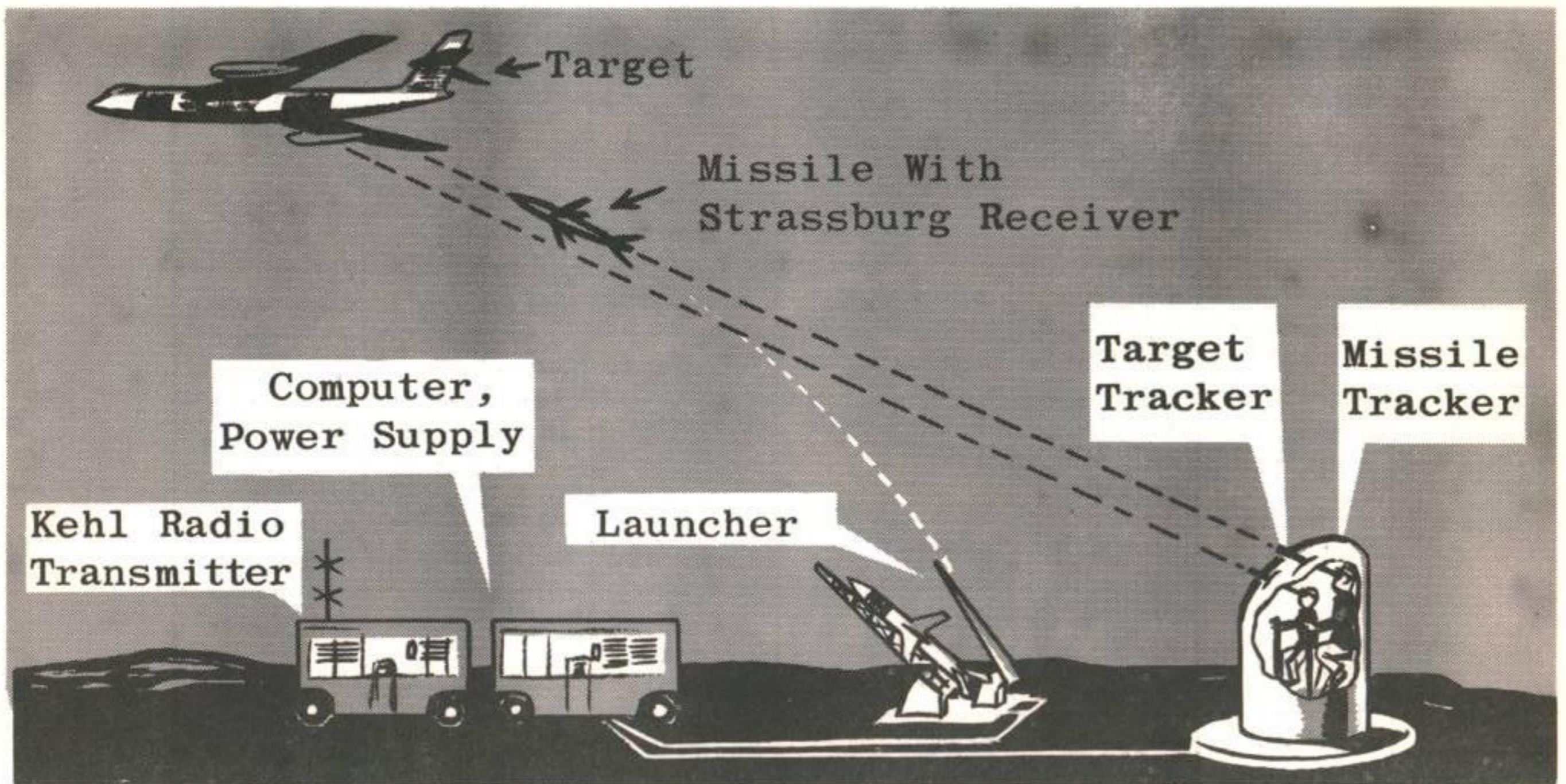


Figure 1 - Burgund Guidance System Components

The target tracker maintained the target in the cross-hairs of his optics by turning the director in azimuth and moving the optics in elevation. This also set the launcher along the line of the target prior to firing. The missile tracker

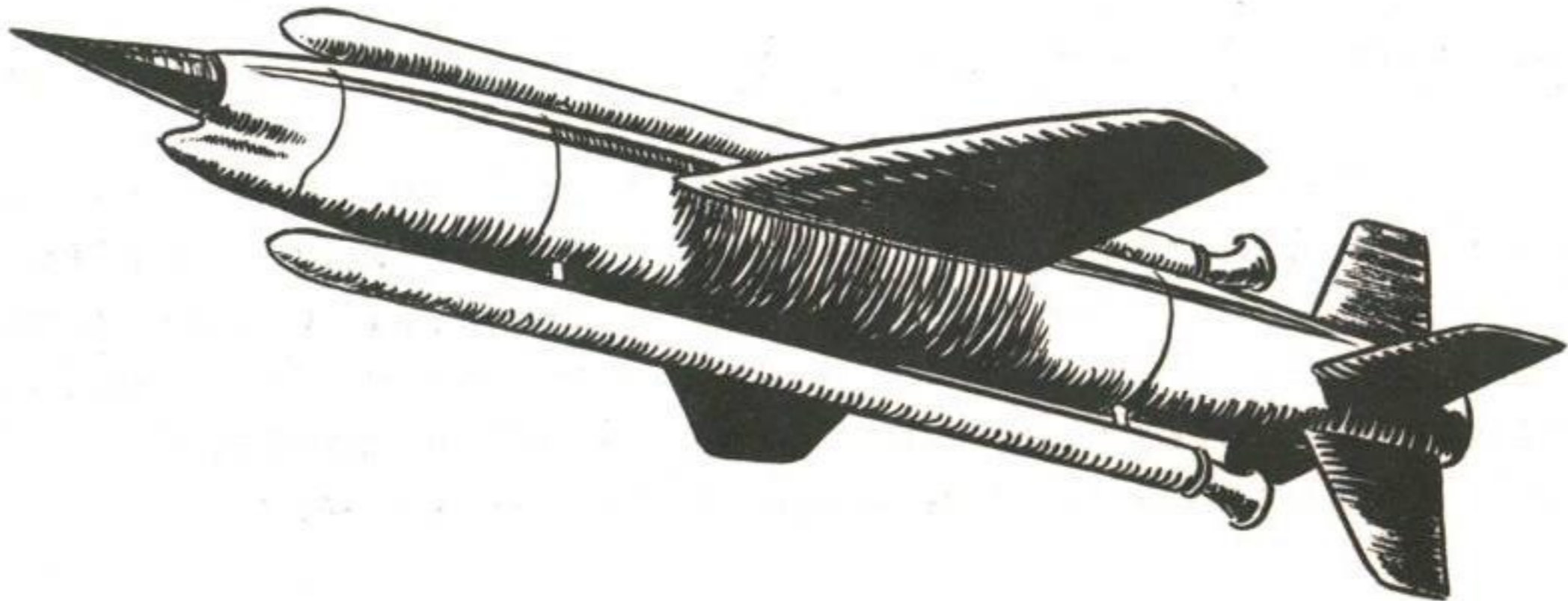


Figure 2 - Schmetterling (HS-117) Missile

ensured that the missile remained centred in the cross-hairs of his optics by moving a control called a KNUPPEL, similar to the hand control on an AI radar set. As the Knuppel was moved, left-right and up-down, error signals were fed to the computer. After correction for parallax and other errors, corrective command signals were sent from the Kehl transmitter to the receiver in the aircraft (Figure 4).

Because this system always maintained the missile on the line-of-sight to the target, no prediction of the tar-

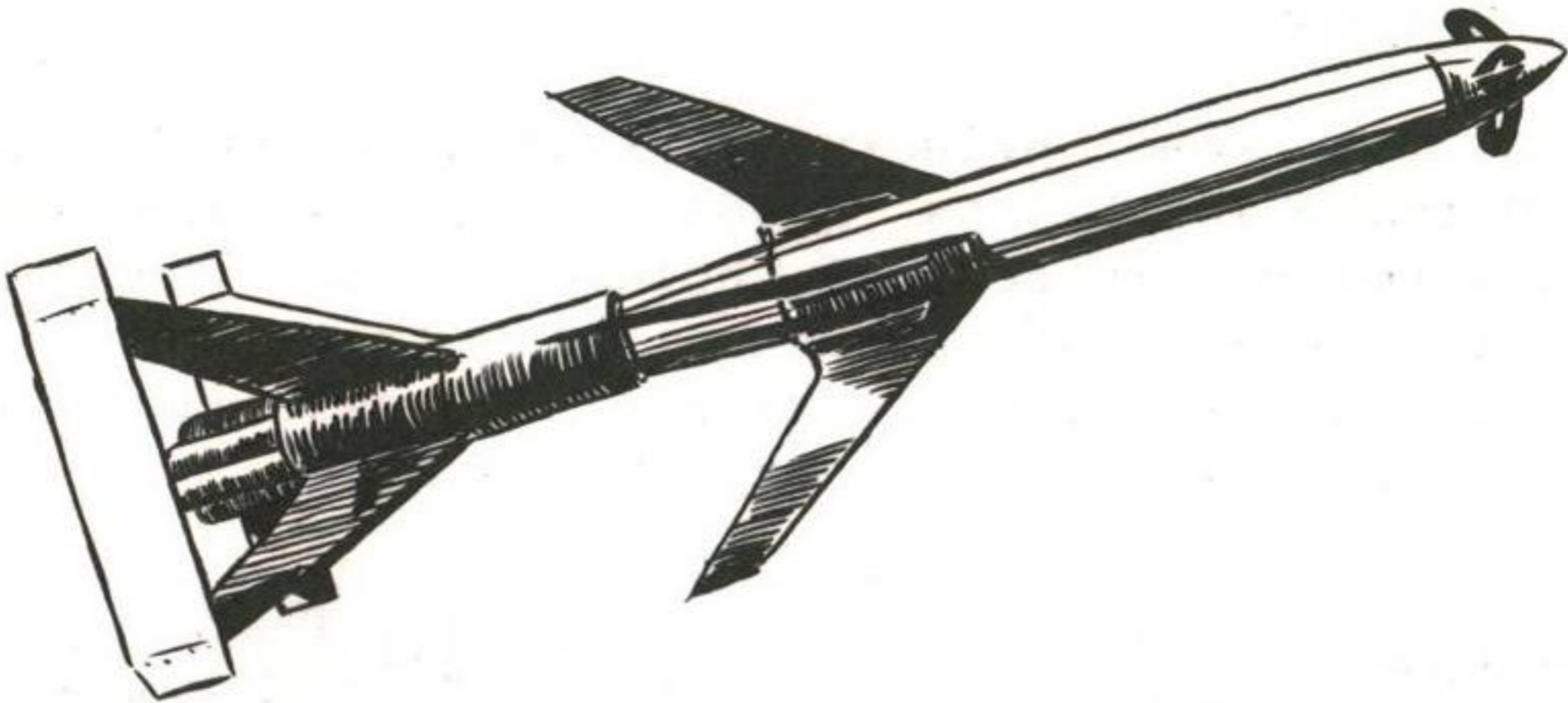


Figure 3 - Rheintochter I Missile

get and missile positions was required. This advantage was offset, however, by a long missile trajectory and a tendency for excessive control when the missile neared the target.

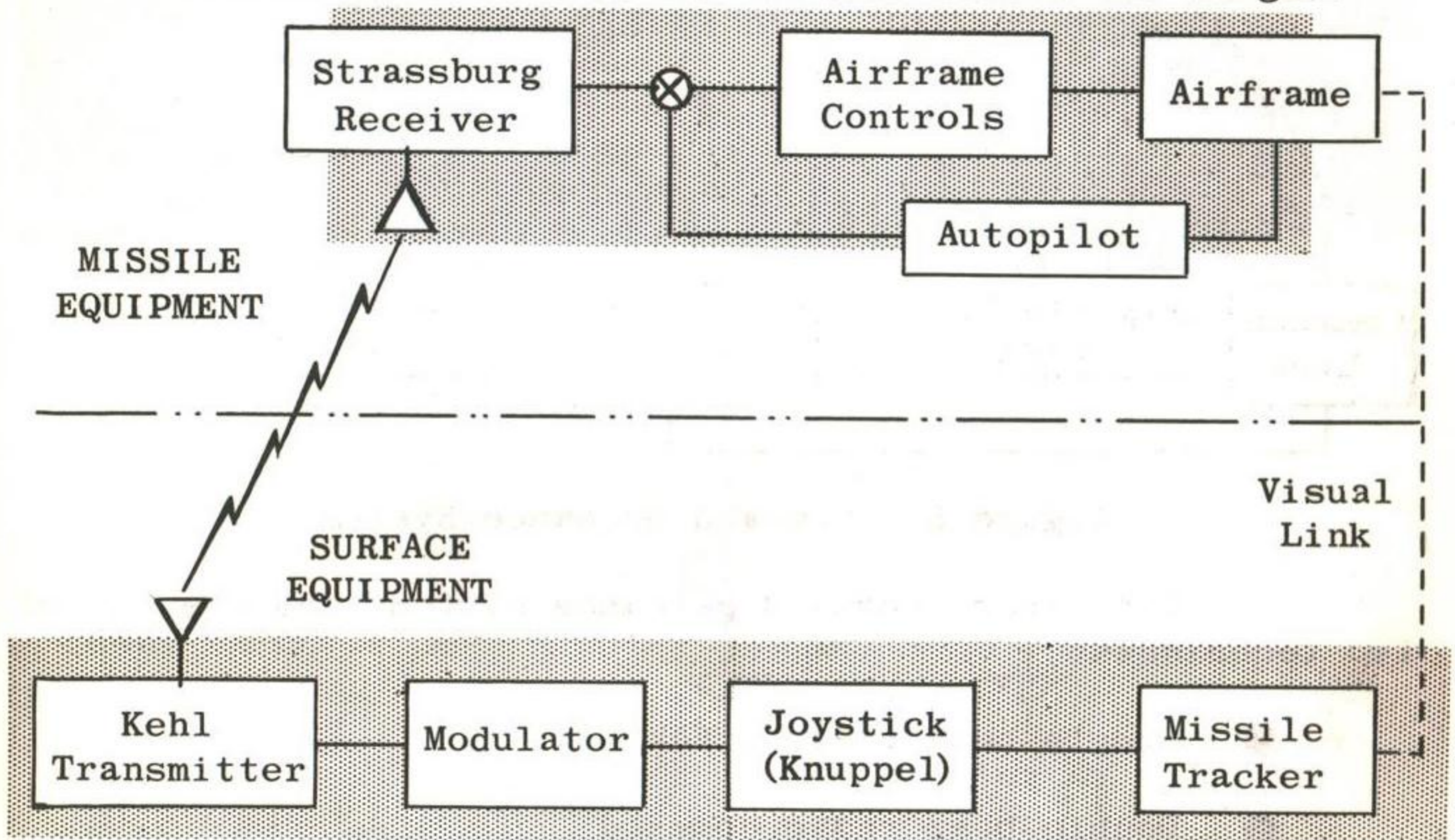


Figure 4 - Burgund Guidance System

The Kran-Brigg command link was developed late in the war as an alternative to the Strassburg-Kehl components. This system featured different frequencies and a modified control stick.

The Elsass command guidance system was proposed for the Wasserfall and Rheintochter missiles: this was basically the Burgund system, with radar tracking of the target and missile.

### Command Guidance

The same principles that were employed in the German Burgund and Elsass guidance systems are equally appropriate today. In general, however, visual command is not used, other than in experimental and trial roles, and has been replaced by radar tracking. The essential components of the command system are shown in Figure 5.

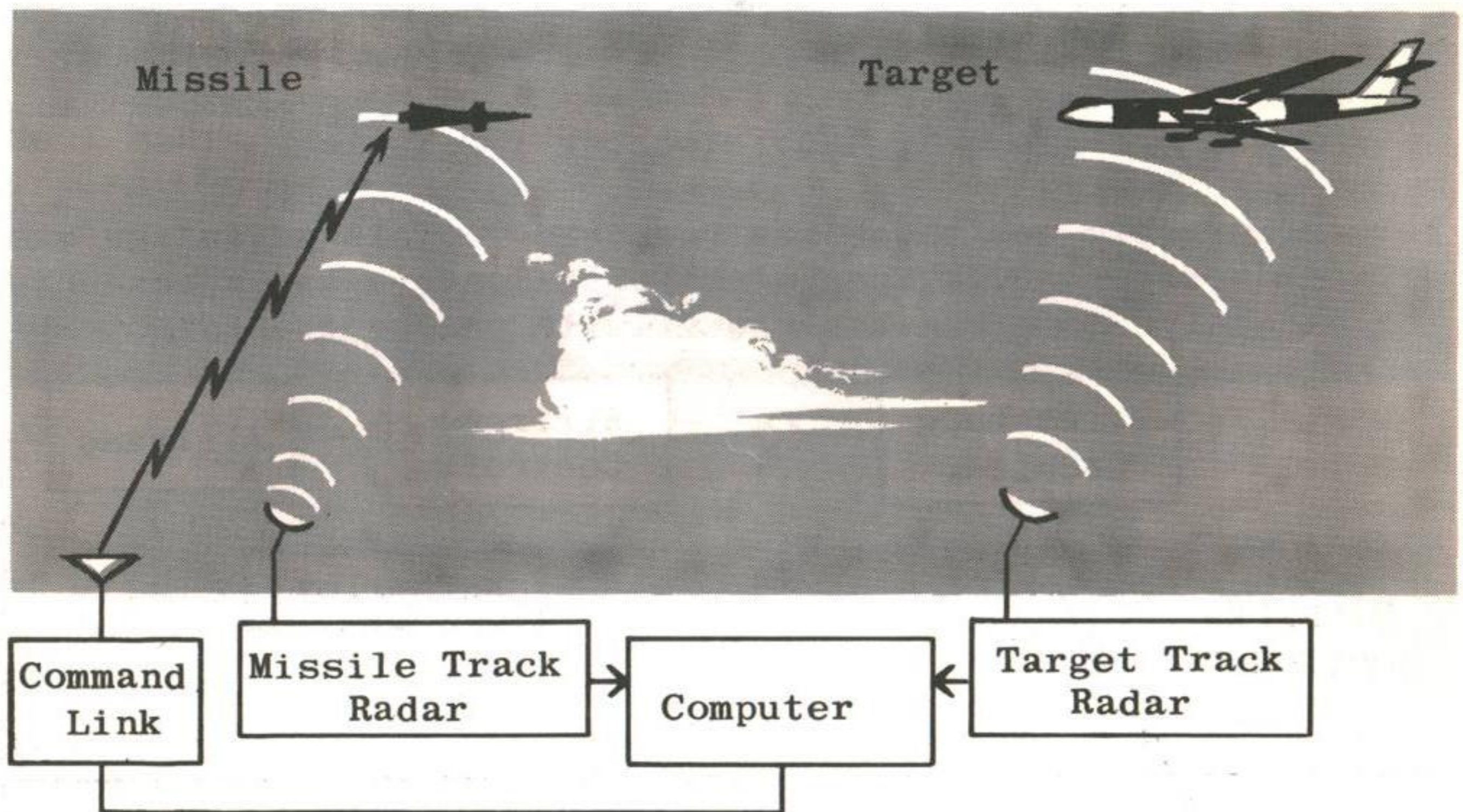


Figure 5 - Command Guidance System

The radar command guidance system can use one of two techniques:

- Single-beam radar track
- Double-beam radar command

In the single-beam system, only the target is tracked by radar; the position and motion of the missile is predicted ballistically. The ballistic data is obtained statistically from the major factors affecting it: velocity, drift (wind effect), elevation of launch, azimuth of launch, and time. On the basis of the data the position of the missile can be computed relative to the target as a function of time. In the event of target manoeuvres, corrective commands are transmitted to the missile, as shown in Figure 6. Obviously, any error in the ballistic data results in a miss.

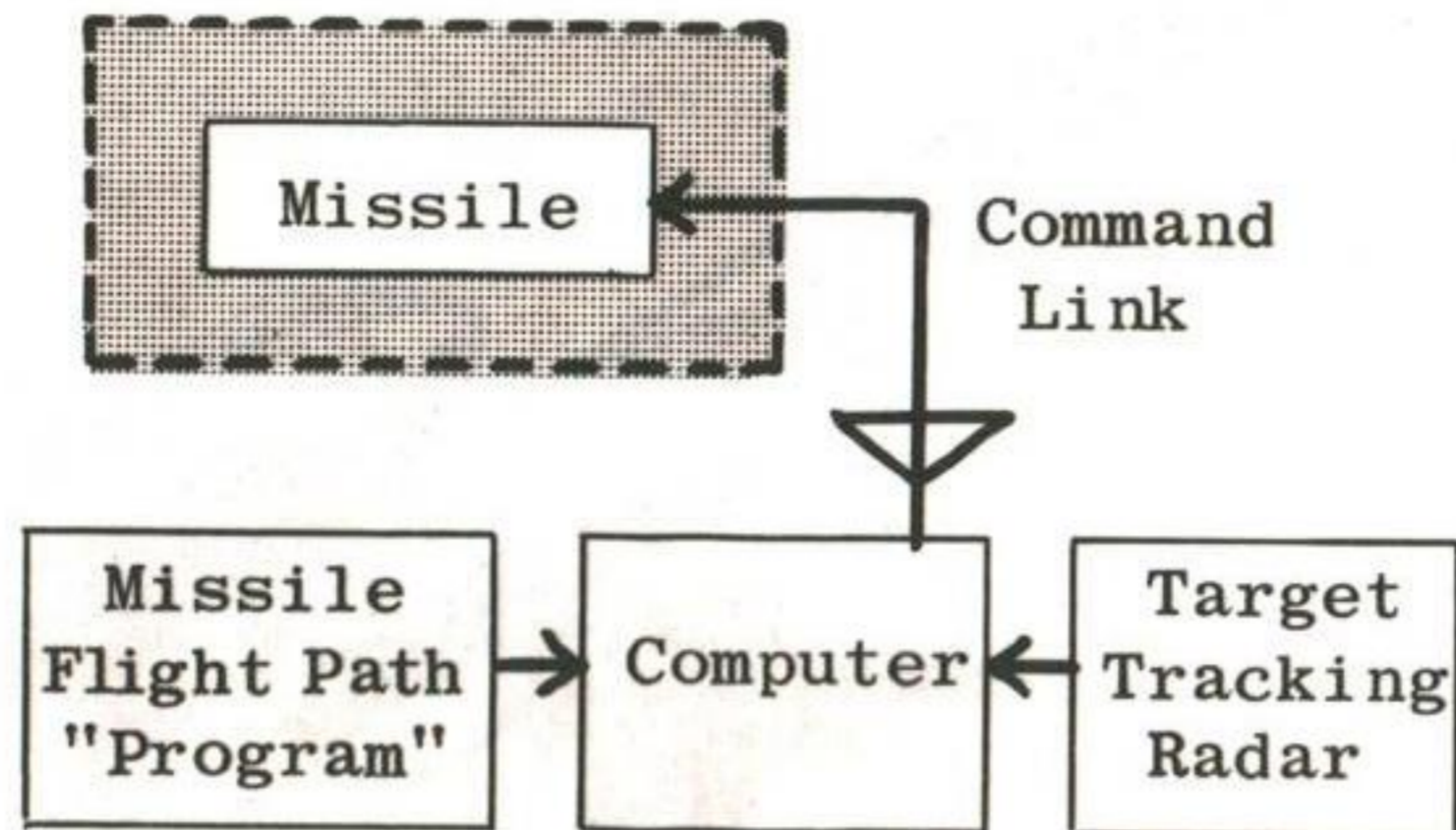


Figure 6 - Single Beam Target Tracking

An alternate arrangement for the single-beam system is available if the missile is equipped with a radar beacon. The radar beam illuminates both the target and missile, but the missile is now forced along the line-of-sight between the target and the ground-control radar set (Figure 7). In addition to the disadvantage of the longer trajectory, the missile must be equipped with both a beacon transponder and command receiver.

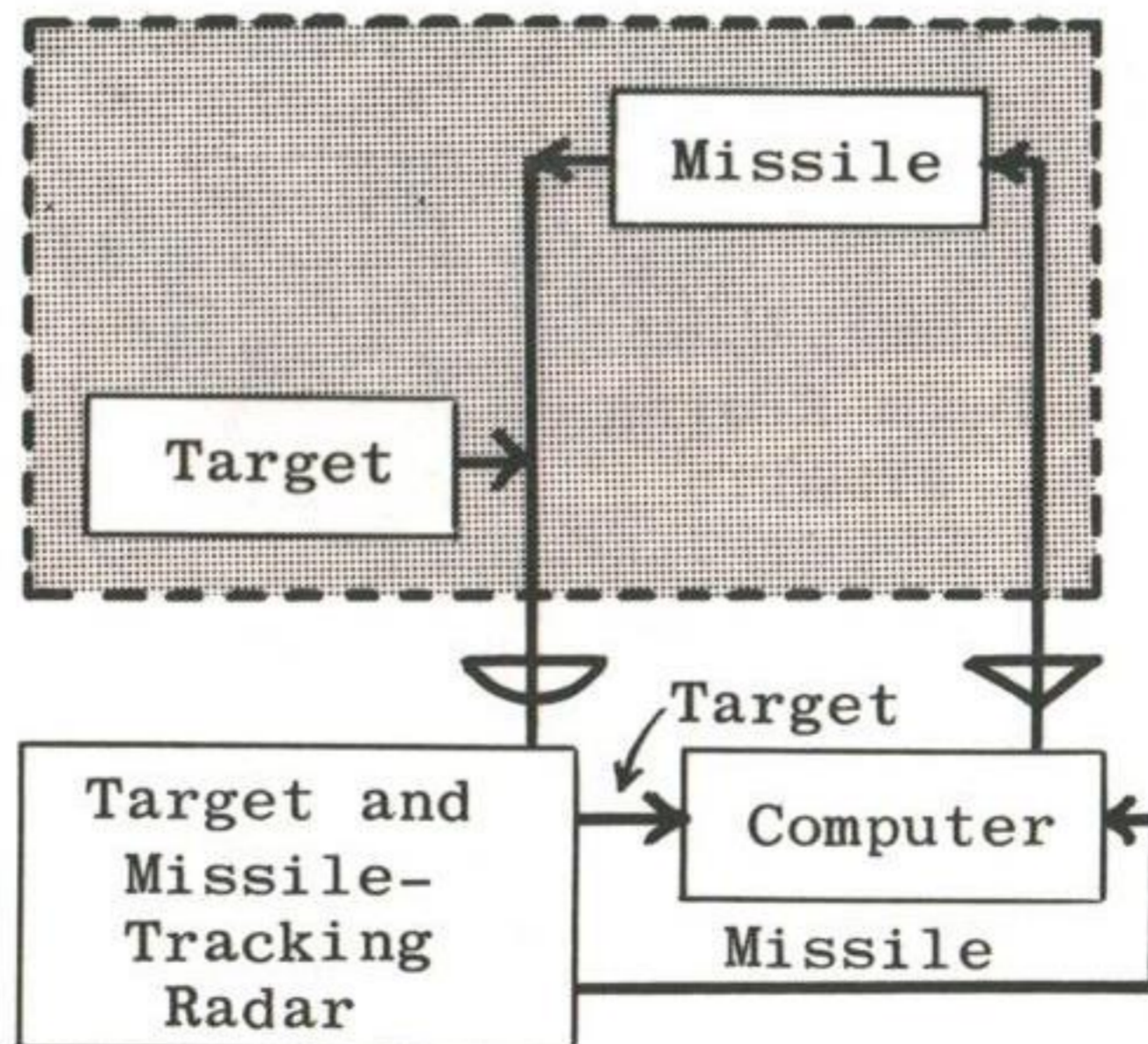


Figure 7 - Single Beam Target and Missile Tracking

The two-beam radar guidance system is essentially the same as that shown in Figure 7. The system components are the missile, target-tracking radar, missile-tracking radar, computer, and command link. The two-beam technique is more flexible than either single-beam system, and has better accuracy.

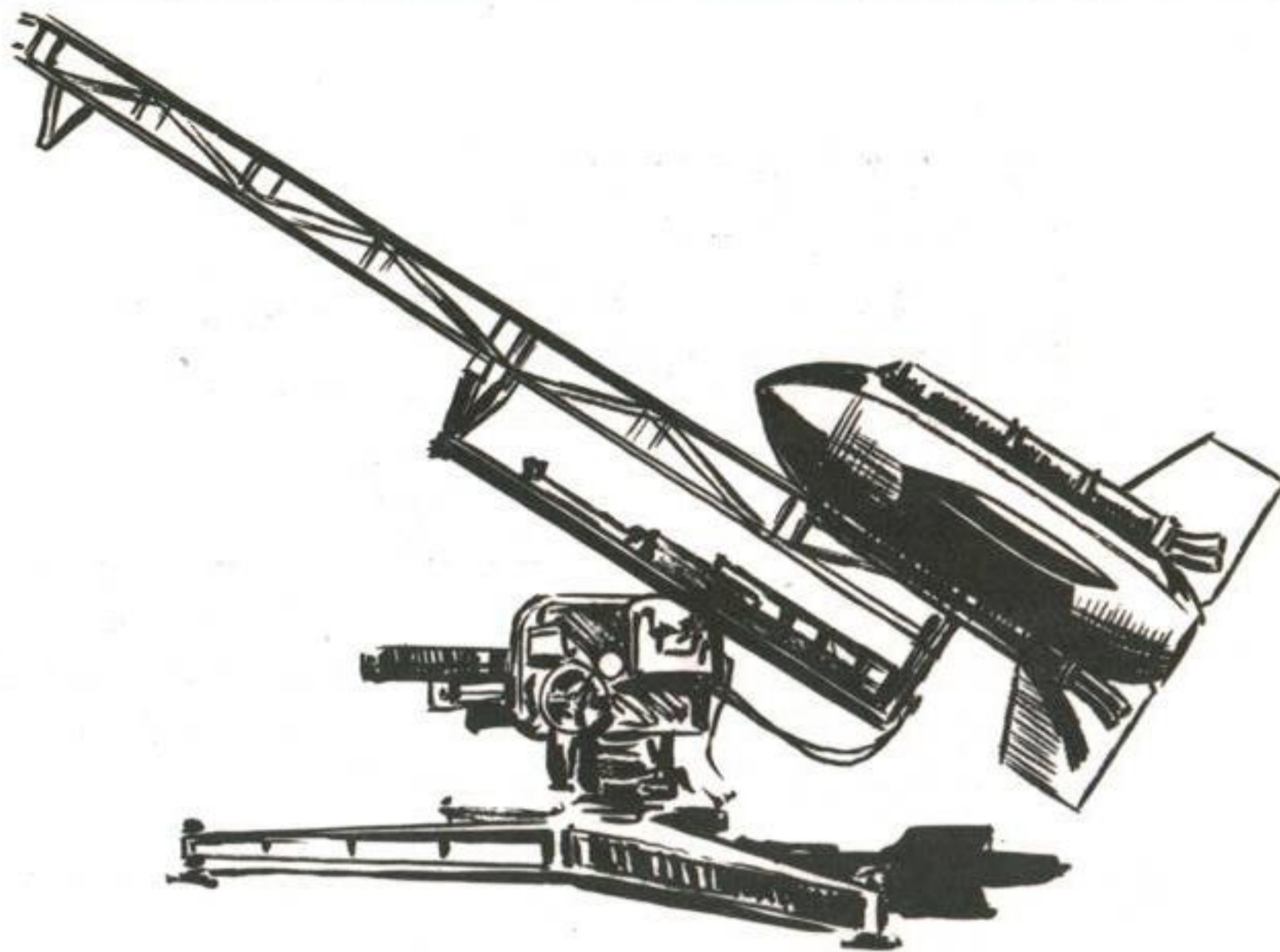


Figure 8 - Enzian Missile

### Beam-Rider Guidance

Beam-rider systems employ a radar beam directed into space, with the beam axis forming the missile trajectory: the beam may be fixed or moving. The essential components of the system are illustrated in Figure 9. The

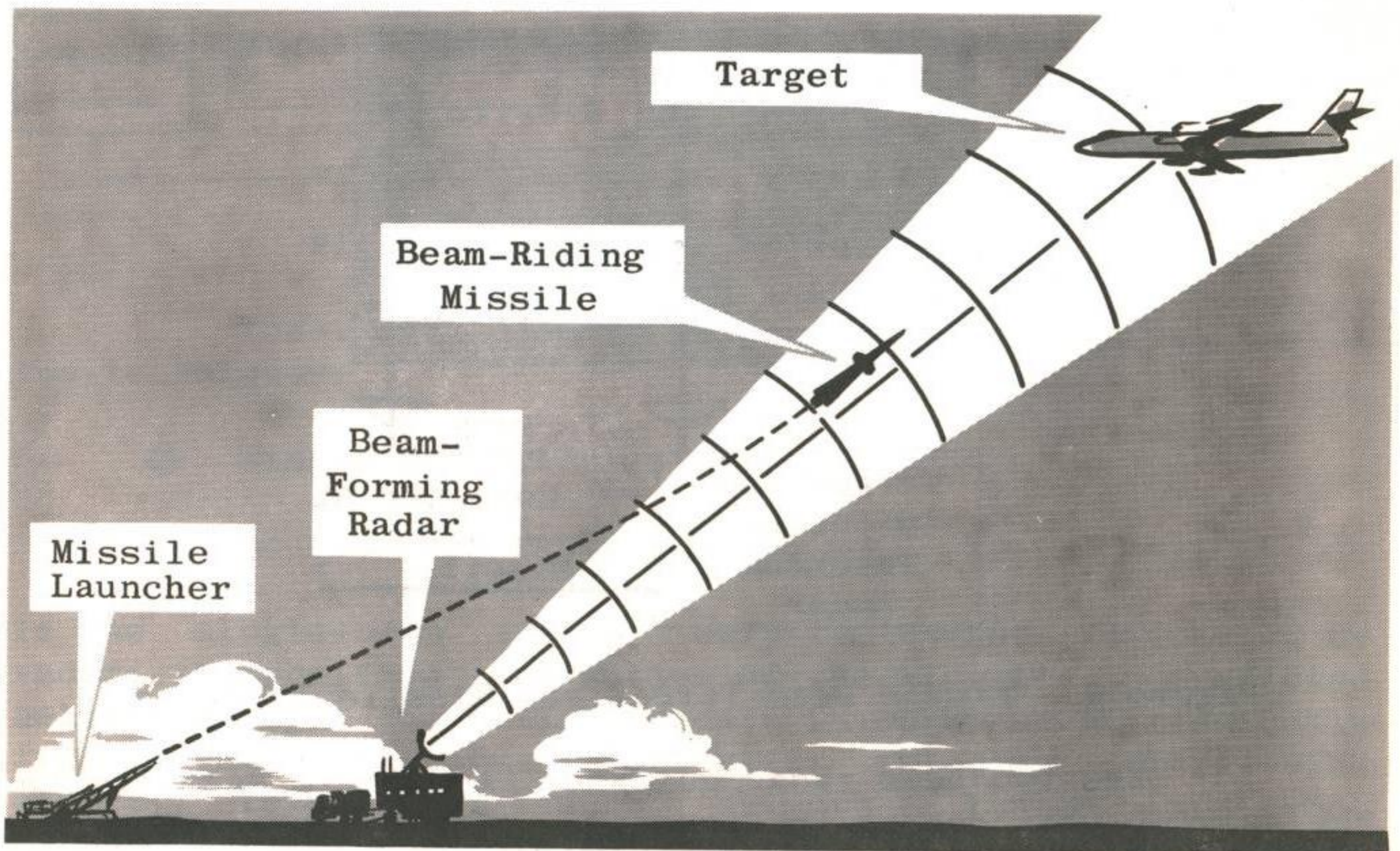


Figure 9 - Beam-Rider Guidance

missile is equipped with a rearward-facing antenna, a de-

tector which senses the azimuth and elevation departure from beam centre, and the control surface actuators. Roll-stabilization is normally required, just as it is required in the surface-to-surface missile\*.

### Homing Guidance

The three methods of homing guidance discussed for air-to-surface missiles\*\* are equally appropriate for surface-to-air guidance. The three techniques are illustrated in Figure 10.

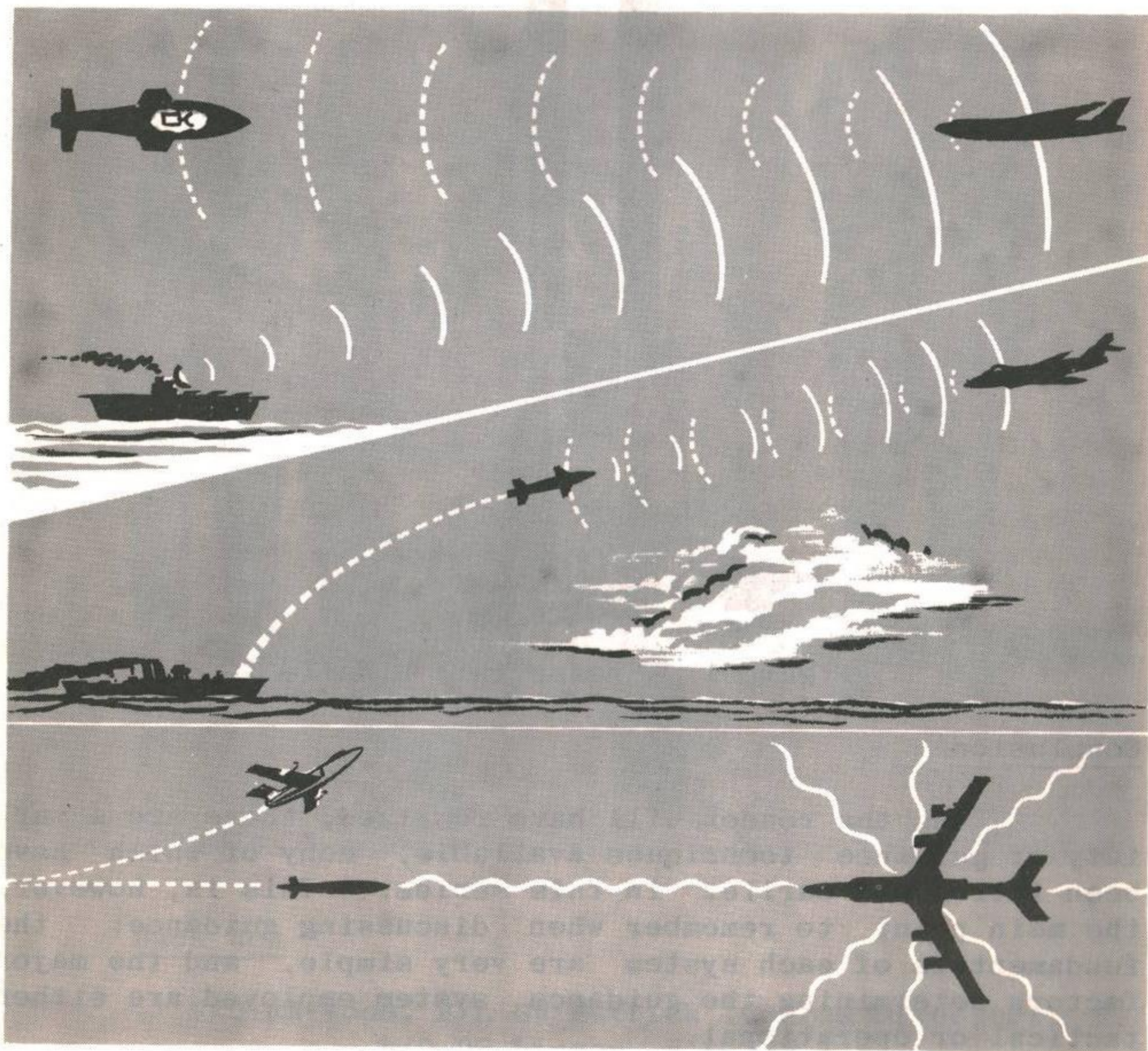


Figure 10 - Homing Guidance

\* RCAF OBSERVER - Jan 59

\*\* RCAF OBSERVER - Apr 59

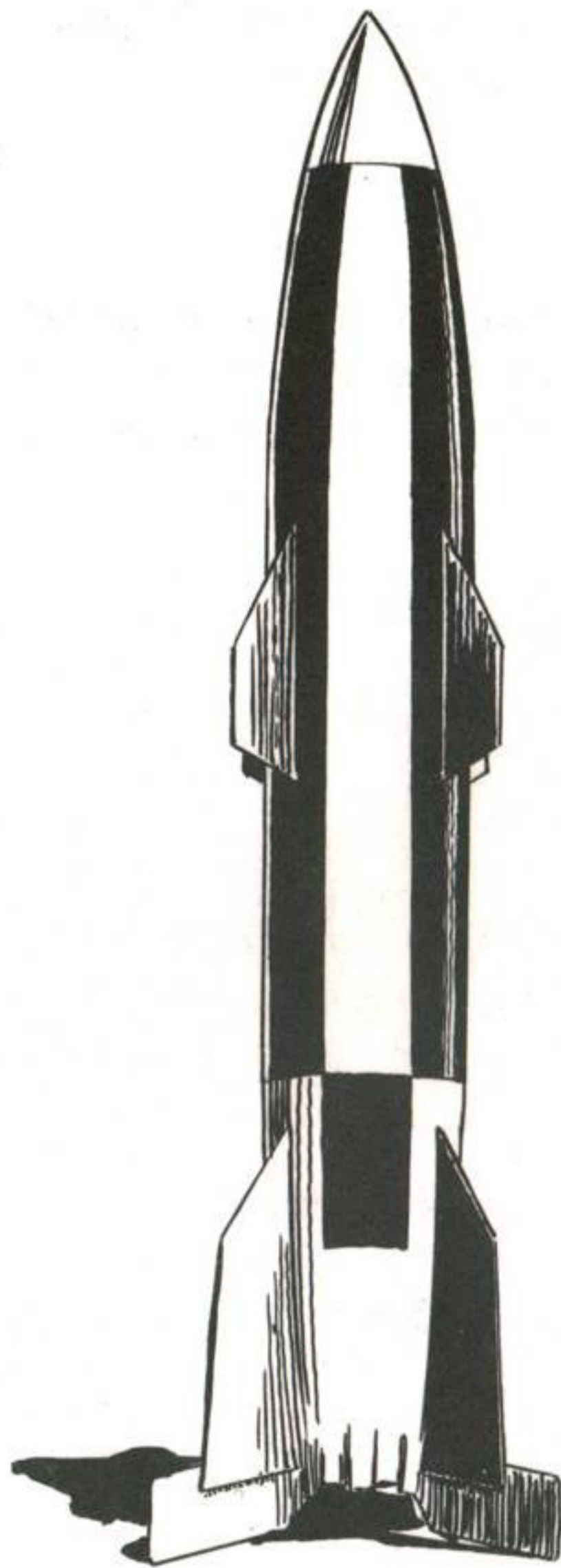


Figure 11 - Wasserfall Missile

### Conclusion

As the reader will have realized, there are a variety of guidance techniques available, many of which have been introduced earlier in this series. This is, however, the main point to remember when discussing guidance: the fundamentals of each system are very simple, and the major factors determining the guidance system employed are either tactical or operational.

# 3 SO(AI)I

4 May 59 - 14 Aug 59



Back Row

F/O RA Wood, F/L GW Patrick (Course Director),  
F/O DG Lisson, F/L JRP Ray

Front Row

F/O JALP Desmedt, F/L RK Wilson

# INFRARED

## *Part 2*

by

Flying Officer DK Schneider  
Central Navigation School

In Part I of this series, the theory of Infra-Red (IR) wave propagation was very briefly discussed. This final article describes how IR waves can be detected, and how IR detectors might be used today.

### IR Detectors

Detectors of IR radiations fall into two classes: broad-band detectors for determining the density or total amount of radiation received, and narrow-band detectors for detecting specific wavelength bands.

A common broad-band IR detector is the bolometer, which uses a device with the descriptive name of "thermistor". The thermistor exhibits a change in its resistance in proportion to the amount of heat energy striking it; the bolometer circuit measures this change, compensates for local temperature, and gives an indication of the radiation intensity striking the thermistor. These devices are used in mosaic form (Figure 1) for IR mapping and surveillance, but their response time is too slow to detect rapidly-moving targets.

Modern narrow-band IR detectors stem from a German development of World War II. Certain semi-conductors\* suffer

\* "Transistors", RCAF OBSERVER Vol 2 no 3.

a drop in their resistance upon being struck by IR energy. A given number of electrons are released for each unit of IR energy striking these materials. Thus the current flow for a given applied voltage will increase in proportion to the energy absorbed. In general, narrow-band detectors react much more quickly to IR energy than broad-band detectors, but

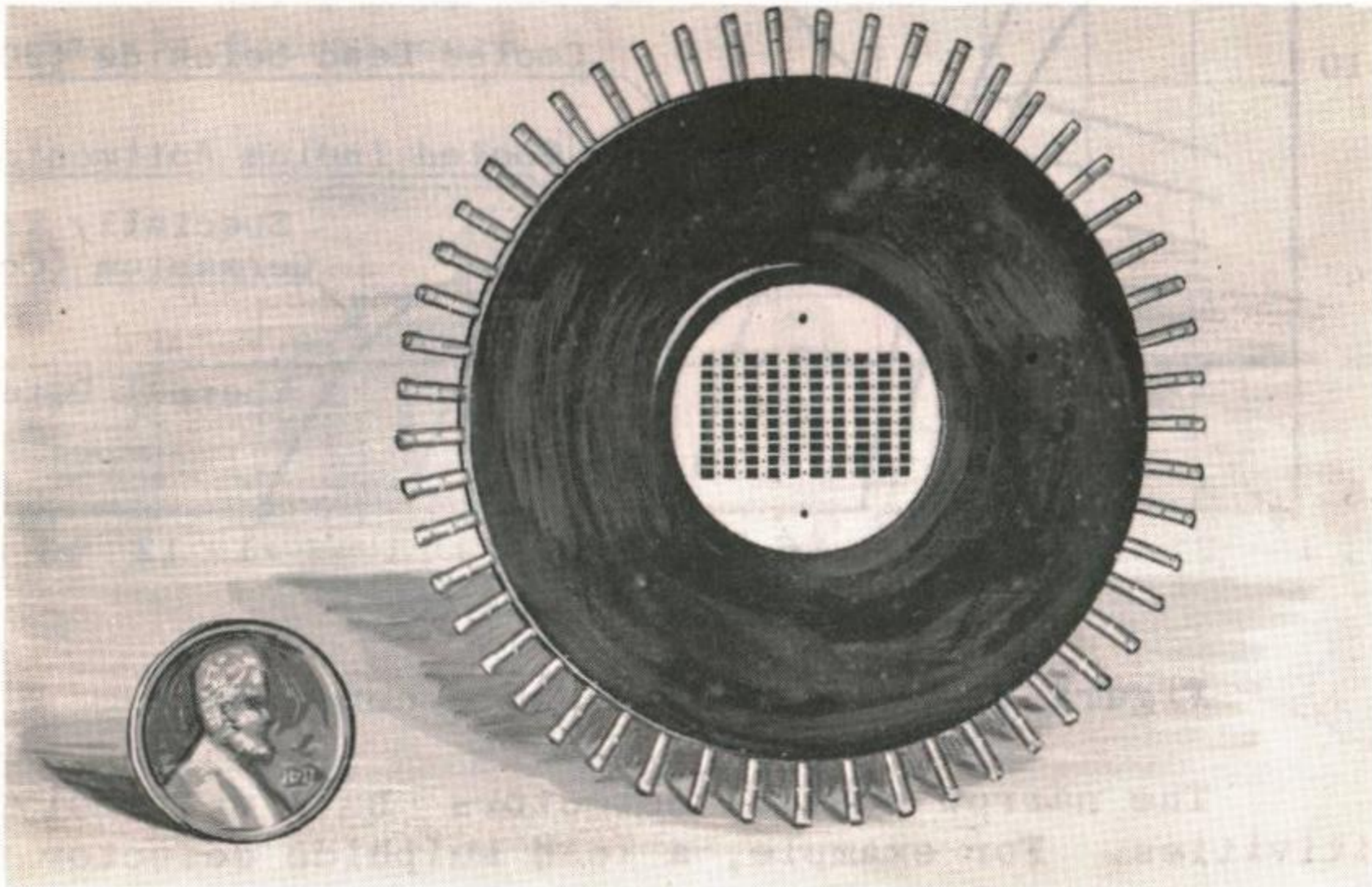


Figure 1 - Mosaic of Thermistor Detectors

respond only to certain wavelength bands. Some examples of materials used for narrow-band detectors, and the wavelengths to which they are most sensitive, are:

Lead Sulphide	- 3 $\mu$
Lead Telluride	- 4.5 $\mu$
Lead Selenide	- 6 $\mu$
Indium Antimonide	- 7 $\mu$

A problem arises with these semiconductors: in order to obtain maximum sensitivity from them, they must be refrigerated. One way of doing this is to fill the chamber containing the detector with a liquid nitrogen refrigerant. If the detector is to be used in an airborne application, the refrigeration equipment adds undesirable weight.

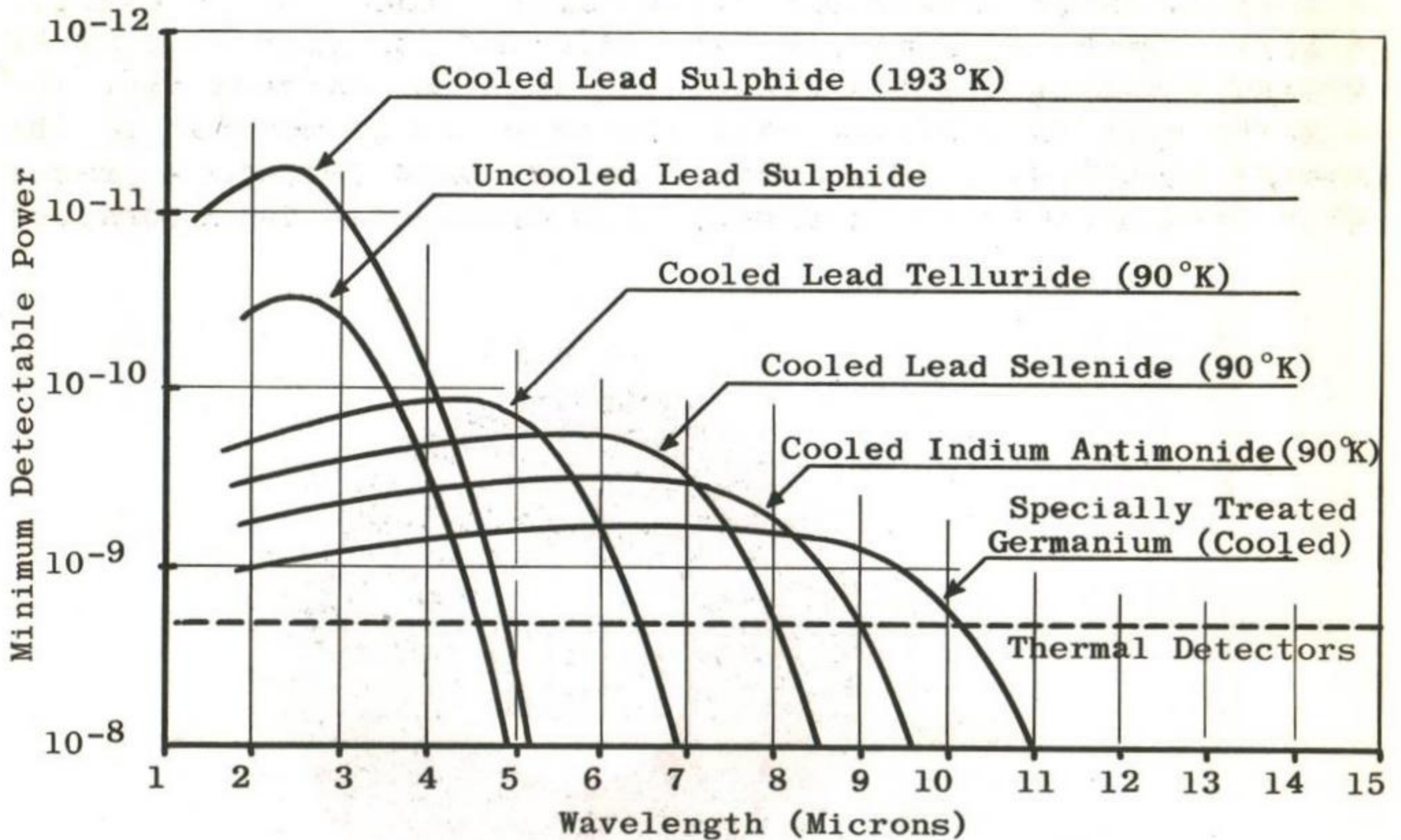


Figure 2 - Response of Photo-conductors

The narrow-band IR detectors have extremely high sensitivities. For example, a lead sulphide detector with a focussing mirror 3 inches in diameter can detect the heat from an electric stove at a distance of at least ten miles; when incorporated in a telescope, it can detect the heat from stars. It was mentioned earlier that these detectors respond to IR waves very quickly. Their response times are in the order of microseconds. These properties enabled the Germans to develop a device for detecting night bombers using a lead sulphide detector mounted in a searchlight mirror with a 150 cm diameter. The Germans also perfected a device called Madrid, which was an IR-seeker suitable for use in guided missiles.

Today, IR devices for detecting aircraft and directing missiles are vastly more important than during World War II, simply because modern aircraft are literally "hotter" than those of the Second World War. IR-controlled missiles also possess a considerable advantage over their radar-controlled counterparts because they are strictly passive, and as such are virtually unjammable. Also, the target-discrimination capability of an IR missile guidance system is vastly superior to a comparable radar system. For example, a

3 cm radar with a scanner one foot in diameter can distinguish between two aircraft at a range of 5 miles if the aircraft are 1 mile apart; an IR system with a 3 inch scanner can distinguish between the engines on a single aircraft 5 miles away. The only defence a jet aircraft has against an IR missile, which will literally fly up its exhaust, is a decoy target whose temperature is the same as that of the jet exhaust. A highly-successful IR air-to-air missile is the US Navy's Sidewinder.

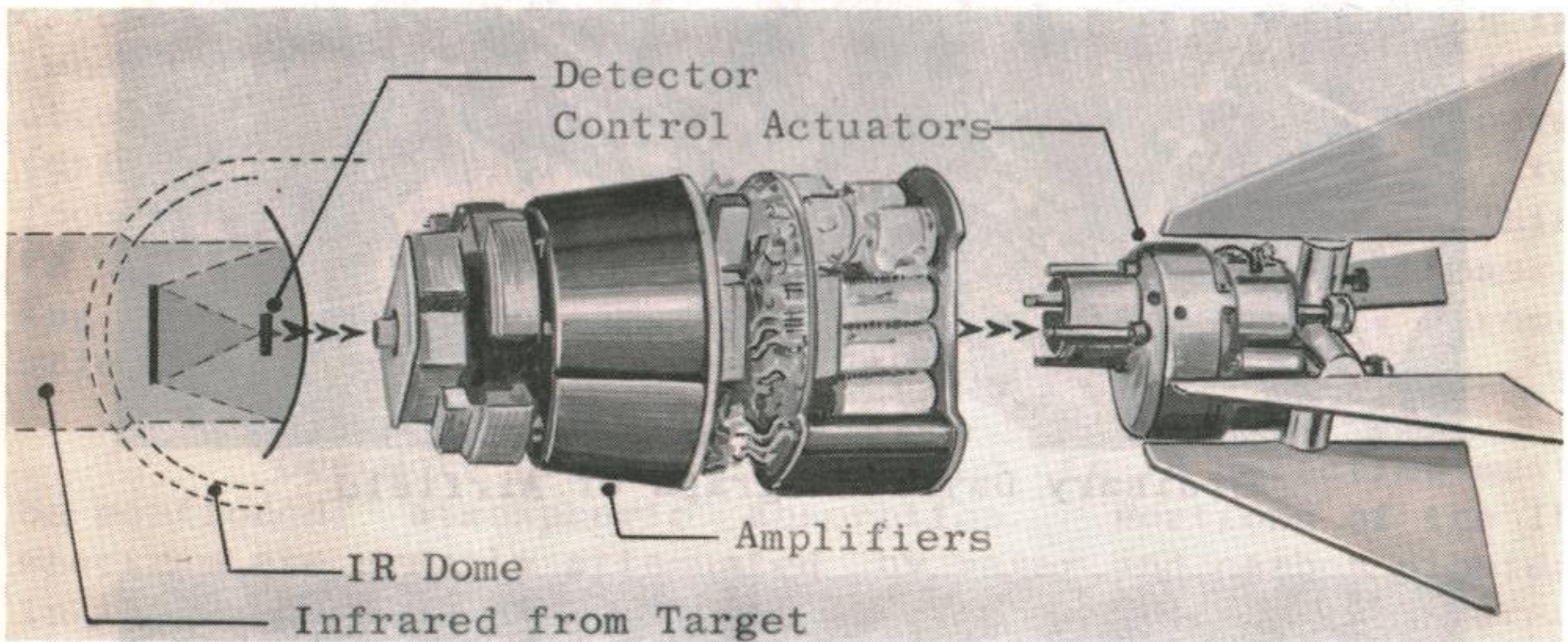
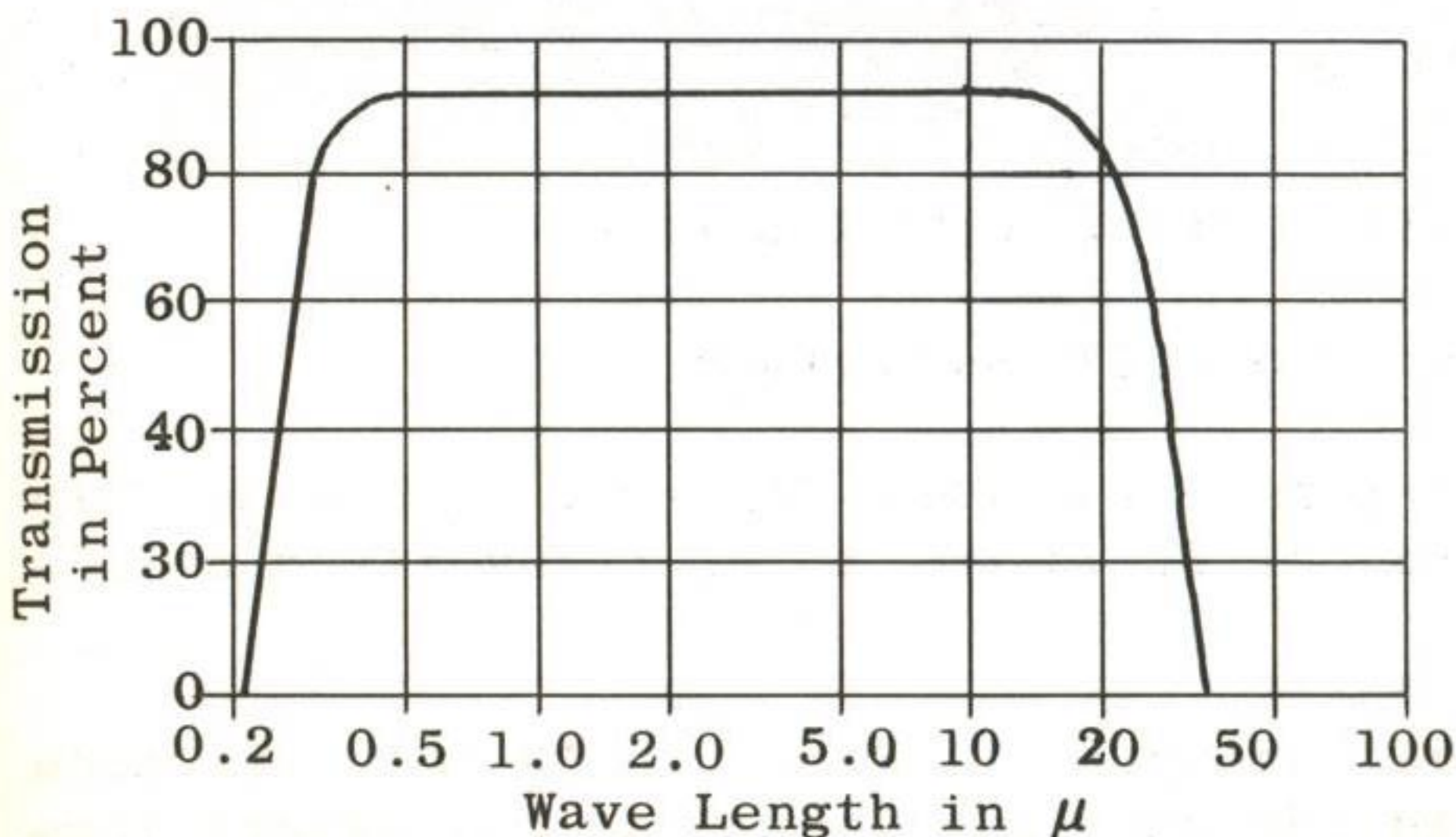


Figure 3 - IR Guidance System for Missiles

Specially designed cameras and IR-sensitive film have long been used for night photography. The design of such a camera poses a few problems because the lenses used



Potassium Bromide (KBr)

Figure 4 - IR Lens Transmission

must be capable of transmitting heat energy with a minimum of absorption and hence of re-radiation. Not all the energy striking a lens is transmitted through it. The portion which is absorbed heats the lens and is subsequently re-radiated at a different wavelength, thus fogging the film. Continual development and improvement is in progress on lenses which will transmit efficiently a wide band of IR wavelengths.



Ordinary Day Photograph of Airfield



IR Night Photograph of Airfield

Figure 5 - IR Photograph

Other lenses will act as band-pass filters, allowing only narrow, selected bands of IR waves to be transmitted efficiently.

The physical construction of an IR lens is much more complicated than the construction of an equivalent lens for the visible light spectrum, since the visible spectrum comprises only a very narrow band of wavelengths, while the

useful portion of the IR spectrum covers a much wider bandwidth:

Visible Spectrum = 0.75 to 0.4 microns

IR Spectrum = 300 to 0.75 microns

Even though a very small portion of the whole IR spectrum is presently in use (16 to 0.75 ), this gives a bandwidth 45 times as wide as the optical bandwidth. The problem of chromatic aberration is therefore much greater with an IR lens than with a lens for visible light. Chromatic aberration is the tendency of rays of light of different colours (different wavelengths) coming from a common source, to focus at different points when passed through a lens. This is because the amount a ray of light is refracted when passing through a medium depends on the ray's wavelength. Chromatic aberration might be termed a "prism effect".

One more problem encountered in IR detection must be mentioned: atmospheric absorption. Portions of the IR spectrum are greatly attenuated by water and carbon dioxide in the atmosphere. The amount of attenuation will of course

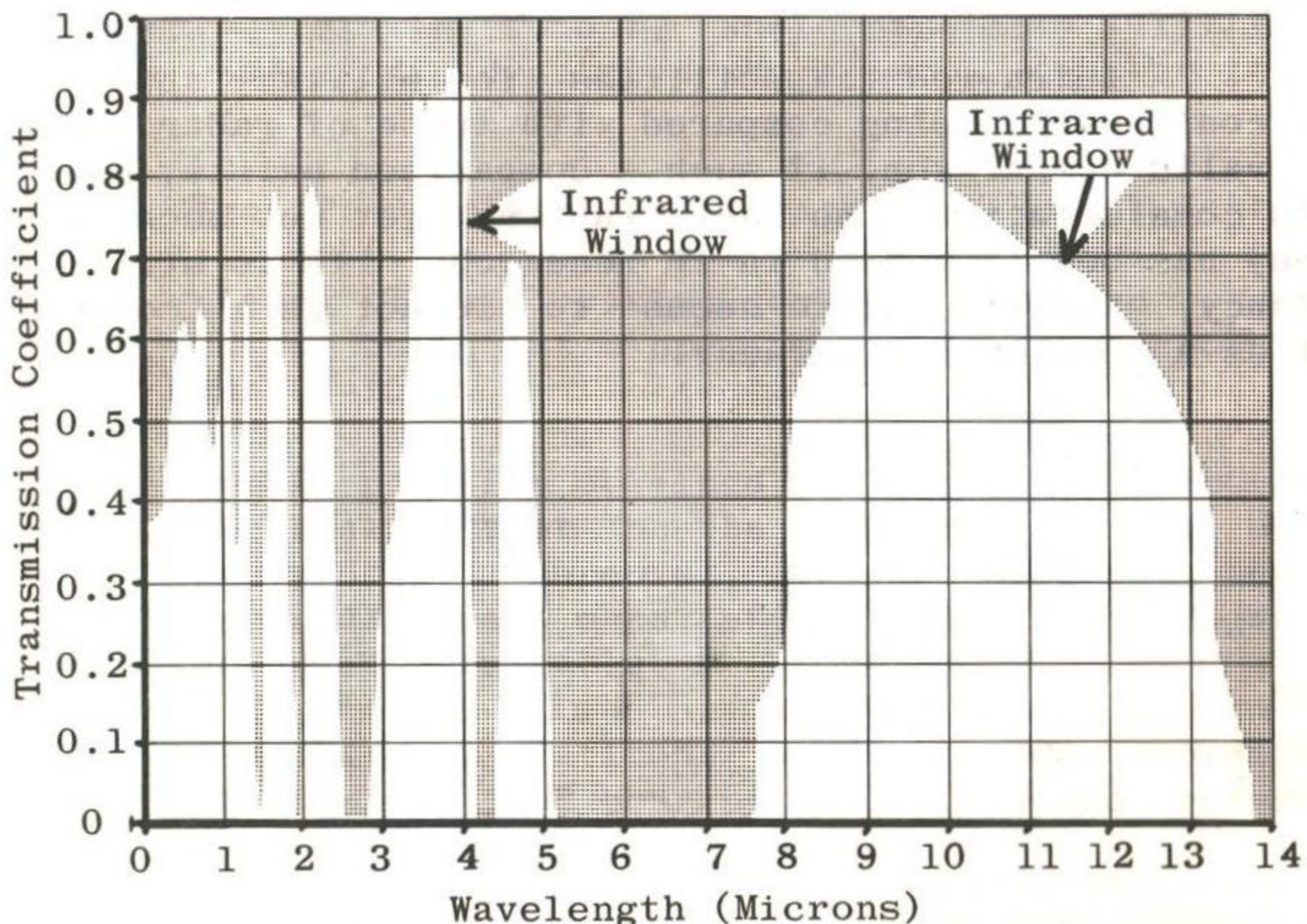


Figure 6 - Atmospheric Attenuation

depend on the quantities of these substances present. As a

matter of fact, IR energy is attenuated in fog and cloud in pretty much the same manner as visible light. Even in clear weather the atmosphere attenuates large portions of the IR spectrum, leaving what are known as infra-red "windows". At increased altitudes the bandwidth of these IR windows increases, until at heights above 30,000 feet there is attenuation only in very narrow bands around  $2.8\mu$  and  $4.4\mu$ .

The implications of atmospheric absorption as far as airborne IR is concerned are easy to see. An IR air-to-air missile will not suffer range losses because the altitudes at which it will presumably be used are above the main bulk of the atmosphere. On the other hand, any IR surveillance or mapping system can only detect objects whose wavelengths of radiation fall within one of the atmospheric windows, and then only in clear weather. Fortunately, one of the atmospheric windows allows detection of objects whose temperatures range between approximately  $-40^{\circ}\text{C}$  and  $100^{\circ}\text{C}$ , so that it is possible, in clear weather, to photograph objects whose temperatures fall within the "normal" temperature range.

### Conclusion

Infra-red capabilities for military applications are continually being compared with those of radar. However, any valid comparison, if such a comparison exists, must take into consideration the fact that as yet not much time or money has been invested in IR research. IR is still in its infancy, and its future seems to lie not as a competitor, but as a complement to radar.



# R- $\theta$ in JET NAVIGATION

by

Flying Officer DE Sharpe  
Flying Officer NS Freeman  
440 AW(F) Squadron

A few years ago the RCAF recognized the need for a DR instrument which would provide accurate and speedy navigational information to crews of CF-100 aircraft. The High-Speed API was one of the initial aids employed and is still being used. This instrument, while partially fulfilling a need, has several disadvantages where jet navigation is concerned:

- The API displays an air position which in itself is of little value until a wind velocity is applied. This operation requires time and space, the latter being at a premium in the rear cockpit of the CF-100.
- The DR position obtained using the API depends to a certain extent on the plotting accuracy of the individual. Moreover, the use of grease pencils and small-scale maps tends to limit the degree of accuracy obtainable.
- The API uses latitude and longitude coordinates when range and bearing to a desired reference point would be more convenient.

Since July 1957, 440 AW(F) Squadron has had a number of aircraft equipped with the R-Theta Computer. This instrument eliminates some of the disadvantages of the API

and reduces other disadvantages to a more acceptable minimum. This article will attempt to appraise the R-Theta system as it has been used in the navigation of CF-100 aircraft on 440 Squadron. Also, suggestions are included for operating procedures which may be used under normal flight conditions.

### General Operation

Briefly, the computer portion of the R-Theta is an independent DR instrument which displays range and bearing to a reference point, as well as true track flown. The second instrument is a Ground Speed and Interception Computer, which allows wind velocity and variation to be manually set and electro-mechanically fed to the computer, along with TAS and TH obtained from normal heading and airspeed inputs. These vectors are used to solve the triangle of velocities. A reset feature allows changes to be made in bearing and range of the reference point to agree with fixes obtained from a GCI or any other fixing aid. The only requirement is that fix information be in R-Theta coordinates. GCI is the most common fixing aid used. Rapid correction of the R-Theta is made possible from the range and bearing coordinates provided by this aid.

### Airborne Appraisal

Before attempting to appraise the R-Theta as a practical navigation aid, certain conditions were met so as to arrive at standard operating procedures. By so doing, it was hoped that an average DR error could be determined and used to facilitate the prediction of navigational accuracy for a flight where the following procedures were used:

- > A climb wind velocity was set on the GSIC until flight altitude was reached. This wind velocity was then changed to the forecast wind velocity for the operating altitude.
- > After one hour (approximately) at height, a fix was obtained and a new wind velocity was calculated by comparing the fix and the DR position. The vector from the R-Theta (DR) position to the true position is a wind correction vector and may be applied to the original wind to obtain a new wind velocity.
- > The R-Theta was reset to the new position and the new wind velocity set on the GSIC.

—> The aircraft remained at altitude until over base, so as to be affected by the same wind for the remainder of the flight.

Under these conditions, it was observed that an average circular error of close to 15 nm was obtained on returning to base. This error presumably could be expected on flights of 1 1/4 to 1 3/4 hours duration where a fixing aid is available, and would include one reset operation and a change of wind velocity if necessary. Unfortunately, the R-Theta error obtained covers a limited number of trials and therefore is put forward only as an indication of the accuracy which may be expected. However, it has been noted by observers on 440 Squadron that the general accuracy of the instrument closely approaches this figure and may be less, depending on the experience of the operator and the reliability of information fed to the system.

#### Determining Factors

The factors which affect the operation of the R-Theta computer do not differ greatly from those affecting other DR instruments. As is the case with these other instruments, the accuracy of the final DR position is mainly dependent on the reliability of the wind information. In turn, the wind information is dependent on the reliability of the fix used to find the new wind velocity. In a case where no reset is anticipated, the governing factor then becomes the forecast wind. It has been our experience that the forecast winds, when compared with winds obtained in flight, usually agree within limits acceptable in jet navigation. Therefore, we could safely predict a circular error for a normal flight with no fixing aids, of slightly greater than that assumed for a flight conducted where fixing aids are available.

In obtaining an accurate wind, a certain time delay is incurred. During this time (generally 2-3 minutes) the computer is operating with an old wind which may be incorrect. In practice, it has been noted that the DR error introduced by this time delay is negligible, except in cases where an unusually high wind vector is involved.

A correct assessment of the R-Theta must take into consideration the human errors which are introduced in plotting, computing and resetting. It is probable that a com-

combination of these errors on the part of aircrew and GCI controllers accounts for some percentage of the error encountered in flight. Moreover, the system has an instrument error of plus or minus 2%, which must also be considered in determining an over-all DR error.

### Summary

From the foregoing assessment of the R-Theta System, the following advantages are apparent:

- It is a direct-reading instrument, providing an immediate DR position.
- Since no plotting is required, personal as well as general plotting errors are eliminated.
- In view of this 'no-plot' feature, a reduction of DR errors encountered in the API is possible.
- The coordinates supplied are more appropriate for the type of flying which is done in the CF-100.

In consideration of these advantages of the R-Theta System over the High Speed API, it can be said that the system adequately fulfills the need for a semi-automatic DR instrument for jet navigation in the CF-100.



by

Flight Lieutenant MD Gates  
Central Navigation School

The calculation of a Point of No Return (PNR) has always been considered a routine step in flight planning. The practical accuracy of this PNR depends upon variations from the forecast wind velocities over the route, but the required accuracy can be maintained by in-flight re-calculation. In any event, the variation in the distance to the PNR caused by wind changes is usually small, and is unlikely to exceed the 10% allowance used to derive the Prudent Limit of Endurance (PLE) from the total take-off fuel load. Is our complacent acceptance of present methods for determining the PNR well-justified?

An examination of the PNR formula reveals that no allowance is made for the possibility of engine failure. Yet there are aircraft in use in the RCAF which possess single-engine characteristics that cast doubt on the validity of a normally-calculated PNR. A C-119, for example, suffers a 20% reduction in airspeed and an increase of 16% in fuel consumption when flying on one engine. If this aircraft were to attempt a single-engine return from a normal PNR on a long over-water flight, the results would be drastic, because there would not be sufficient fuel. This condition is not restricted to the C-119: the same holds true for any aircraft which experiences a large loss of airspeed without a comparable decrease in fuel consumption with an engine out. Obviously, then, there is a requirement for some means of calculating a PNR which takes into account the possibility of engine failure in these cases.

Simple mathematics can easily produce the required formula. The fuel consumed for any period is equal to the consumption multiplied by the time. Also, the fuel consumed in reaching a PNR, plus the fuel consumed in returning from a PNR, must equal the PLE. Since time equals distance divided by groundspeed:

$$\frac{X}{O} C_1 + \frac{X}{H} C_2 = \text{PLE}$$

Where:

- X = Distance to PNR (nm)
- O = Actual G/S Out (K)
- C<sub>1</sub> = Normal Fuel Consumption (Lbs/hr)
- H = Reduced G/S Home
- C<sub>2</sub> = Fuel Consumption with Engine Out
- PLE = Total Fuel (lbs), less 10%

Removing X, and reducing to a common denominator:

$$X \left( \frac{C_1}{O} + \frac{C_2}{H} \right) = \text{PLE}$$

$$X \left( \frac{C_1 H + C_2 O}{O \times H} \right) = \text{PLE}$$

Transposing:

$$X = \frac{\text{PLE} \times O \times H}{C_1 H + C_2 O}$$

Thus a formula for calculating the PNR, taking into consideration the changes in airspeed and fuel consumption, can be used. This formula need not be applied to all types of aircraft, only to those having the unusual characteristics previously mentioned. It is probable that the Comet falls within this category, and possibly all turbojet-powered aircraft will require a revised procedure to determine a PNR. A few practical examples applied to any type of aircraft will determine the necessity for these special considerations.

Comments to the OBSERVER on this problem, and the suggested solution, would be appreciated.

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