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Contents

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The RCAF OBSERVER

Incorporating the RCAF Navigation Bulletin

Founded 1949

Since the beginning of the Second World War, research and development in the navigation field has been concerned mainly with the production of new aids. As a result, there are many new radio-fixing systems such as Decca, Tacan, and Cytac. Radar has been vastly improved, doppler equipment is now in service, and work is progressing on pure inertial navigation systems.

The rapid appearance of new aids has been accompanied by an increase in automatic features. The R-Theta computer, Position and Homing Indicator, and improved Air and Ground Position Indicators, have reduced the need for human computation and plotting.

In view of these advances, it is rather startling to learn from the article "Comet Navigation" in this issue that astro is considered the primary aid in the RCAF Comets. Surely one would expect to find the latest navigation equipment in these high-performance jet transports, if it is to be found at all in the RCAF.

The absence of new equipment in the Comet has many causes: Canadian doppler systems are still being evaluated; despite the variety of new ground aids, only experimental chains exist at present; existing aids, such as Loran, are ineffective because of antenna difficulties. On the other hand, the reliance on astro is well-founded: it is universal; at the operating altitudes of jet transports, weather seldom denies its use; and the absence of turbulence compensates for the increased acceleration errors.

The conclusion must be that astro is far from being on its way out as a primary navigation aid, and it will certainly long remain as the primary stand-by in normal operations. Because of the requirement for self-contained navigation systems in military operations, astro will continue to be one of the major aids until it is replaced by inertial systems.

What improvements have been made in astro navigation? Only two significant advances are being made use of today: the periscopic sextant, and AP 3270 sight reduction tables. The sum total, then, is that accuracy has been increased somewhat, and the time required for computation has been reduced slightly.

Thus there is still much room for improvement in celestial navigation: the accuracy which could be achieved is far from being fully exploited, and the methods of computing and plotting remain prone to error and time-consuming. Perhaps this field, more than any other, offers observers the opportunity to compete for cash suggestion awards!

missile

Guidance part 2

by
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3(AW) OTU

The air-to-surface or stand-off guided missile is essentially the same as the surface-to-surface projectile that has reached the mid-point in its flight. Three of the unmanned guided missiles developed during World War II were the German HS-293 series, and the Weary Willy and Assault Drone in the USA. These weapons were, however, supplemented by glide bombs. As their name implies, they were unpowered. All of the glide bombs used some form of guidance, with the exception of the GB-1 (USA) which consisted of a very simple monoplane airframe structure attached to a general-purpose bomb, and controlled by a pre-set autopilot. The techniques used with the early glide bombs are basically the same as those used today, particularly in the terminal-guidance phase of flight.

Guided Bombs

Before making a detailed study of the different guidance techniques used for the air-to-surface missile, it would be advisable to study the techniques used to control the glide bomb of World War II. This might, if nothing else, prevent everyone from becoming too complacent about the so-called "state of the art" today. Almost every technique now used can be found in the 'old' weapons of World War II. Some of these not-so-new techniques are described in the following paragraphs.

Television. The American GB-4 (Figure 1) had a television camera and transmitter in the bomb, and the picture was monitored by an operator in the launching aircraft. The control surfaces of the bomb were then actuated by radio command to steer the weapon to the target. While the missile was given only limited use at the end of World War II, it was used against U-boat pens and certain German industrial targets. The Robin and Roc were two other US weapons that were developed using this guidance technique. The television system was also used in the Weary Willies, mentioned previously. These were old bombers, unfit for further operational service, which were loaded with explosive.

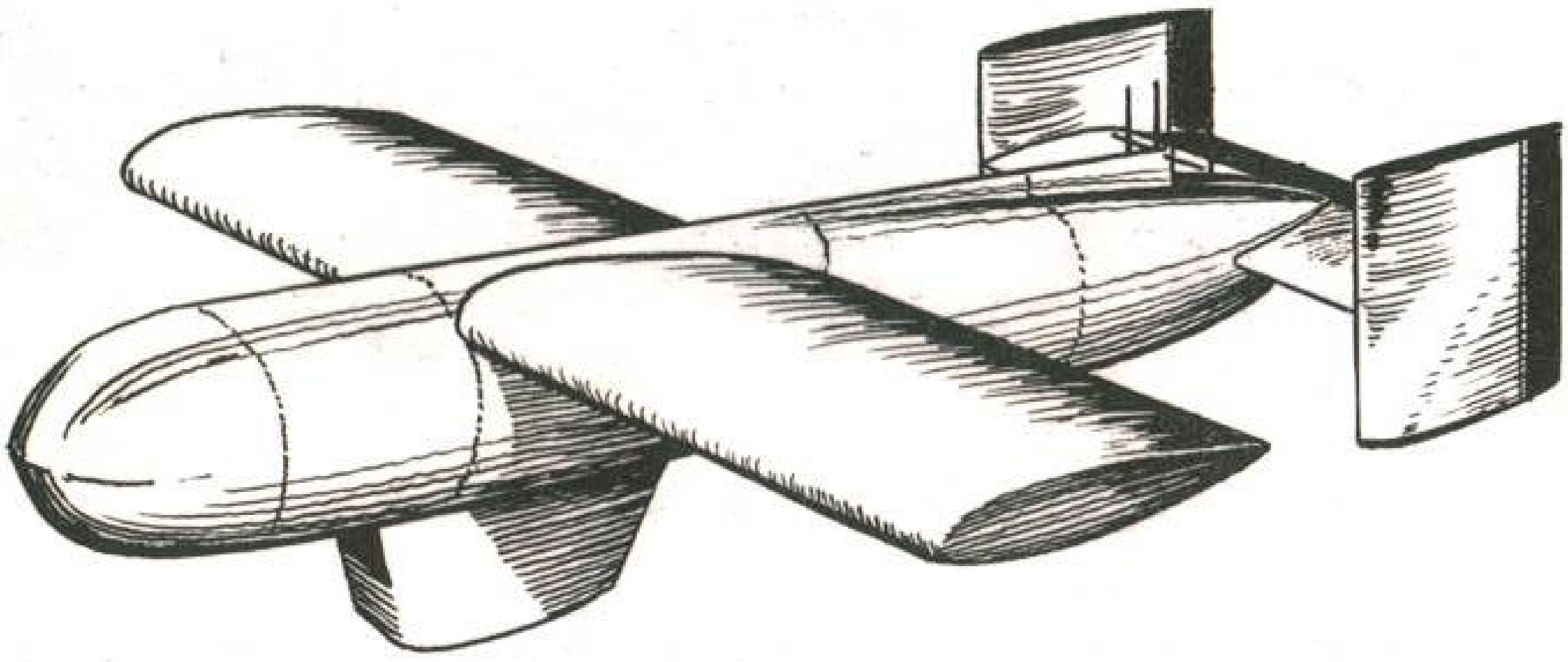

Figure 1 - American GB-4

Radio Command. Radio command of a target along the visual line of sight was used by both Germany and the USA. The German Fx-1400 (Figure 2), and Azon, which entered production in the USA in 1943, used this technique for azimuth control. When World War II ended, the USA still had Razon and Torzon under development: both used radio commands for range and azimuth control.

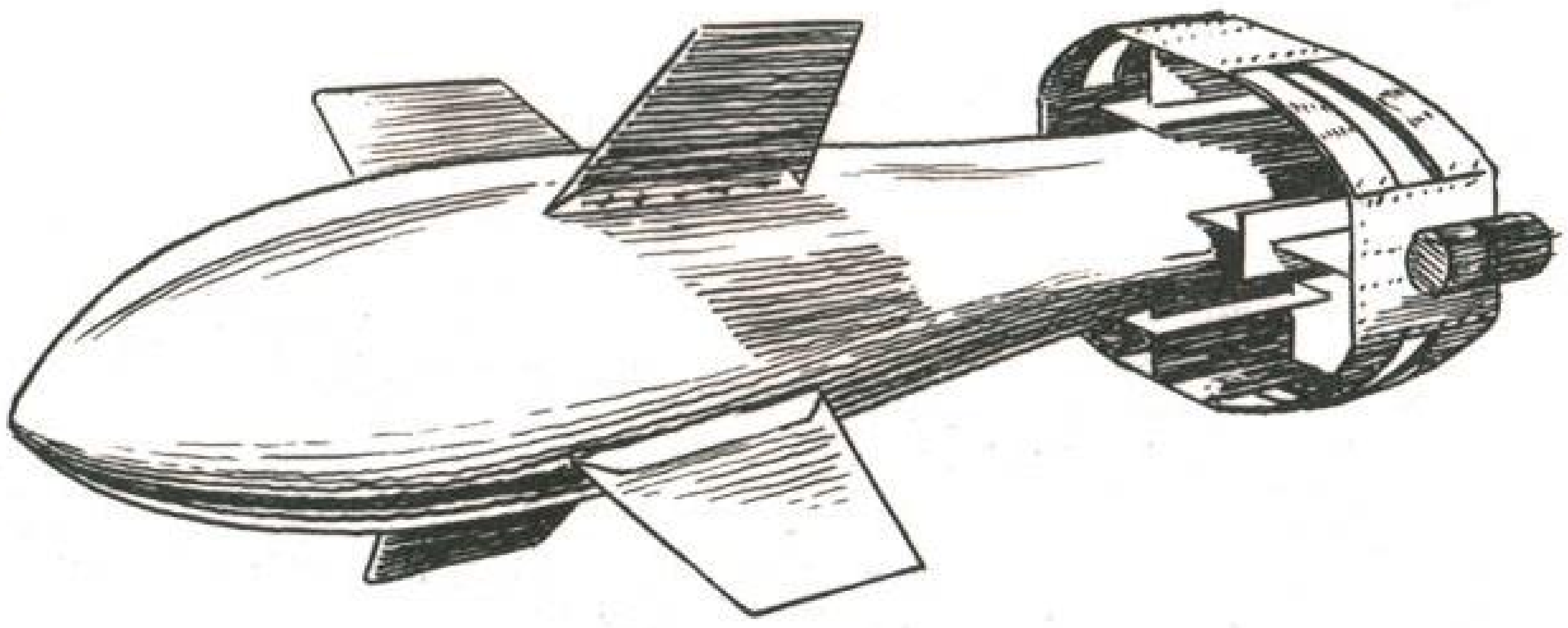

Figure 2 - German Fx-1400

Radar Homing. One of the first weapons employing radar homing was the Bat (or SWOD Mark 9, shown in Figure 3) developed for the US Navy. The Bat was a mono-wing glider containing a complete radar system which, when locked, tracked an isolated target automatically and guided the weapon into a collision with the target. This weapon saw only limited action against Japanese shipping, but was extremely satisfactory.

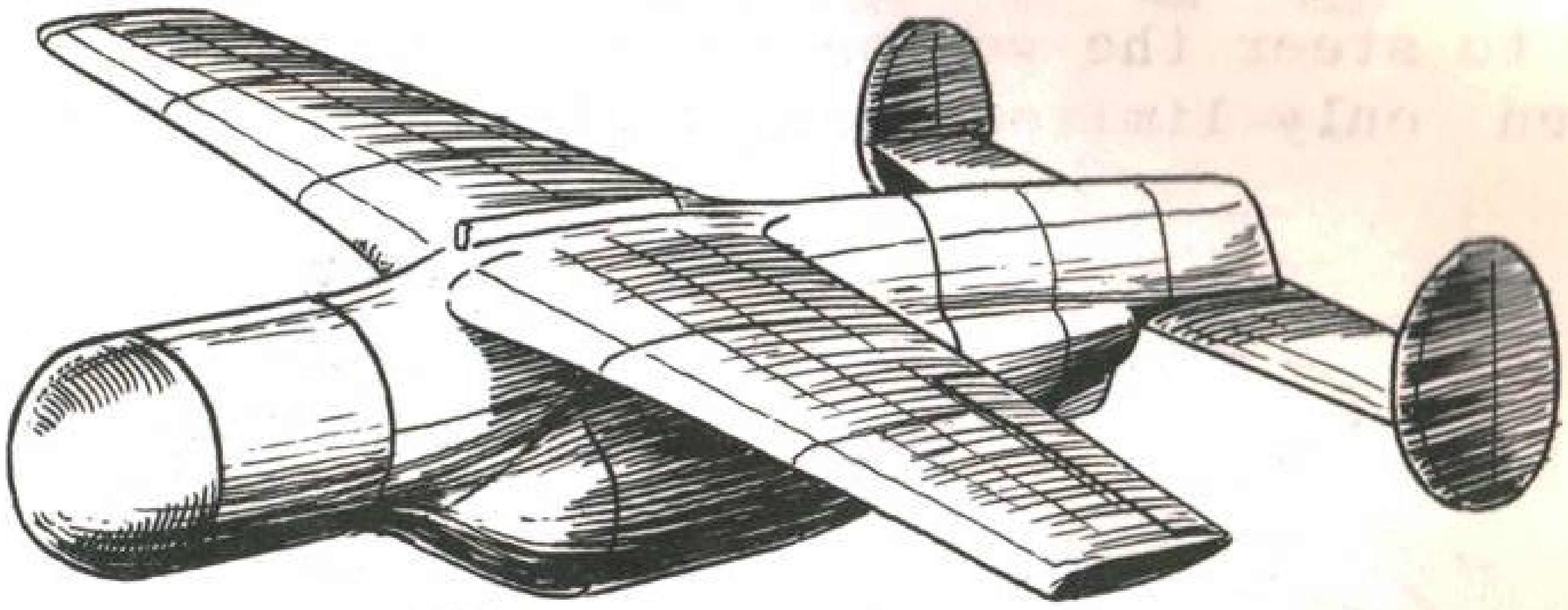

Figure 3 - US Navy Bat

Infra-Red. While infra-red guidance is not known to have been used during World War II, it was proposed for a USAF missile, the Felix. Man-made targets, such as steel mills and furnaces, are heat sources and transmit infra-red radiation to a greater extent than the earth's surface: the Felix detected this higher level of radiation to home onto the target.

German HS-293

The German HS-293 (Figure 4) was probably the first air-to-surface guided missile, under the present definition. While it was called a glide bomb, it was supple-

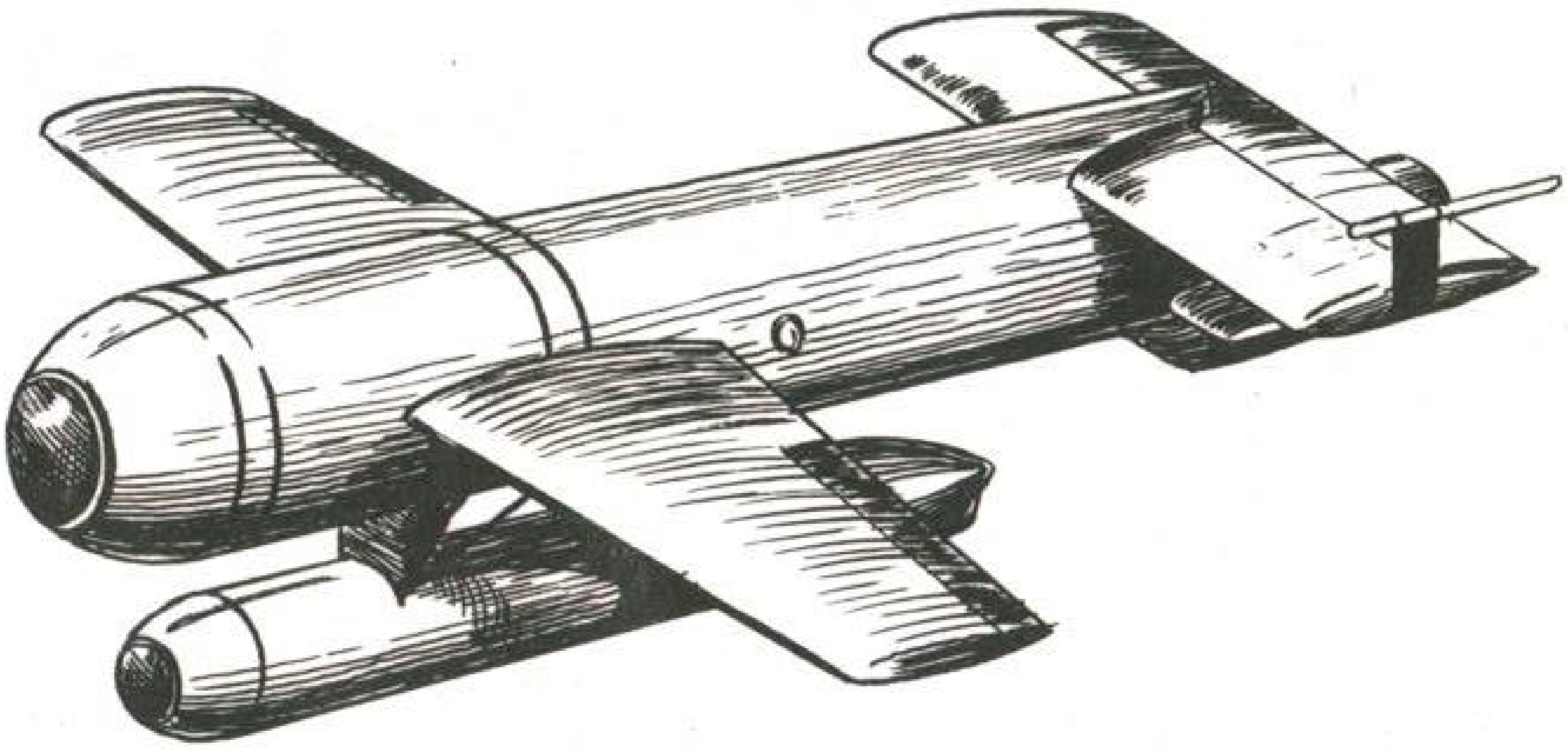

Figure 4 - German HS-293

mented by a liquid-rocket engine, giving it a speed of 350 mph, and was guided by radio command. The first report of its use was against a British convoy in the Bay of Biscay in August 1943, when a successful attack resulted.

Radio Command Guidance

In the air-to-surface command guidance system, the position of the missile is measured, relative to the target, through an optically-monitored system within the launch aircraft (Figure 5). Flight-path error is resolved in the launch aircraft and transmitted to the missile to correct its trajectory.

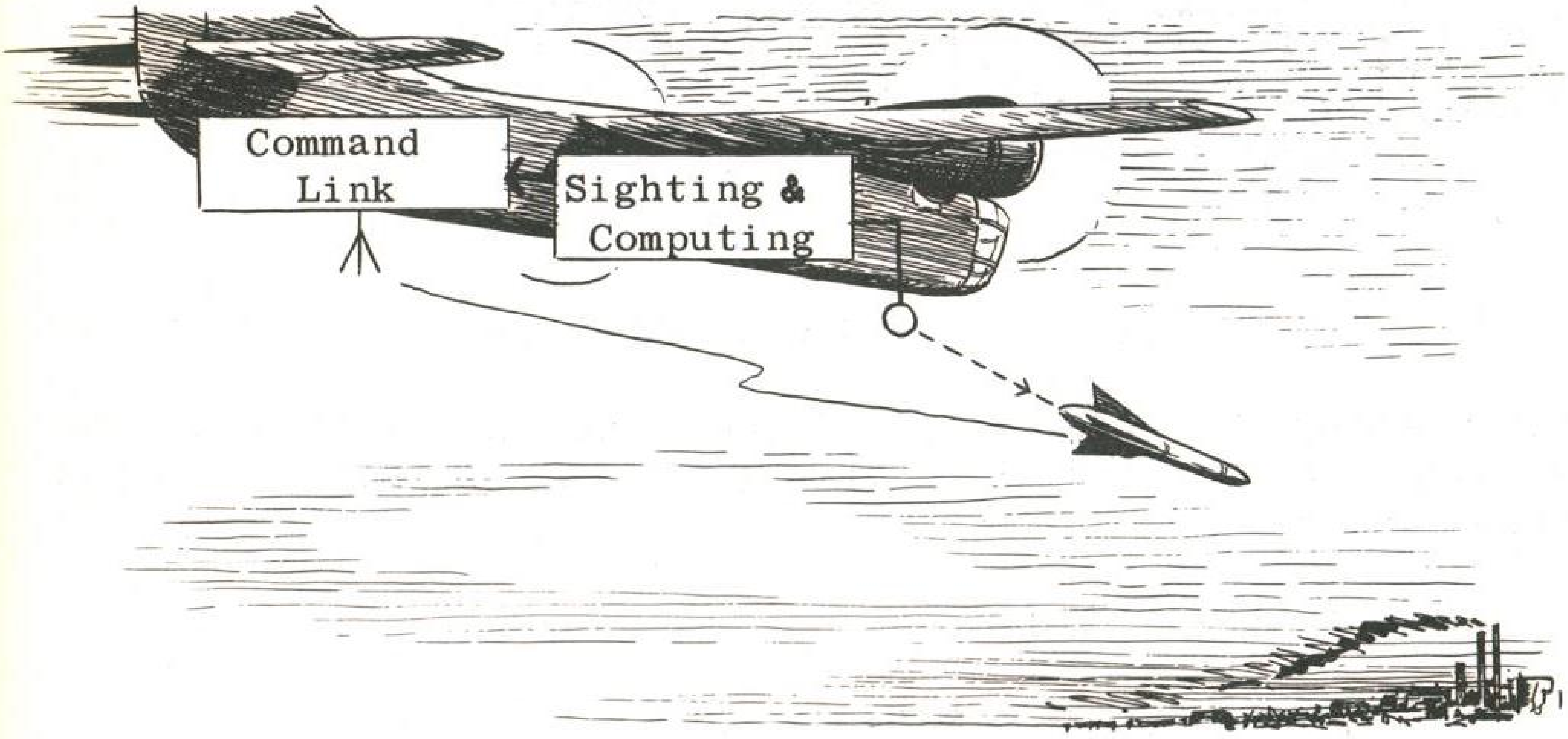

Figure 5 - Optical Radio-Command Guidance

In practice, missile deviation is normally resolved in cartesian coordinates, and the corrective information is transmitted to the missile by a radio link. The missile merely has a receiver and actuators which operate the control surfaces (Figure 6). Obviously, television or radar monitoring of either the target and/or missile could be used with equal success, but in many ways radar monitoring is most easily adapted to the role. The prime disadvantage of the technique lies in its range being limited to that of the radar horizon.

Homing Guidance

The "Glossary of Missile Terms" describes homing guidance as a self-contained system, activated by some dis-

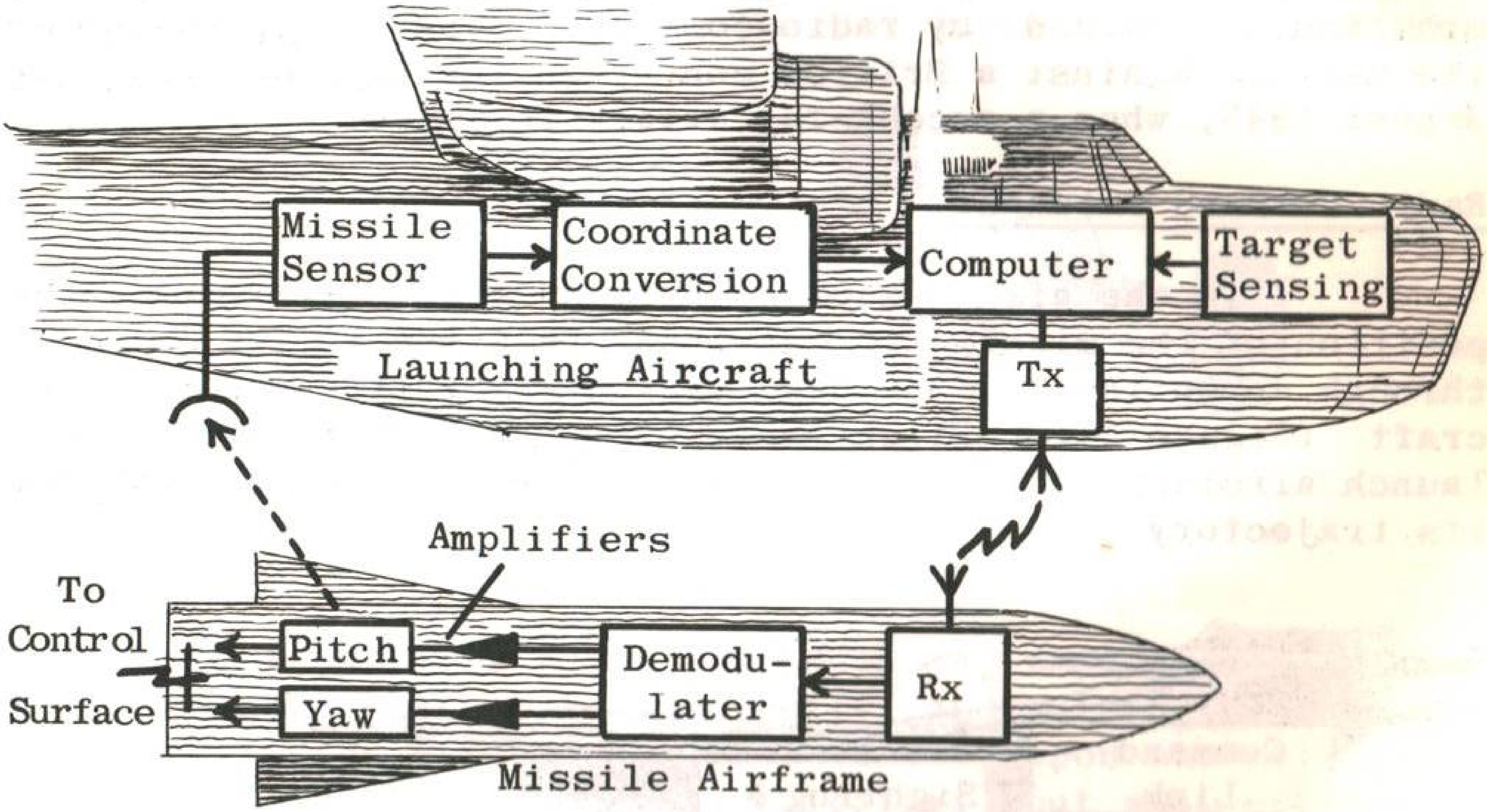

Figure 6 - Radio Command Link

tinguishing characteristics of the target so as to steer the missile to that target. This guidance classification has three general categories:

- Active homing
- Semi-active homing
- Passive homing

Active Homing

The simplest form of active homing guidance consists of a system to transmit energy, and a receiver to detect the presence of a target (Figure 7). The basic components of a guidance system of this type are the transmitter and receiver, a computer to predict the target's future position if it is moving, and the control-surface circuits. The system may use radio, heat, light, or sound waves, but the first is the most common. The advantage of this technique lies in the fact that after weapon release, the launch aircraft has complete freedom of manoeuvrability: a significant point if thermo-nuclear warheads are involved. This

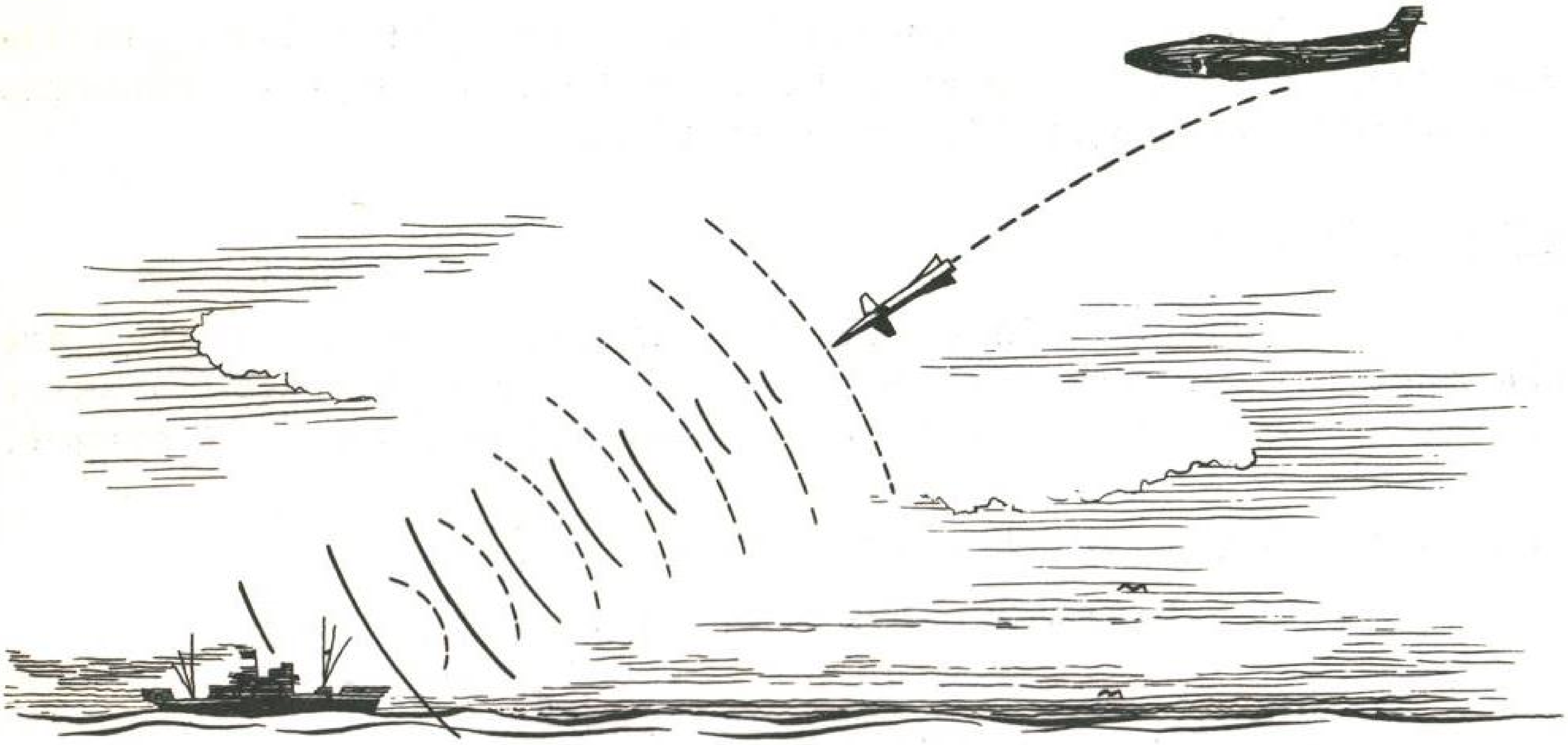

Figure 7 - Active Homing

advantage is, of course, offset by the large, complex guidance system.

Semi-Active Homing

The semi-active guidance system is very similar to its active counterpart, the difference being that the target is illuminated from an outside source, such as the radar in the launch aircraft (Figure 8). Except for the omission of the transmitter, the components within the vehicle are identical to those for the active missile.

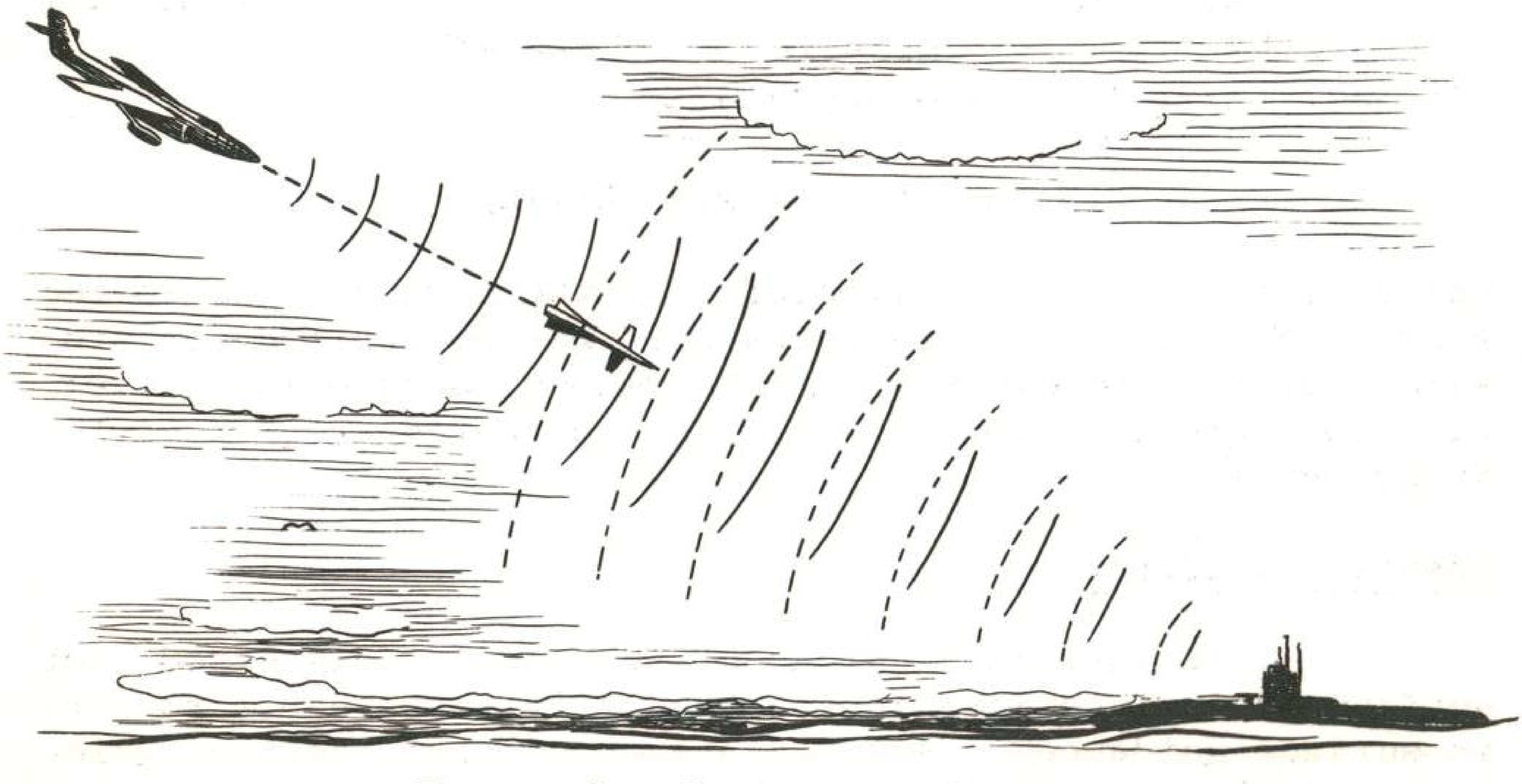

Figure 8 - Semiactive Homing

The main disadvantage of the system lies in the fact that the target must be illuminated by the launcher throughout the missile's time of flight.

Passive Homing

The components of the passive homing system are the same as for the semi-active type. However, the passive vehicle homes onto radiations emanating from the target, rather than on energy reflected from the target back to the source (Figure 9). This technique may be applied for missiles homing onto electro-magnetic emissions from the target, or onto thermal radiations in the infra-red region of the frequency spectrum.

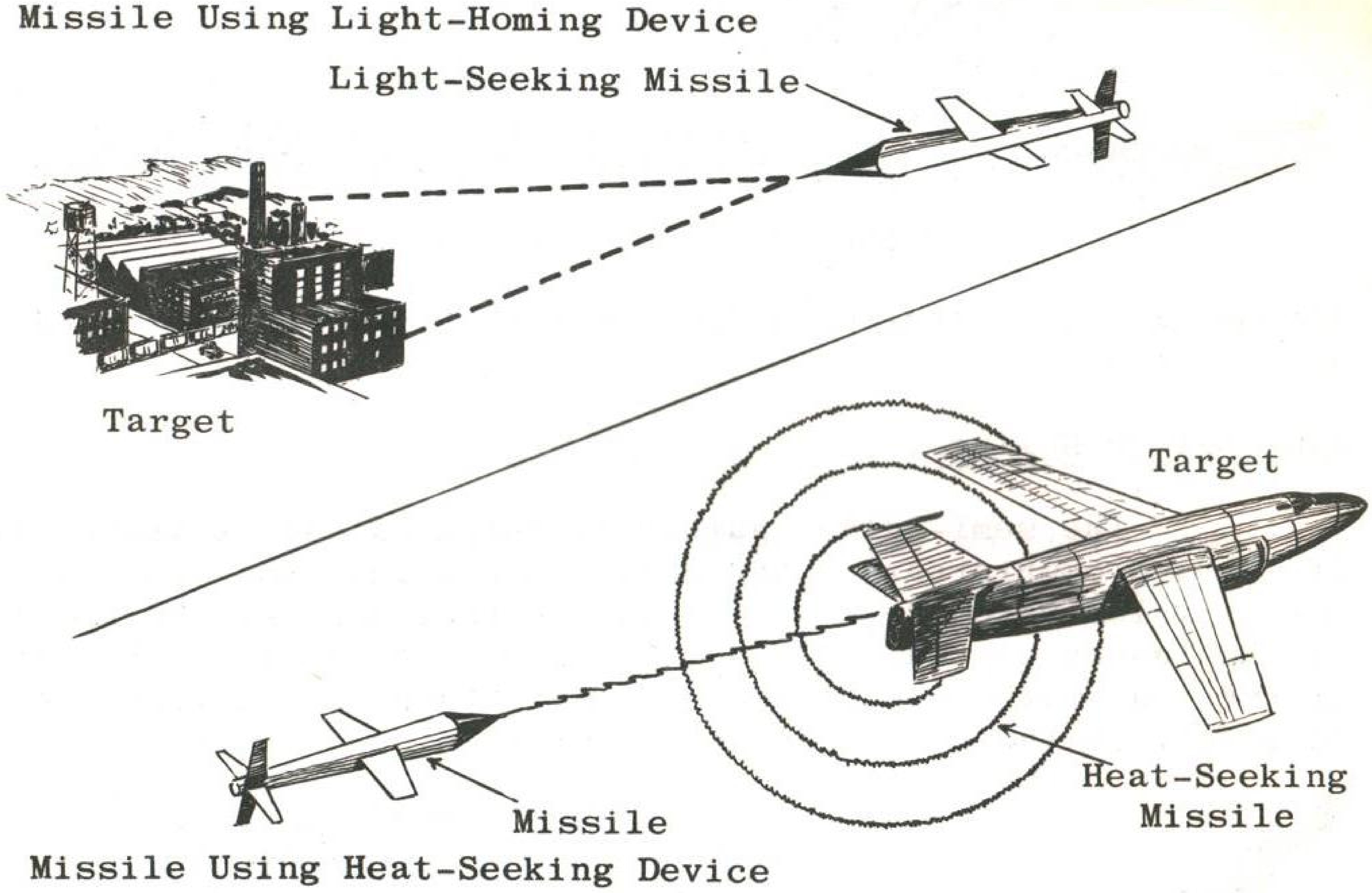

Figure 9 - Passive Homing

Inertial Guidance

The inertial guidance techniques discussed for surface-to-surface missiles* are equally applicable to air-to-surface guidance. The advantages of pure inertial guidance are:

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* RCAF Observer - Oct 58, Jan 59

- It is not limited by the radar horizon
- No emission is required from the missile
- The system is not dependent on target emission

The normal problems of component accuracy and pre-launching alignment, which have tended to prevent use of this technique in the past, still exist. Of the systems available, however, it is closest to the ideal.

The first example of a simple form of this type of guidance is the V-1 missile, which was air launched against Britain during the second phase of the V-1 campaign.

Conclusion

This article has briefly outlined the techniques used to guide air-to-surface missiles, and discussed some of the major limitations of these weapons. Their impact on air defence is particularly important because they have destroyed the concept of local defence; in fact, the advent of the long range, inertial-guided bomb makes even area defence difficult.

The next issue of the RCAF OBSERVER will contain the third article in this series, and will be concerned with surface-to-air missiles.

CASH SUGGESTION AWARD

A $1,000 cheque, largest ever awarded to a member of the RCAF for an original suggestion, was presented recently to S/L RS Burks for his improved aircraft compass calibration procedure. It has been estimated that this procedure, which has been adopted by the RCAF, will save many thousands of dollars a year. The procedure is described in S/L Burks' article, "Revised Compass Swinging Form", in the Jan 57 issue of the RCAF Observer.

COMET navigation

by
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Flying Officer LJ Halpin
412 (T) Sqn

Introduction

Before getting into the navigator's job on the Comet a few pertinent details of the aircraft may be of interest. The two being flown by 412 (T) Sqn are the same aircraft purchased in 1953 by the RCAF(the first military force in the world to own jet transports). Basically Comet 1's, they were extensively modified following the BOAC disasters and re-designated Comet 1A's. Leading particulars are:

Maximum All-up Weight(AUW)	117,000 lbs
Fuel Load	6950 Imp Gals (55000 lbs)
Maximum Flight Plan Endurance	6 hrs and 30 mins (with standard reserves)
TAS on climb and descent	310 K(Approx)
TAS on cruise	390 K(Approx)
Passenger capacity	36
Crew	6
Operating altitude	30-40,000 ft (dependent on AUW and temp)

Cabin altitude	8000 ft at 40,000 ft (8.25 lbs/in^2 max differential)
Limiting Mach(Normal)	.73 M (.77 Max)
Limiting IAS(Normal)	260 K (300 Max)
Engines	4 Ghost 50's of 5000 lbs static thrust each

The Comets are used mainly for special VIP transport flights, plus three scheduled flights per month to 1(F) Wing, Marville (longest stage length, Gander-Marville, 2304 nm). In addition, radar-testing and affiliated exercises with ADC are carried out.

Flight Planning

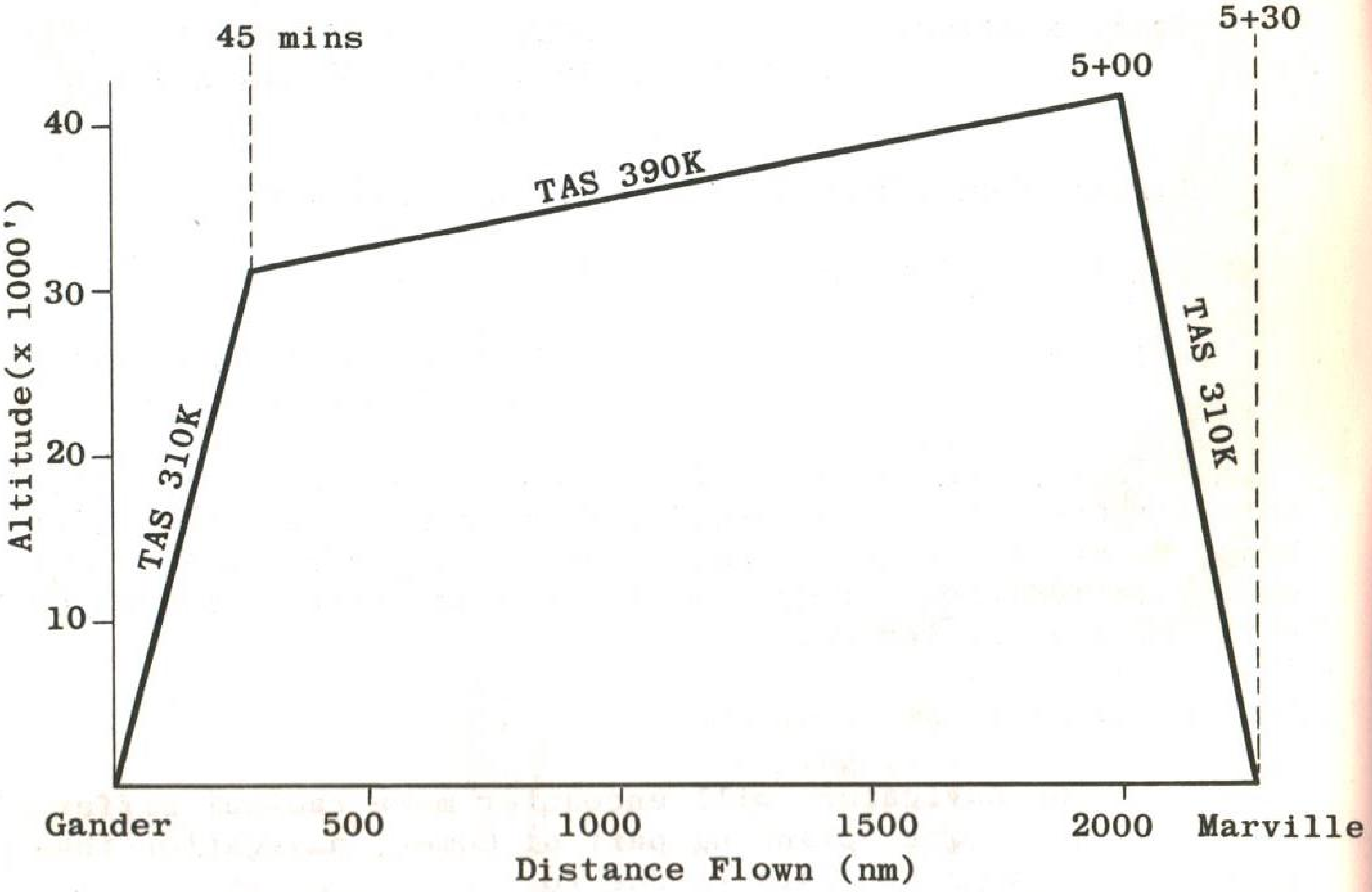
The navigator will encounter more radical differences in the flight planning part of Comet navigation than in any other aspect. This is due to:

→ The importance of carrying only sufficient fuel to safely carry out the flight.

→ The rate at which fuel consumption changes during flight. For example, an aircraft at maximum AUW would burn approximately 10,000 lbs of fuel during a 45 minute climb,would start the cruise consuming approximately 8500 lbs per hour, and near the end of a long cruise will be drawing less than 6000 lbs per hour, a reduction of nearly 50%.

To give an idea of how important it is that no excess fuel be carried, consider a Gander-Marville flight. If 1000 lbs extra fuel were loaded, only 650 lbs of this would be available for use, the other 350 lbs having been consumed in carrying the extra weight of fuel. For this reason,Comet flight plans are made in the reverse of normal order, starting at 1000 ft over the alternate, working back to 1000 ft over the destination, up through the descent, and finally back to take-off.

The following diagram gives an idea of the average speeds, heights, and times a Comet would show during a typical Gander-Marville flight (+50 K wind component assumed).



It will be noted that even during the cruise the aircraft is not at a constant height, a "climb-cruise" technique being employed; this will be discussed in more detail later.

Now for the actual steps involved in preparing a Comet flight plan:

- Determine the empty tank weight (the all-up weight of the aircraft including passengers and cargo, but with no fuel in the tanks).
- Having selected a suitable alternate aerodrome, enter the special short-range tables, and extract the weight of fuel required and time to proceed to alternate.
- To this alternate fuel add holding fuel, landing fuel, and a suitable reserve for forecast errors to obtain the total reserve fuel required.
- Add the weight of the reserve fuel to the empty tank weight to obtain the all-up weight of the aircraft at 1000 ft over destination. Use this weight in conjunction with air temperature (20000 ft) to extract from descent tables the fuel, time and TAS on descent to 1000 ft.

- Using the 20000 ft wind, calculate the descent distance.
- Using the wind component for 35000 ft estimate the approximate amount of fuel which will be burned on the cruise. It is now possible to estimate the aircraft weight at the top of the climb.
- Using this weight at the top of the climb in conjunction with the air temperature at 25,000 ft over the starting aerodrome, extract from climb tables the fuel, time and TAS for the climb, and calculate the climb distance using the 25000 ft wind.
- Subtract the climb and descent distances from the total to obtain the cruise distance.
- Using the average weight of the aircraft during the cruise, in conjunction with the air temperature at 35000 ft, extract the TAS from cruise tables.
- Calculate the time at cruise, and with this figure re-enter the cruise table to determine the cruise fuel.
- It is now possible to add up the total flight time and fuel required(reserve plus descent, climb, and cruise).

A "Howgozit" is constructed in more-or-less standard fashion. However, the critical point and PNR are obtained by a graphical solution on the Howgozit.

Cruise Control

Cruise control in the Comet is solely the navigator's responsibility. A very simple procedure of "climb-cruise" is employed, wherein the engine RPM remains constant and the TAS almost constant.

Indicated airspeed is continually varied, as the weight of the aircraft changes, in such a way that the TAS is a constant multiple of that TAS corresponding to minimum drag (Vmd). The multiple almost always used by 412 (T) Sqn is 1.3 Vmd.

Thus during cruise the navigator obtains a new aircraft weight from the flight engineer every 30 minutes, and passes to the pilot a corresponding reduction in IAS (as an average figure, the IAS normally decreases about 4 K every 30 minutes).

Under this system the aircraft seeks its own altitude according to the ambient air temperature. It will of course normally climb as the IAS and weight decrease, the gain in height balancing out the decrease in IAS to give an almost constant TAS. (Occasionally instances occur where, due to a large increase in ambient temperature, the aircraft will actually sink slightly during the "climb-cruise"; in these cases the TAS drops off correspondingly).

ATC clearances for the above type of flight are of course becoming increasingly difficult to obtain; this is particularly true on the North Atlantic route with the advent of commercial jet transports. Future flights will have to be conducted on either a level-cruise basis, or at least using a "step-climb" with 4000 ft intervals. Flight-tests are presently being conducted by the de Havilland Company in England to determine the fuel penalty which must be borne for these types of cruise.

Certainly flight-times will become less, but it is very doubtful if the Comet 1A will then have sufficient endurance to schedule flights on a regular basis over such stage-lengths as Gander-Marville.

Guidance

The navigation equipment presently installed in 412 Sqn Comets is indeed archaic for such a high-performance aircraft. Present aids are briefly discussed below, along with a few words on new equipment it is hoped will be installed in the near future.

Compasses

The Gyrosyn CL2 is the primary heading reference, with a P12 standby compass. This arrangement has proved entirely satisfactory, except for some serious P12 semi-permanent deviation of a large value, which was caused by lightning striking one aircraft.

Kollsman Periscopic Sextant

This must definitely be counted as the primary navigation aid of the Comet. Fortunately the cruise is normally carried out above all cloud, although this may be considered as only "warm comfort" on daylight, trans-Atlantic flights. Entirely satisfactory accuracies are being obtained whenever stars are available, in spite of the fact that acceleration errors are four times the magnitude encountered in aircraft such as the North Star.

Loran

The APN-9 set is installed, and up to the present has been virtually useless. The problem is almost certainly connected with the antennae available; obviously no trailing aerial is possible, and the present hook-up to the fixed HF antenna is definitely not satisfactory. Tests have been conducted using an antenna-matching unit, but still without success. RAF Comet II's have encountered the same problem, and recent reports indicate that the RAF has produced a modification to the HF system which alleviates most of the trouble.

Radio Compasses

Two Marconi AD 7092 Radio Compasses are installed, with master controls at the Navigator and R/O stations. On the whole this installation has proved fairly satisfactory; good bearings have been obtained at ranges exceeding 300 miles, and the radio compass must be counted the secondary navigation aid in the Comet. Consol has of course been of inestimable value on North Atlantic trips.

Radar Altimeters

An SCR 718 altimeter is carried,but climb-cruising naturally forbids the use of pressure pattern lines. In any event, returns at altitudes above 30,000 ft are, to say the least, uncertain.

Search Radar

The EK Cole E38 radar presently installed is most unsatisfactory except from a weather-detection point of view. Maximum range is only 40 nm, and with the downward tilt of only 10°, it is obviously impossible to bring the beam to bear on targets within this range.

API Mk 1

Served by an AMU Mk III, this instrument performs satisfactorily, but can be considered of little importance on the steady headings and constant true airspeeds at which the Comet normally operates.

Mach Meter

A standard Mach Meter in conjunction with an outside air temperature gauge is an entirely satisfactory method of obtaining TAS.

NEW AIDS

It is hoped that the coming year will see at least some of the following new aids installed:

Doppler

This is obviously the primary requirement. Apart from its value as a fixing-aid, it would be of great value in detecting and using jet streams using the "zero-drift" method.

Search Radar

The Bendix RDR-1 Search Radar is presently being installed, and will definitely be of great value. The chief advantage to be gained over the present equipment is the 150 nm range, normally an ideal figure at which to commence a descent. Also, a Cosec^2 facility should allow much better map-reading.

VOR

It has become increasingly apparent that to send an aircraft into the USA without VOR is just asking for trouble. Clearances out of major airports are becoming more and more "via Victor". VOR equipment will be installed soon.

Dectra

With the installation of a good Doppler set, this requirement may be superfluous. However, there is always the possibility that ICAO may adopt Dectra as the standard trans-Atlantic navigation aid,and may well require it for aircraft separation.

Conclusion

Navigating the Comet is certainly by far the most interesting work the writers have encountered. Flights are normally of fairly short duration, but the work is quite intense (a crew on a Marville flight is back in Montreal 50 hours after leaving,having flown some 7000 nm).

To stay within recognized track and time tolerances with groundspeeds often over 500 K is always a challenge on the North Atlantic, and will probably remain so even with the introduction of new aids. Quite decidedly this is the way to travel, and to work.

ROCKET PROPULSION

Part 2

by
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Central Navigation School

Part I of this article, in the previous edition of the RCAF OBSERVER, outlined the history of rocket propulsion and discussed the capabilities and limitations of the solid-fuel rocket motor. This second part will consider the liquid-fuel motor, including some of the different fuels and systems in use today.

LIQUID-FUEL ROCKETS

The liquid propellant rocket is a much more complicated apparatus than its solid-fuel counterpart. Its major advantage is its longer operating duration at high temperatures. This is attributable to both its larger fuel capacity and its cooled combustion chamber. In addition, the liquid propellant generally produces more thrust per pound of fuel. A further advantage is that the rocket motor may be operated intermittently.

Liquid-fuel rockets may be further classified by the type of propellant they use:

- Monopropellants, which are capable of releasing their chemical energy without the addition of an oxidizer.
- Bi-propellants, requiring the fuel and oxidizer to be stored separately.

Monopropellant Fuels and Motors

Monopropellant fuels are highly desirable because of the simplicity they afford in the rocket motors. Two of the monopropellants in common use are listed in Table 1 with some of their characteristics.

Monopropellant Fuel	Characteristics
Hydrogen Peroxide (H_2O_2)	Colourless Liquid Freezing Point 140°F Boiling Point 280°F Storage tanks must be glass, pure tin, pure aluminum, or stainless steel Risk of explosion if impurities present Burns skin on contact in 70% - 90% concentration Deteriorates in storage
Nitro-Methane (CH_3NO_2)	Colourless Liquid Freezing Point 190°F Boiling Point 214°F Slightly Toxic Non-corrosive

Table 1 - Monopropellant Liquid Fuels

Monopropellants are stable (do not decompose easily) under ordinary conditions of temperature and pressure. However, when activated by some initial ignition system, monopropellants decompose, releasing gases at high temperatures and pressures as by-products. Large variations of atmospheric pressure and temperature may make the propellant unstable and susceptible to explosion, which is a most undesirable characteristic.

The monopropellant motor is a very simple device. In its most basic form, using hydrogen peroxide, it would operate as depicted in Figure 1. The H_2O_2 is injected into the combustion chamber, where it comes in contact with the catalyst, $KMnO_4$. Instantaneous ignition (hypergolic ignition) produces superheated steam and oxygen, which are accelerated out of the motor nozzle as the propelling mass. In order to eliminate the necessity of storing a liquid catalyst, a solid catalyst such as silver can be built into the combustion chamber (Figure 2). The Specific Impulse (Isp) of monopropellants is usually low because of the relatively low chamber temperature, and they are used only where simplicity of construction is the overriding consideration. The lower chamber temperature does permit longer burning times without cooling the combustion chamber. Monopropellant motors are used mainly in RATO units.

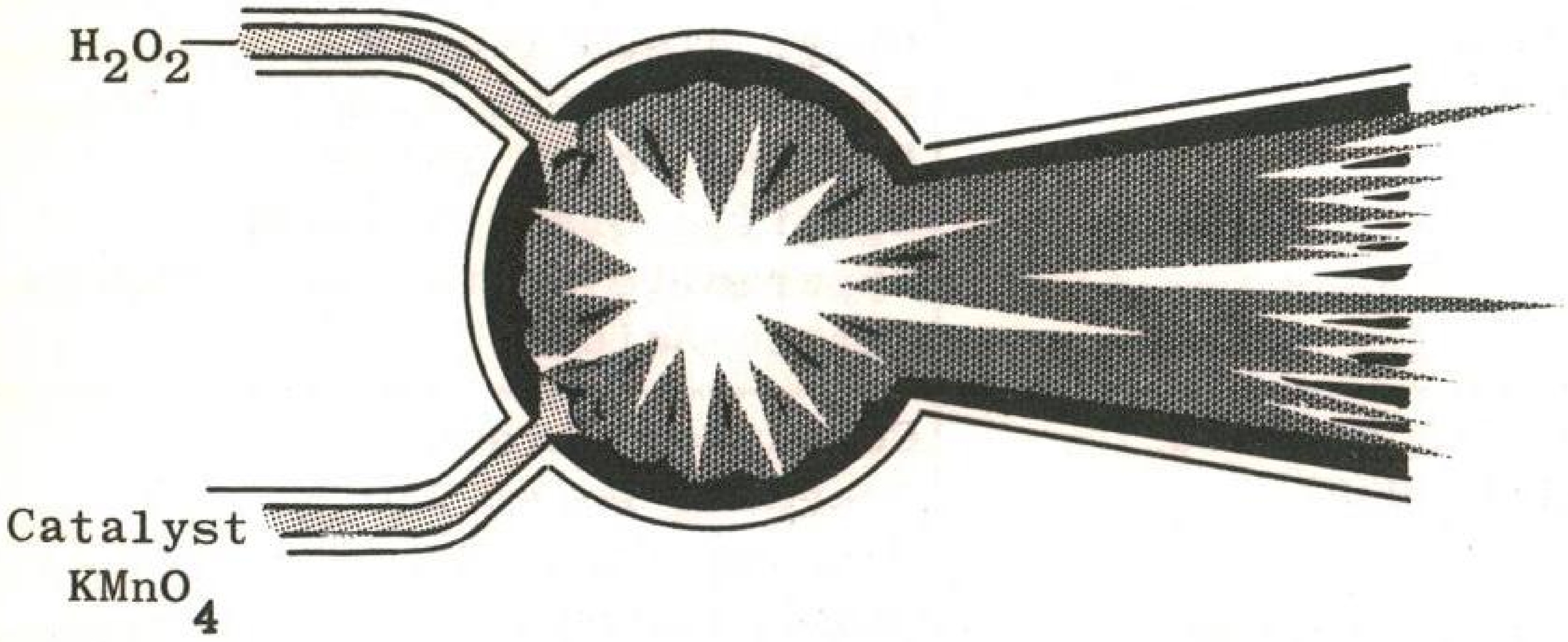


Figure 1 - Liquid Catalyst Monopropellant Motor

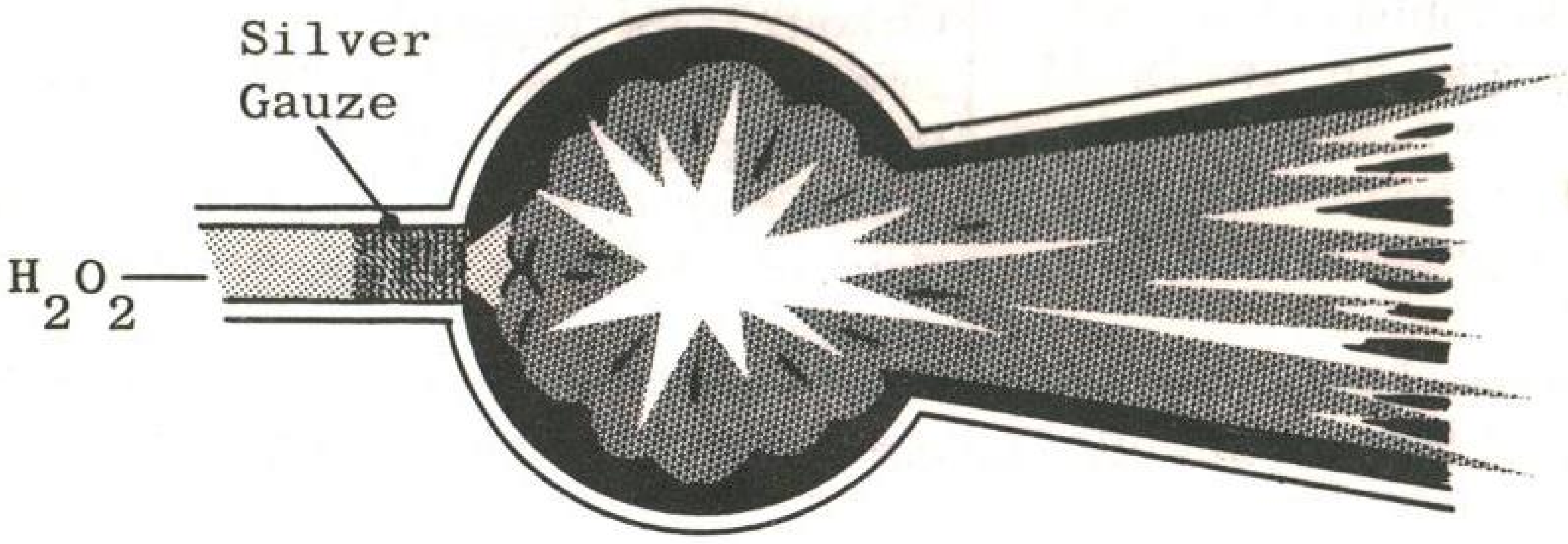


Figure 2 - Solid Catalyst Monopropellant Motor

Bi-propellant Fuels

Bi-propellant liquid rockets carry their propellant mass, an oxidant and a fuel, in two separate storage tanks. The two liquids are sprayed into the combustion chamber, where ignition takes place. The liquids used as fuels would, if chemically analyzed, display a high content of carbon and/or hydrogen. Table 2 lists some of the present fuels and their characteristics.

Bipropellant Liquid Fuel	Characteristics
Anilene ($C_6H_5NH_2$)	Oily, clear liquid Freezing Point 21°F Boiling Point 363°F Specific Gravity 1.022 Hypergolic with Red Fuming Nitric Acid
Hydrazine Hydrate ($N_2H_4.H_2O$)	Colourless Liquid Freezing Point -40°F Boiling Point 242°F Ammonia Smell Corrodes all containers except stainless steel or glass Explosive if gaseous concentration with air greater than 25% Irritates skin and attacks mucous membrane Hypergolic with Hydrogen Peroxide.
Ethyl Alcohol (C_2H_5OH)	Colourless Liquid Freezing Point - 178°F Boiling Point 173°F Specific Gravity less than 1.0 Toxic only in large internal doses

Table 2 - Bi-propellant Liquid Fuels

Some other fuels in use are gasoline and kerosene. These would be more common in mixed-powerplant aircraft where kerosene could act as the fuel for both a rocket and a turbojet engine. Such may be the case with the proposed DeHavilland mixed-powerplant, interceptor aircraft.

Some of the most common oxidants in use are liquid oxygen, hydrogen peroxide, and acids. Liquid oxygen is an excellent oxidizer, supporting combustion with almost all substances. It does have an extremely low boiling point, -297°F, resulting in an appreciable loss when in storage or while preparing a rocket for launching. The V-2 rocket had an evaporation rate of 4.4 lbs per minute, making it necessary to constantly retop the tank while preparing to launch. It is easy to handle and non-toxic, but will cause severe burns (as does dry ice) on contact with the skin. Although non-corrosive, it chills the rocket's plumbing to the point where water vapour freezes on the pipes, and thus there is a danger of valves sticking.

Hydrogen peroxide has already been discussed as a monopropellant. It is used as an oxidant because upon decomposition of 90% H_2O_2, approximately 42% of the product is gaseous oxygen.

Some of the acids with large quantities of oxygen may be decomposed to provide the necessary oxygen for combustion. One of these is white fuming nitric acid (WFNA), which consists of concentrated nitric acid (HNO_3) plus 2% water. Red fuming nitric acid (RFNA) is the most frequently used and most powerful of all the acids. It consists of concentrated nitric acid in which nitrogen dioxide (NO_2) is dissolved. It varies in color from orange to brick red: the name is derived from the red fumes of the nitric oxide. It is easily obtained because of its commercial use in explosives and fertilizers. RFNA is highly corrosive, and stainless steel is necessary for tanks and delivery pipes. The fumes are extremely poisonous, and severe burns result from direct contact with the liquid. It gives up approximately 63% of its oxygen when it is used with aniline. Another acid oxidant is mixed acid, composed of concentrated nitric acid (HNO_3) and a small amount of sulphuric acid (H_2SO_4).

If it were possible to have an ideal propellant, the most desirable characteristics it could have would be:

→ High calorific heating value per unit propellant

→ High specific gravity (more fuel in less space)

→ Low molecular weight of gas products of combustion

→ Ease of storage and handling, with no deterioration while in storage

→ Hypergolic (spontaneously ignitable)

→ Low toxicity and corrosiveness

→ Low FP and high BP

→ High thermal conductivity, so that it might be used as a chamber coolant

These conditions for an ideal fuel have not been realized, but continued research will undoubtedly produce fuels more closely approximating the ideal.

Specific Thrust (Tsp)

As with solid propellants, there must be some means of comparing liquid fuels. In the case of the liquid propellant, Tsp rather than Isp is used. Tsp is defined as the thrust produced when the propellant is consumed at one pound per second. Mathematically it can be stated:

$$Tsp = \frac{T}{W}$$

Where:

Tsp = Specific Thrust in lbs/lb/sec

T = Thrust in lbs

W = Weight rate of flow in lbs/sec

It may be of advantage at times to compare the propellant flow to develop one pound of thrust. This term is Specific Propellant Consumption (SPC), and is the reciprocal of Tsp.

Liquid-Fuel Motors

There are two basic types of liquid rocket motors: the pump-fed, and the pressure-fed.

Pressure feed systems may be sub-divided into stored-pressure systems and generated-pressure systems. The stored-pressure system has an integral tank for pressurizing the fuel tanks, thereby forcing the fuel into the combustion chamber (Figure 3). The disadvantage of the stored-pressure system is that the pressure forcing the propellant into the combustion chamber falls off as the propellant is consumed, and the rate of propellant flow therefore decreases. As a result, the system is suitable only for smaller rockets. In an attempt to eliminate this disadvantage, the generated-pressure system was designed. It consists of a pressure-

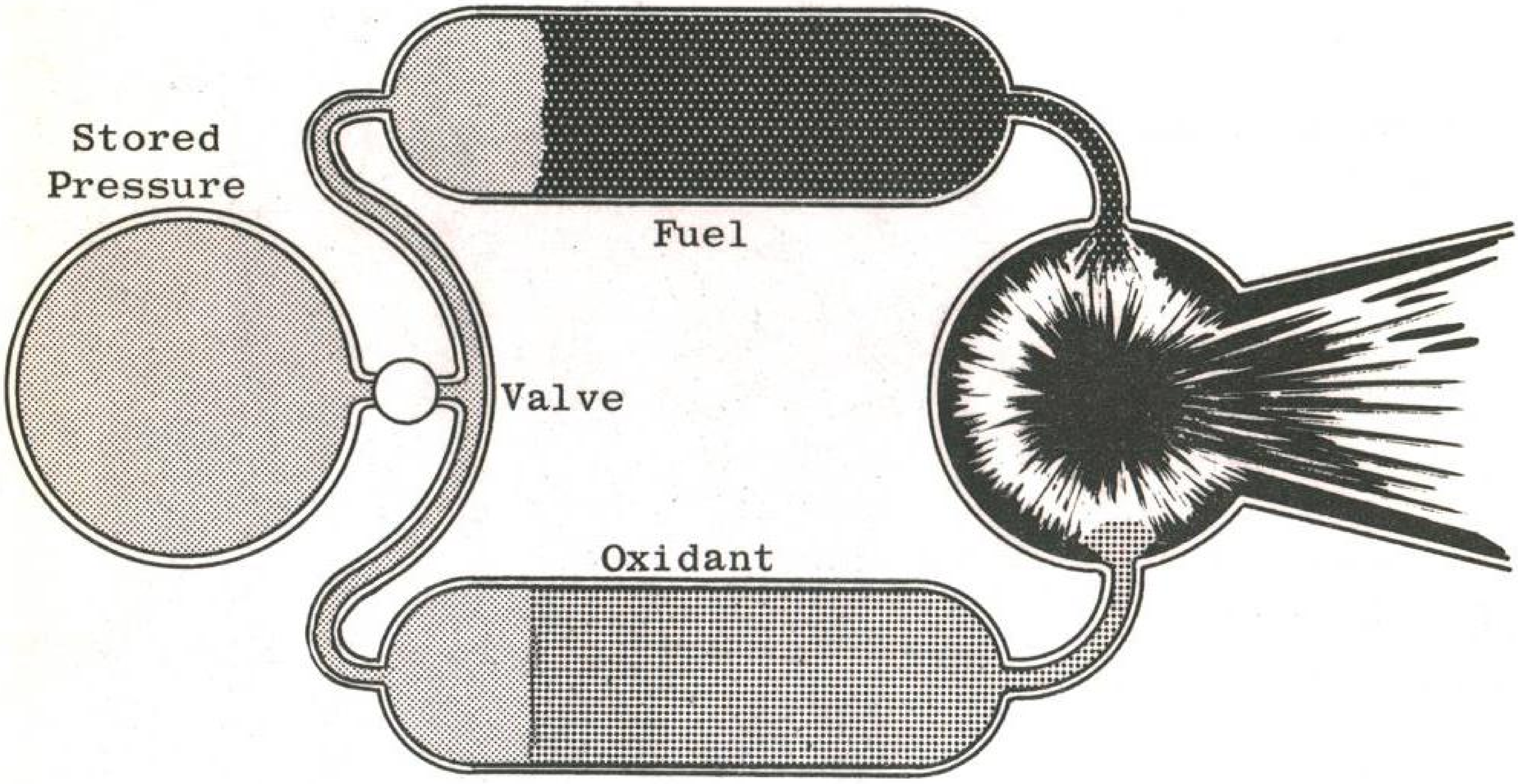


Figure 3 - Stored-Pressure System

producing steam generator, which is in effect a small mono-propellant motor using H_2O_2 (Figure 4).

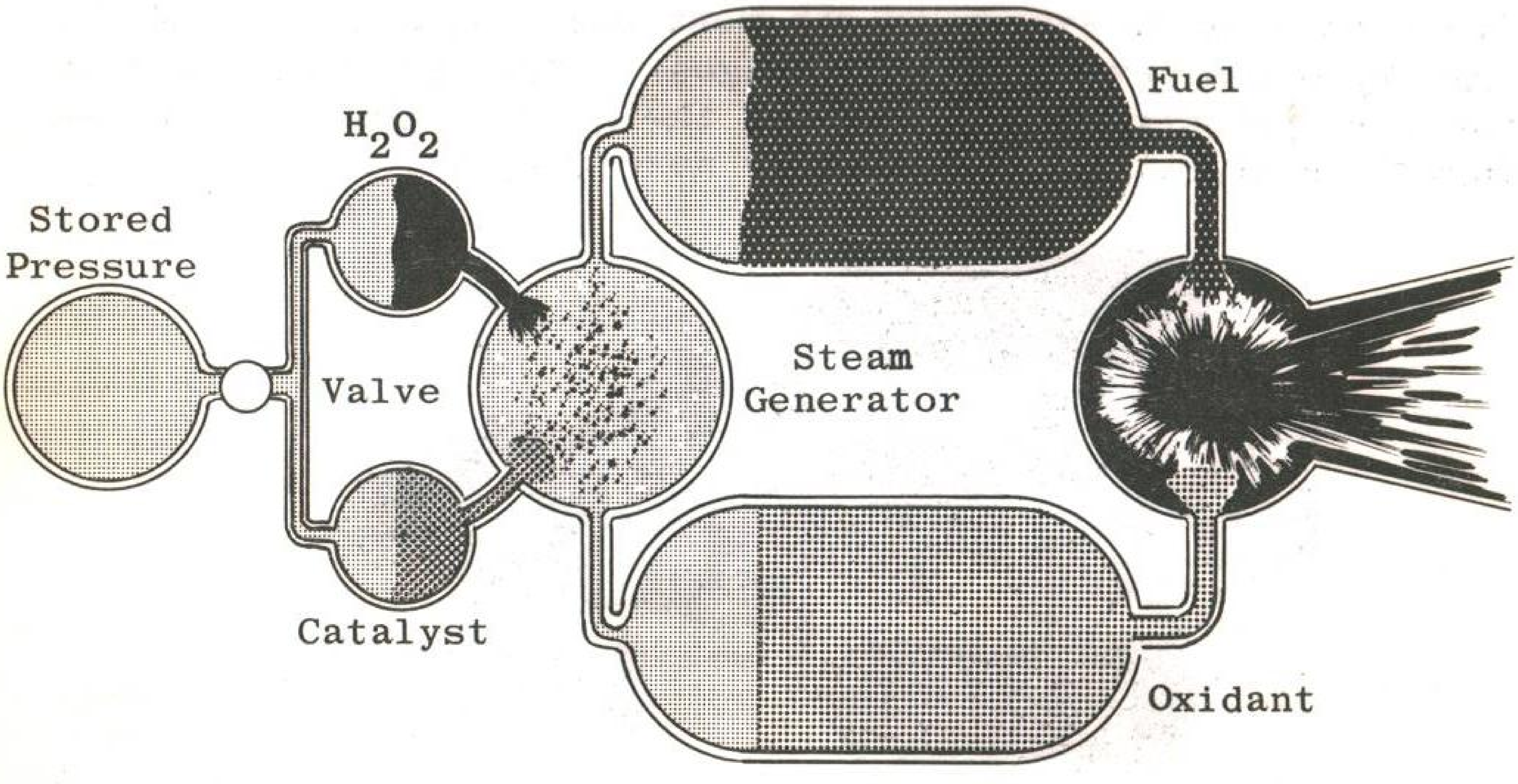


Figure 4 - Generated-Pressure System

21 SORI

F/L WH Stockdale

F/O GS Gillespie

F/O DK Schneider
(Course Director)

F/O WW Mazey

In larger rocket motors a pump system is necessary to meet the larger propellant flow requirement, because a pressurized system would involve excessively heavy tanks and plumbing. Figures 5 and 6 illustrate two pump-feed systems. The turbine-pump system is the most popular, since the turbo-pump type has several disadvantages. The major one is that the straight, rear-ward flow of the exhaust gases is interrupted; also, it is mechanically more complex.

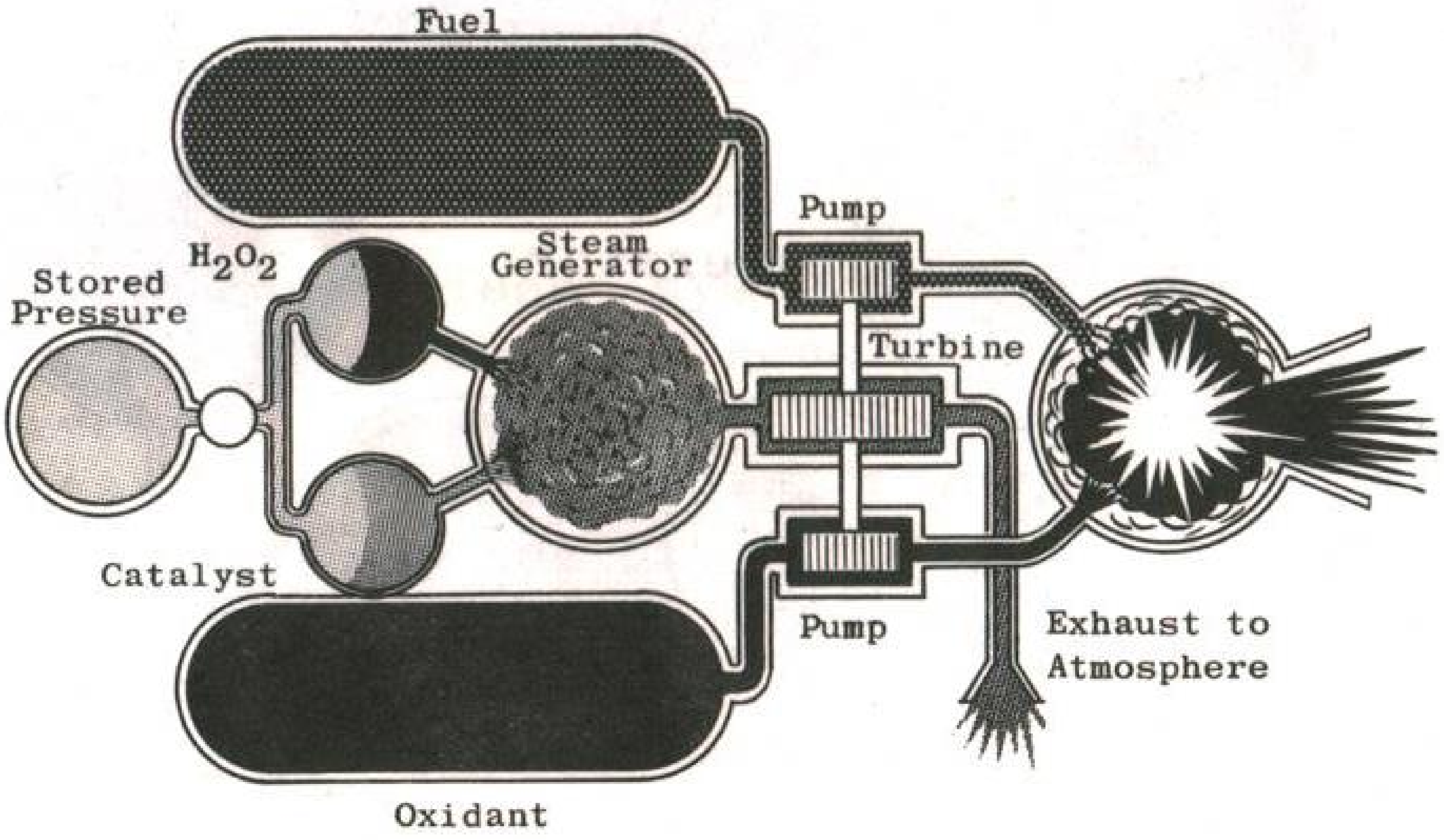


Figure 5 - Turbine-Pump System

35 SONI

Back Row

F/O JAJS Boutet
F/O AM Melville
F/O JA Procter
F/O KG Wright
F/O IPC Sherlock
F/O DH Lewis
F/O GN Friesen

Front Row

F/L LHC Saunders
F/L MS Slezak
(Course Director)
F/O GAD Wilson

Motor Cooling Systems

Because of the tremendous heat generated, it is necessary to cool the combustion chamber (particularly the throat) if sustained operation is desired. There are three common methods of achieving this necessary cooling action: regenerative cooling, film cooling, and sweat cooling.

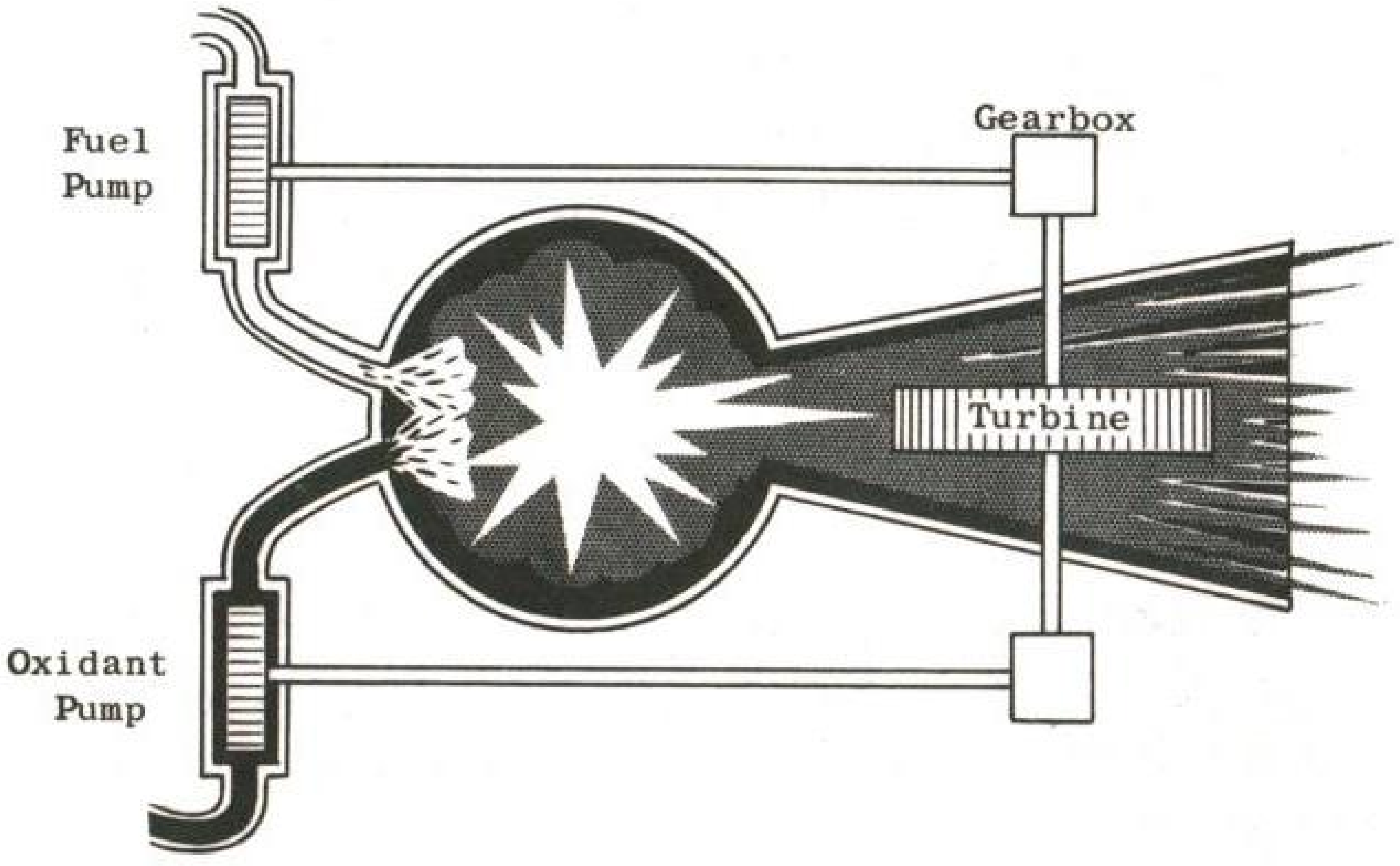


Figure 6 - Turbo-Pump System

In the regenerative cooling process, either the fuel or the oxidant is circulated between the hollow walls of the combustion chamber prior to combustion. The propellant absorbs much of the heat, which also makes the combustion process more efficient (Figure 7).

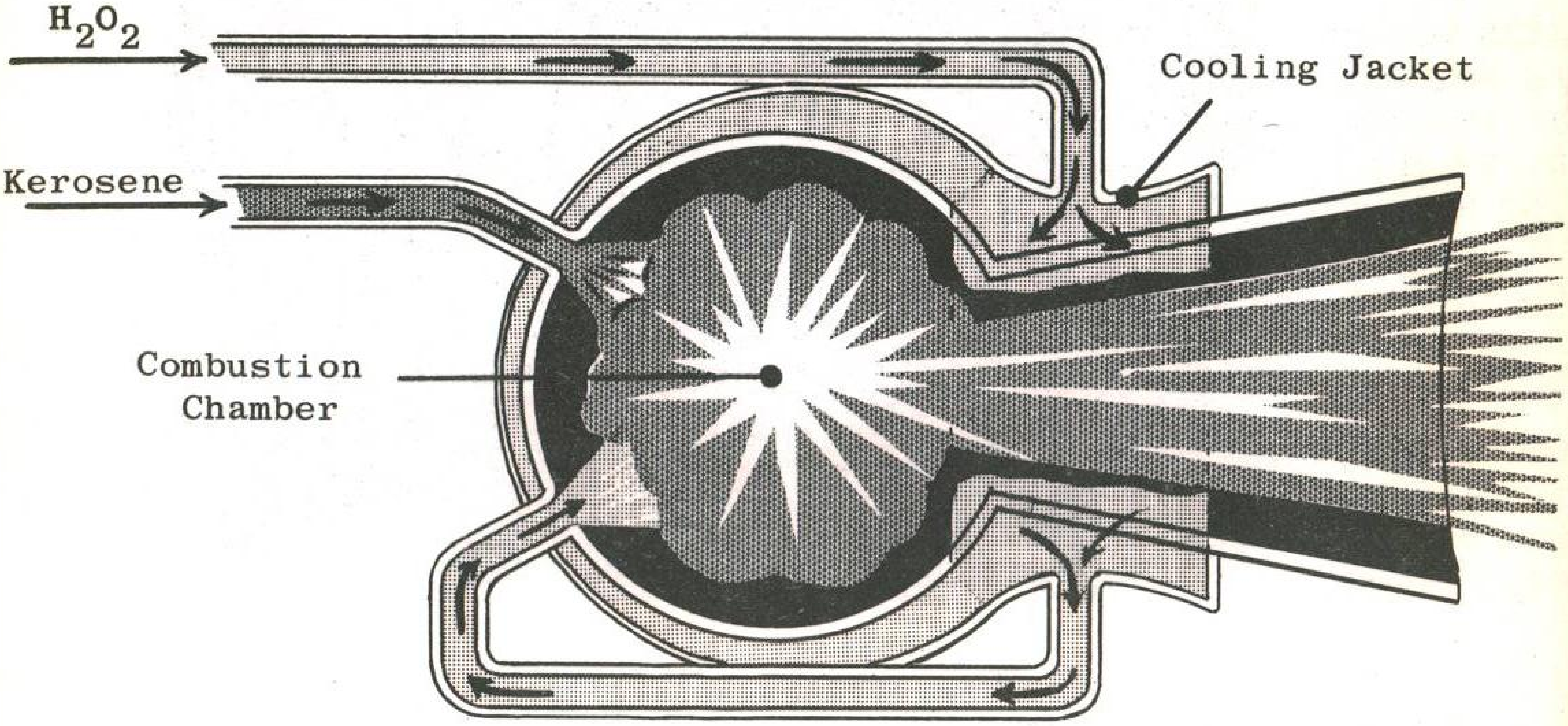


Figure 7 - Regenerative Cooling

The film cooling method consists of injecting the fuel or the oxidant,at a low velocity, at hot spots. Cooling is effected by the evaporation of the fluid. This fluid, if fuel, will not normally burn because of the lack of an oxidant. However, when the fluid leaves the motor it may ignite and produce the large "flame tail" often associated with liquid rockets. Sweat cooling is a method similar to film cooling, except that the complete inner liner of the combustion chamber is porous. The use of this porous material results in low structural strength and added complexity.

Comparison of Propellants

There are two general categories of fuels: low energy and high energy. High energy fuels are those with an Isp greater than 250. Table 3 lists some liquid propellants and their characteristics, which may be compared to the solid propellant details given in Part I of this series.

Propellant Oxidizer and Fuel	Mixture Ratio Oxidant/Fuel	Chamber Pressure lbs/in^2	Chamber Temp. °F	Exhaust Velocity ft/sec	Specific Thrust
Liquid Oxygen and Liquid Hydrogen	5.33	340	5,430	10,800	335
Liquid Oxygen and Hydrazine	0.50	300	4,500	8,350	259
Liquid Oxygen and Ammonia	1.4	300	4,950	8,220	255
Liquid Oxygen and 100% Ethyl Alcohol	1.5	300	5,250	7,810	243
Liquid Oxygen and Gasoline	3.0	300	5,470	7,780	242
Liquid Oxygen and 75% Ethyl Alcohol, 25% water	1.3	300	5,080	7,700	239
Gaseous Oxygen and Nitromethane	0.05	270	4,500	7,300	227
Red Fuming Nitric Acid and Aniline	3.0	300	5,020	7,090	221
Nitromethane	--	300	3,950	7,010	218
White Fuming Nitric Acid and Furfural Alcohol	1.9	300	5,020	6,890	214
Hydrogen Peroxide, 87% pure, plus water	--	300	1,310	4,060	126

Table 3 - **Propellant Performances**

Final Weight vs Final Velocity

The formula for calculating the final velocity of a rocket is:

$$Vf = Ve \,.\, \log_e \frac{\text{Original Mass}}{\text{Final Mass}}$$

Where:

Ve = Initial Velocity in ft/sec

Vf = Final Velocity in ft/sec

$$\frac{\text{Original Mass}}{\text{Final Mass}} = \text{Mass Ratio in lbs}$$

It is obvious from the equation that the smaller the final mass, the higher the final velocity will be. This is the reason for making components as light as possible. An increase in final velocities can be achieved only by increasing the mass ratio, or by employing higher energy fuel. An example of how the mass ratio affects the final velocity will serve to illustrate the importance of a low final mass.

Consider a rocket with an initial velocity of 2000 ft/sec, an initial weight of 6,440 lbs, and a final weight of 2,220 lbs:

$$Vf = Ve.\log_e \text{Mass Ratio}$$

$$Vf = 2000 \times 2.3026 \times \log \frac{\frac{6440}{32.2}}{\frac{2220}{32.2}}$$

$$= 2000 \times 2.3026 \times \log \frac{200}{69}$$

$$= 2{,}128 \text{ ft/sec}$$

If the final weight were reduced by 610 lbs (approximately 27% of the previous final mass), the final velocity would be:

$$Vf = 2000 \times 2.3026 \times \log \frac{\frac{6440}{32.2}}{\frac{1610}{32.2}}$$

$$= 2{,}770 \text{ ft/sec}$$

This represents a 30% increase in the final velocity, amounting to an additional 369 mph. Thus the most important fact illustrated by the formula is that the same result (higher final velocity) can be achieved by decreasing the final mass of a rocket, as by increasing the Tsp of the fuel. Solid propellants, which generally have a lower Isp than liquid propellants, may therefore be capable of producing higher final velocities, because heavy pressurizing equipment and plumbing is not necessary.

Solid vs Liquid Propellant

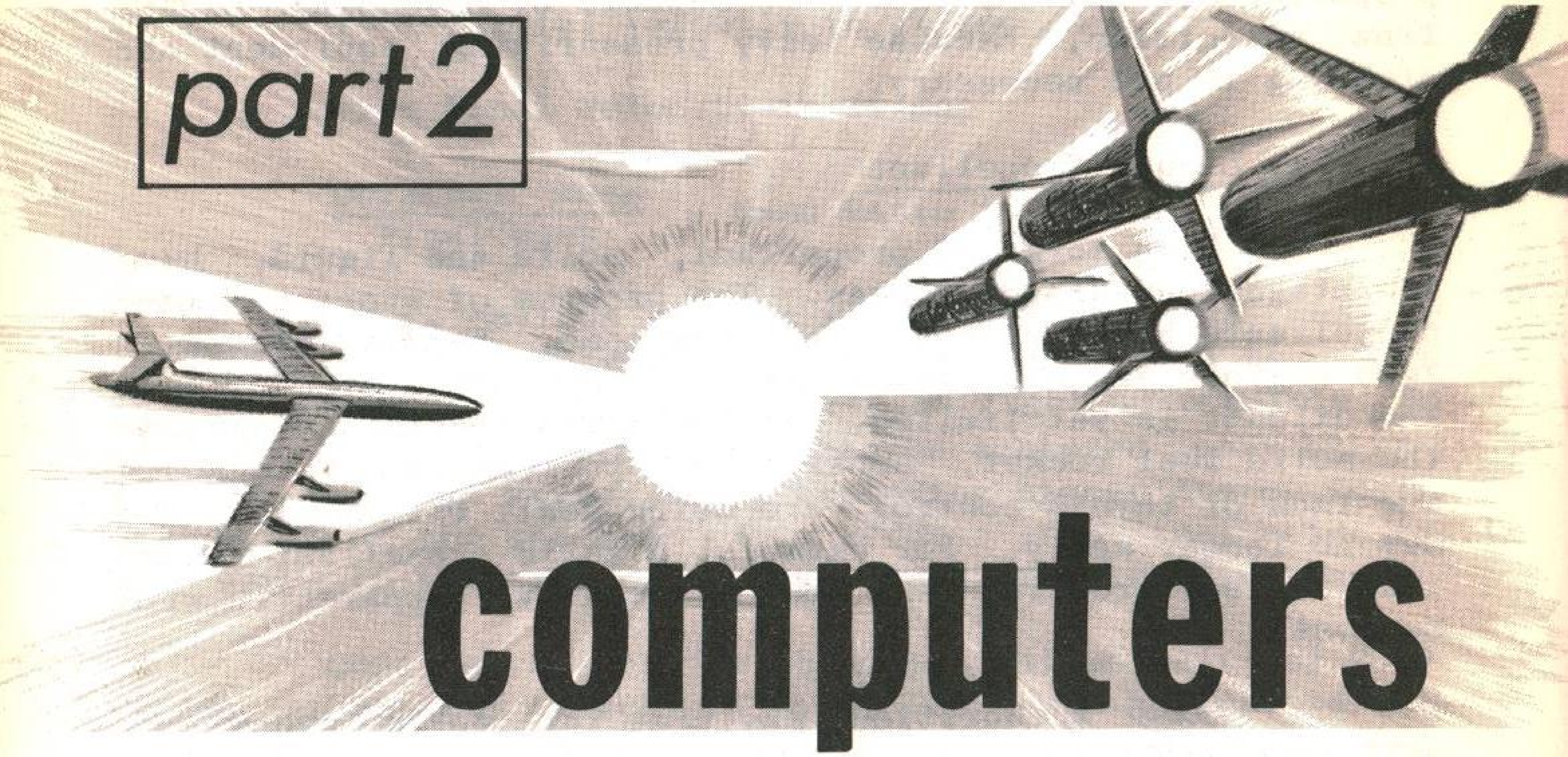
Both forms of propellant, solid and liquid, have advantages and disadvantages. The problem of storing liquid propellants has apparently been overcome, because pre-packaged engines are now advertised, although the choice of fuel and oxidant is yet limited. The two major complaints against the solid fuel rocket, sensitivity to temperature changes and lack of thrust control, are being dealt with rapidly and may no longer apply. For example, a solid propellant rocket that can be throttled was tested recently, apparently with success.

Some authorities say that the solid propellant will eventually replace the liquid, even in larger missiles, because it produces a higher mass ratio and is less complex. The individual missile's purpose may dictate the propellant to be used: the Polaris IRBM uses a solid propellant partly because it would be next to impossible to fuel a missile with dangerous liquids while at sea.

Conclusion

In the search for more efficient propulsion for space vehicles, new techniques are being evolved. One of these is a motor which accelerates ionized gases in a magnetic field to produce thrust. Undoubtedly, nuclear and thermonuclear devices will be developed to replace present conventional fuels.

This article has been a very simple introduction to rocket propulsion. It can serve only as a background for following the developments, so rapid in this field, which are becoming increasingly important in everyday life.



part 2

computers

by
Flight Lieutenant GR Hunn
3 AW(F) OTU

In Part I of this article, the progress made in electronic computers was discussed, and the main characteristics examined. The general arrangement of the components and the data flow of the analogue type of mechanism were explained. Part II will discuss the digital type, covering the history, principle of operation, and several different forms of this computer.

Early Digital Calculators

The Abacus, a device similar to a rack of beads used as a counting device by a child, appears to be the earliest example of a digital calculator. Although its origins are lost in history, it is still widely used in Asia. The first mechanical adding machine was introduced in 1642 and was followed by a multiplier in 1694, but practical versions of these devices were not made available until after the industrial revolution. The first reliable, inexpensive digital calculator was offered for sale in the nineteenth century, and the first punched-card accounting machine was produced in the 1880s.

The concept of the modern digital computer,capable of automatic operation and the selection of successive operating steps from among several alternatives, is attributed to Charles Babbage, who suggested the design of an "analytical engine" in 1883. In 1854, an Englishman named George Boole published a book in which he introduced a branch of mathematics called the "algebra of logic". This system, now known as "Boolean Algebra", is the basis of most modern electronic digital computers.

In 1944 Babbage's ideas were given practical realization when a machine was produced under the joint efforts of Howard Aitken and the International Business Machines (IBM) Company. This was followed in 1945 by the production of the ENIAC(Electronic Numerical Integrator and Calculator) which used electronic techniques on a large scale for the first time. Recent developments have included the provision of large-scale number storage and the miniaturization of components. In the past few years, the Hughes Aircraft Company in the USA has produced the first practical airborne digital computer, called Digitair.

The Basic System

It was mentioned in Part I that the digital computer uses discrete numbers (the desk adding machine is an example of such a device). In order to understand the requirements of an automatic computer, its function should be compared with the human solution of a problem. Consider the case where an operator is required to use an adding machine; the steps are essentially as follows:

- The problem is analyzed in terms of steps or operations which can be performed.
- The steps in the computation are written down, leaving spaces for the answers to these steps.
- Each step is computed using the adding machine.
- Intermediate answers to each step are entered in the spaces provided.
- The final result is computed from the intermediate answers, and the solution to the problem written down.

The electronic digital computer carries out the functions of both the adding machine and the operator,and solves the problem in a fraction of the time.

The basic components of a digital computer are illustrated in Figure 1. The input-output component feeds data into the computer and receives the answer,thus corresponding to the human operator pressing the keys of an adding machine and reading the final answer. The arithmetic element corresponds to the adding machine. It adds, subtracts, multiplies, or divides to solve each portion of the problem. The memory component corresponds to the operator's computation sheet, as it contains the original input data and acts as a note pad to store the intermediate results of the computation. The control unit directs the arithmetic and memory components to carry out the required operations, thus functioning as the human operator in programming the steps of the computation.

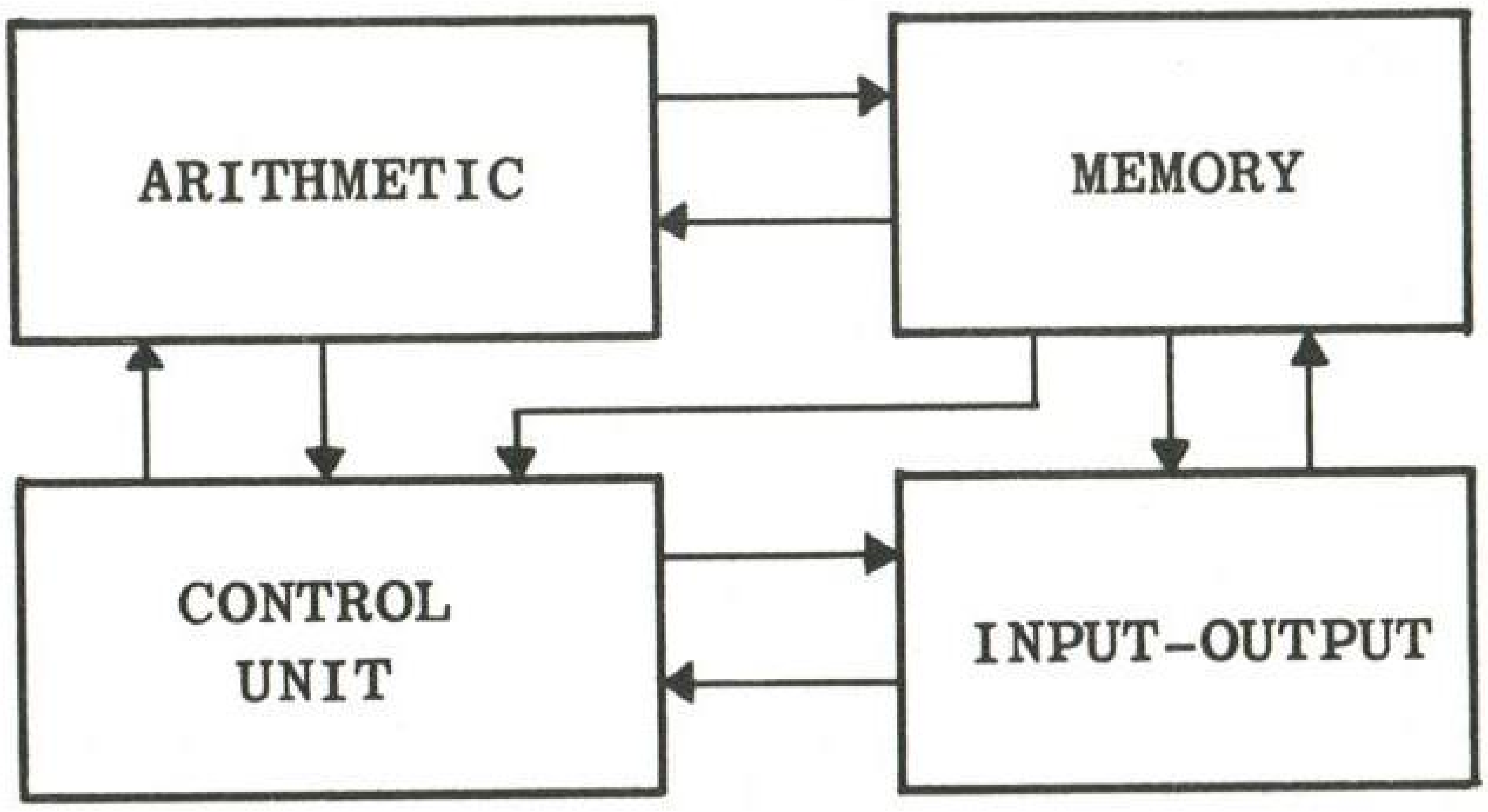


Figure 1 - Digital Computer Components

The basic data-flow diagram assists in this discussion of the functioning of a digital computer, but the reader must realize that in practice these components are not physically distinct, and that various components may be used for more than one function.

The Binary Code

Having seen the basic components into which an electronic digital computer can be divided, it is logical to examine now the basic method of computation.

North Americans normally use the decimal system of computation, which represents a value by using a particular combination of the ten digits (0 to 9). In the decimal system, value is based on the raising of the number ten to various powers. For example, $10^0 = 1$, $10^1 = 10$, $10^2 = 100$, $10^3 = 1{,}000$, and so on.

Hence the number 1243 is a shortened version of the quantity $(\underline{1} \times 10^3) + (\underline{2} \times 10^2) + (\underline{4} \times 10^1) + (\underline{3} \times 10^0)$. Any digital computer using the decimal system "sees" an input of information in these terms. The dial telephone exchange and mechanical adding machine are examples of a decimal digital mechanism.

When setting the value 1243 into a standard columnar-keyboard type of adding machine,the operator first presses the "1" key in the fourth row to the left of the decimal point. This key sets in the value 1000(1×10^3). The "2" key in the next column sets in a value of 200(2×10^2), the "4" key in the next column represents the value 40(4×10^1), and the "3" in the column immediately to the left of the decimal point represents the value 3(3×10^0). As the keys were pushed, the machine combined the values 1000, 200, 40, and 3, to accept the input of 1243.

The decimal system is very complex for a machine, as the mechanism must be able to recognize and use one of ten possible values for each digit. In the binary system, which is used in most electronic digital computers,any value may be represented by a series of "bits" of information,each of which can have only two values, equal, for the present, to "yes" or "no". These "yes" or "no" quantities represent the presence or absence of the figure 2 raised to successive powers.

Using the decimal value 1243 again as an example, it can be expressed as $2^{10} + 2^7 + 2^6 + 2^4 + 2^3 + 2^2 + 2^0$; which is $1024 + 128 + 64 + 16 + 8 + 2 + 1 = 1243$. While this method of representing a figure appears cumbersome on paper, it has the advantage that each power of the value two is used only to the extent of a factor of one. All that the mechanism needs to know, therefore, is whether or not each power is used in the value being fed into the computer. If eleven simple switches were used to accept eleven binary digits,the value 1243 can be set in by arranging the switches as follows ("O" denotes switch open, "C" closed):

Switch	10	9	8	7	6	5	4	3	2	1	0
Position	C	0	0	C	C	0	C	C	C	0	C

Switch 10 is therefore used to denote the presence or absence of the value 2^{10}, switch 9 is used for 2^9, etcetera.

In writing a binary value, each closed switch in the above example is represented by the figure 1, the open switches by the figure 0. 10011011101 is therefore the binary equivalent of 1243.

The number 2 has been chosen as a base for the digital code because it can represent all numbers by being raised to a power, without multiplication. For example, if 3 were chosen as the base, there would be no means of representing the number 2, because $3^0 = 1$, $3^1 = 3$, $3^2 = 9$, etc. In order to achieve the number 2, 3^0 would have to be multiplied by 2, which would require more than a simple "on-off" switch.

For fractional values, the reciprocal of two (½) is raised to various powers. Reference to Table 1 will clarify the procedure of the use of powers for whole and reciprocal values of two.

Powers of 2	2^6	2^5	2^4	2^3	2^2	2^1	2^0	$\frac{1}{2^1}$	$\frac{1}{2^2}$	$\frac{1}{2^3}$	$\frac{1}{2^4}$	$\frac{1}{2^5}$	$\frac{1}{2^6}$
Decimal Equivalent	64	32	16	8	4	2	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$

Table 1

Despite this simplicity, the reader may wonder why the binary values are used when decimal arithmetical processing seems even simpler. The computer designer must keep the complexity of his mechanism to a minimum. For each digit in a decimal number, he must provide a computative circuit (for example a stepping relay) which will select the proper value of the digit (from 0 to 9) as has been shown. Each binary digit needs only a simple open/close switch. For the decimal value 1243, then, he must provide four complex switching devices, each having ten positions, with a total of 40 contacts. The binary equivalent, 10011011101, requires only 11 simple contacts. The saving in complexity is greater when dealing with much larger quantities. When it is remembered that in an electrical circuit at least one wire and a ground connection must be attached to each contact, and that many banks of "number" circuits are used in a computer, the use of the binary system becomes even more logical.

The binary system is a particularly suitable choice in the design of computers which are connected with telemetering equipment. The transmission or absence of an electrical pulse for each binary digit will enable complex numbers to be transmitted. Another example is the method of transmitting commands from a Semi-Automatic Ground Environment (SAGE) computer by data link to a guidance computer in a missile, or to the fire-control system computers in a manned interceptor.

Computer Logic

Before a computer can operate properly and satisfactorily employ some numbering system, such as the binary system, it must have the ability to:

- Learn and remember data presented to it
- Make a choice based on previous results
- Make long chains of operations
- Determine if the answer is correct
- Determine when one problem is finished and when to start another

In order for the computer to be capable of the foregoing items, the proper information must be given to it. From this point on it will determine the answer by what is known as logical truth.

Logical truth differs from ordinary truth in that we deal not only with facts but also in suppositions based on facts. For example, the statement "sugar dissolves in water" is an ordinary truth. Here, however, certain things are understood. The amount of sugar is much smaller than the amount of water, for if we tried to mix a whole bag of sugar with a teaspoonful of water, all of the sugar would not dissolve. The computer cannot operate by understanding such limiting conditions, unless these conditions are given to it so that it may form a logical truth pattern to work from.

The failure of the computer to understand ordinary truth is best illustrated by a report from London, England. At a conference of experts discussing language translation machines, some peculiar results were obtained from an electronic computer's efforts at translation. The two examples quoted were:

→ The phrase "Out of sight, out of mind" was translated to "Invisible idiot".

→ "The spirit is willing, but the flesh is weak" became "the drink is tolerable but the meat is uncooked".

DIGITAL COMPUTER OPERATION

Having seen the fundamentals of the digital computer, the next step is to discuss the components in more detail.

Input Unit

All known data of a problem is fed into the computing system through the input unit, and the information may be fed in the following ways:

- Punched paper tapes.
- Punched cards.
- Photographic tapes.
- Magnetic tapes.
- Automatic typewriters.
- Analogue-to-digital transducers.

Of the systems listed above,the punched tape, magnetic tape, and analogue-to-digital transducers are most commonly used in airborne systems. Because the input required is a series of pulses, the digital computer can receive an input from a remote station through a microwave link. This makes it highly suitable as a central data computer and it is used in this role in the SAGE air defence system.

In a punched paper tape system, the original information is transferred to the tape according to a pattern that represents certain digits used in the computer. In the case of the binary digital computer, these digits would be "0" and "1" (indicating the various powers of two). The punched tape passes through a reading unit that permits electrical contact to be made whenever a hole is present under one of the current-carrying brushes. This technique is illustrated in Figure 2.

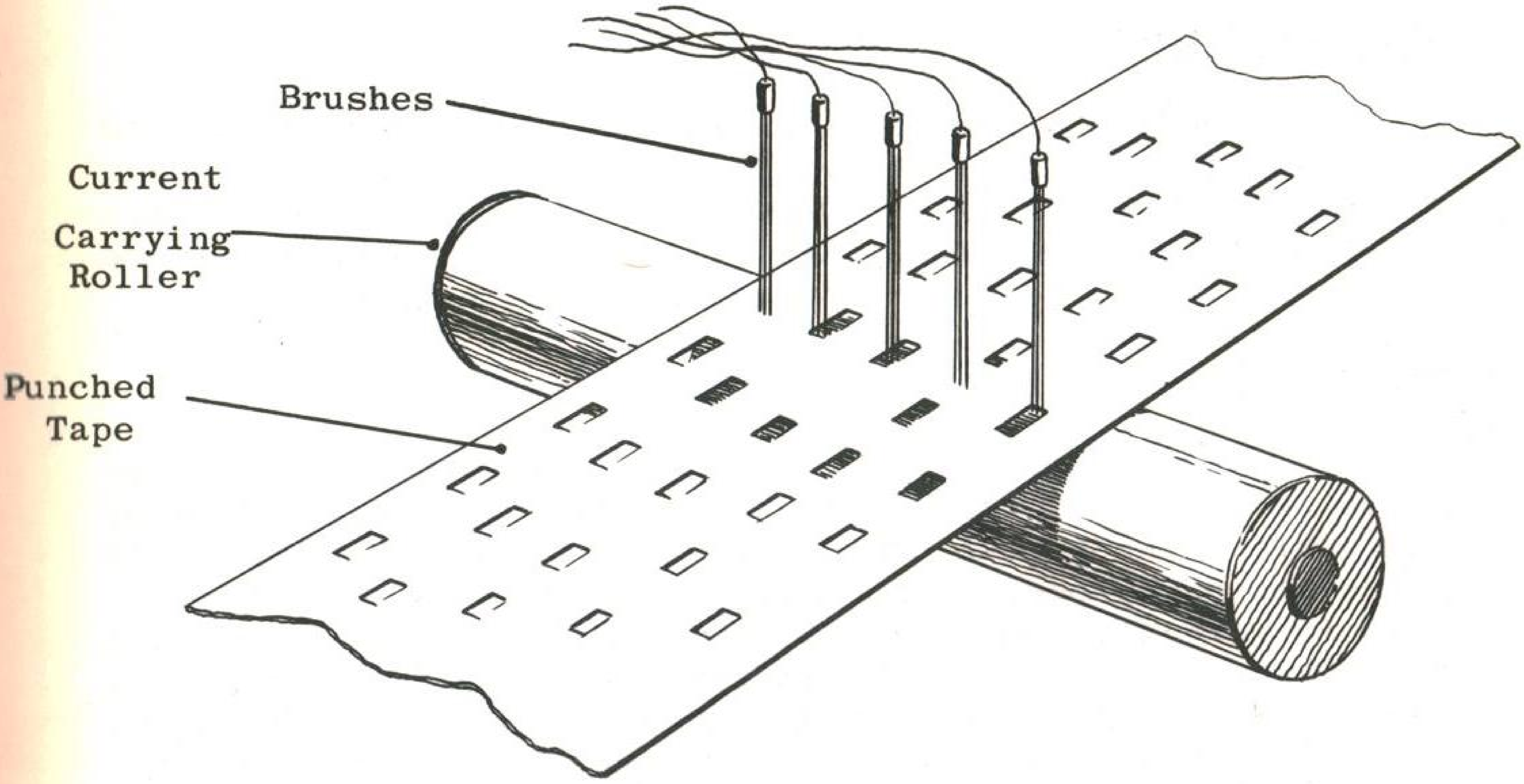


Figure 2 - Punched Tape Input

The normal "reading rate" from a punched card is 150 characters a second.

Another means of supplying the computer with information is by the use of a magnetic tape or wire, upon which alternating currents have been recorded. In this case, the variations of the recorded signal bring about the operation of various components. The magnetic tape and wire reading (or pickup) units are quite similar to those of the commercial tape recorder (Figure 3).

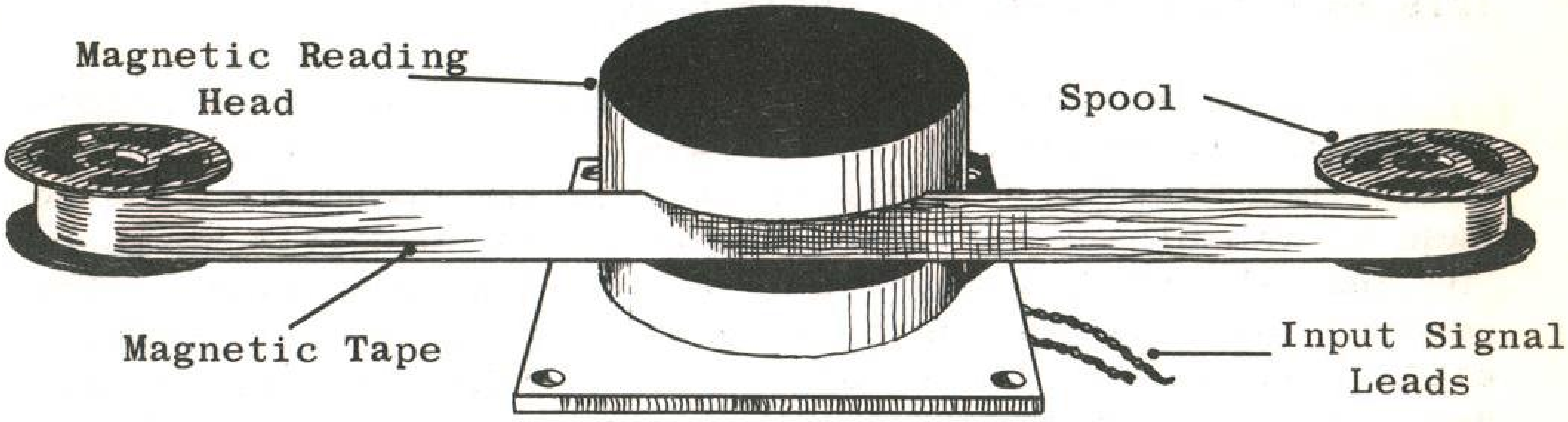


Figure 3 - Magnetic Tape Input

Arithmetic Unit

Addition and subtraction of values can be carried out using relays, a variety of tubes, or as in many modern equipments, the multivibrator or flip-flop principle. This portion of the computer is effectively the simplest, since it is required only to action the incoming signal.

Memory Unit

One of the functions of the "memory" in the computer is to act as the place where one piece of information is carried over to the next step. One of the most adaptable means of high-speed reference storage is the sonic delay line (Figure 4). Sonic delay lines, as the words imply, are lines that function by transmitting sound pulses through a medium of liquid, solid, or gas. The one in the illustration is a liquid-type delay line, using mercury as the transfer medium.

In this delay line, two quartz crystals are used, one as a transmitting element, the other as a receiving element. Quartz crystal is an efficient material in that it exhibits excellent piezoelectric effects, and the acoustical impedances of quartz and mercury are comparable. Matching of acoustical impedances indicates that there will be an optimum transfer of sound energy relayed between the mercury and quartz. For example, a signal is fed into the delay line that has the coding of 101011 (in accordance with the binary system). The quartz crystal sets up sound waves within the mercury that have the same rhythm, or repetition. The sound waves, in striking the quartz crystal at the opposite end of the delay line, reproduce the electrical impulses. These pulses of energy are then amplified and returned to the input of the delay line where the cycle of energy transfer is repeated. This cycle of transmitting and receiving the impulses is continued until a gating circuit is operated that will either transfer the energy to other components or clear it from the system.

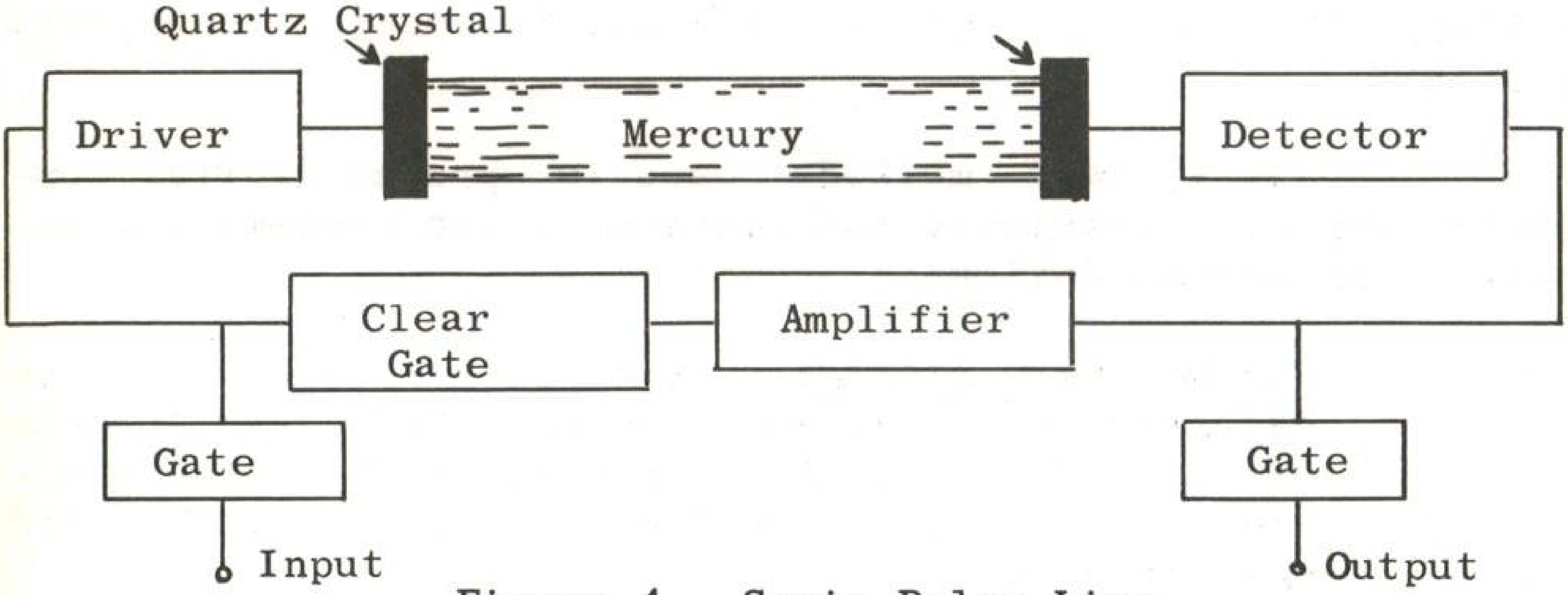


Figure 4 - Sonic Delay Line

Phosphorescent materials are also used for digital storage. In this case a cylinder (drum) is coated with a

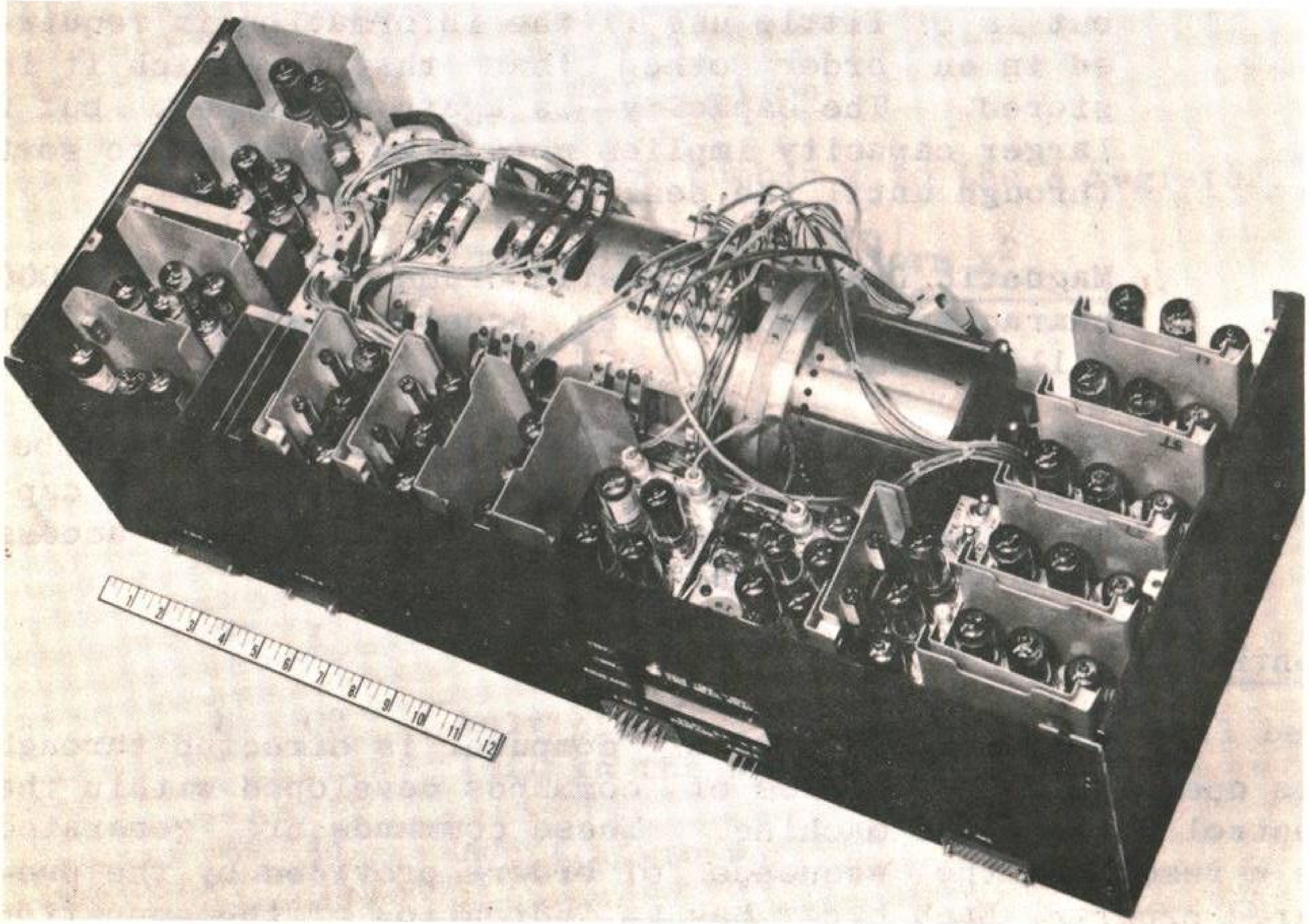


Figure 5 - Memory Drum

phosphorescent material and energized with electromagnetic radiation. The irradiating spots are then read off by means of a photoelectric cell. A device of this type is being used in an airborne digital computer currently under development. This particular drum is four inches in diameter and rotates at 8000 rpm. Storage density around the drum is approximately 100 binary digit bits per inch. Such a memory unit is sufficiently large to store programs for medium complexity problems.

The storage methods used for ground digital computers are very extensive and representative systems and access times are as follows:

Punched Card Storage. The punched card storage capacity is unlimited, but the filing and sorting of cards for a specific problem is slow. The reading rate of the computer is approximately 150 characters per second.

Magnetic Tape. Magnetic tape storage permits "ordered" access to information at a very much faster rate (around 10,000 characters per second), but is of little use if the information is required in an order other than that in which it is stored. The capacity is again unlimited, but a larger capacity implies more time required to sort through until the desired data is located.

Magnetic Drums. Magnetic drums can store 100,000 characters, and have an access time of several milliseconds.

Electrostatic Tubes. Electrostatic storage tubes are a relatively recent development having a capacity of 40,000 characters, with a "random" access time of 12 microseconds.

Control Unit

A high-speed digital computer is directed through its operations by a series of commands developed within the control unit of the machine. These commands are generated as a result of the sequence of orders provided by the prepared program. Each order has an indication of the operation to be performed, plus an address which refers either to the location in the storage where numerical data can be found, or where the answer is to be placed when a particular operation is completed. Computers can use single, double, or triple addresses depending on the design of computer being used.

To illustrate how a problem is coded for solution on a digital computer, the following simple example can be used. Suppose a coder came to a section of a program that called for the evaluation of the polynomial:

$$f(x) = a_1x^3 + a_2x + a_3$$

The numerical coefficients a_1, a_2, and a_3 would have to be stored in three storage locations, C_1, C_2, and C_3. The value of x would also have to be placed in some storage location, address W1, and the final result would have to be placed in a final location W2. The computer would also have to be instructed as to the action to be taken using an operational code, with symbols such as A for transfer, Ad for add, and M for multiply. Once these factors are all determined, the instructions to solve the problem could be written as follows:

Symbol		Explanation
W1	A	Bring the number x to the A register.
M	W1	Multiply by x, to form x^2.
M	W1	Form x^3
M	C1	Form a_1x^3
A	W2	Store a_1x^3 temporarily in the location reserved for the final results.
W1	A	Bring x to the A register
M	C2	Multiply by a_2; the result a_2x will be left in the A register.
W2	Ad	Add a_1x^3 to a_2x.
C3	Ad	Add a_3 to $a_1x^3 + a_2x$
A	W2	Store the solution in location W2.

Each of the symbols would then be replaced with a representative number which the computer could interpret, and the coding and numbers needed would be stored in the designated locations in the computer storage section.

Output Unit

On completion of the computations the solution must be presented. Any of the input devices discussed earlier may be used to display solutions,or they may be on geared indicators similar to those used in a desk calculator. A recently-developed system "speaks" the answer.

CONCLUSION

This has been, of necessity, a very general treatment of the electronic computer, but it is hoped that the reader now has a better appreciation of both their capabilities and limitations. When discussing the speed at which these devices carry out problems, it should be remembered that they also work to fantastic degrees of accuracy. For example,the numerical value of π has been evaluated to 2,000 places of decimals. The requirement for high-speed solution of the complex problems associated with missile trajectories means that the computer will have a growing impact on the service, so the reader should take every opportunity to learn more about these useful tools.

INFRA-RED

Part 1

by
Flying Officer DK Schneider
Central Navigation School

The term "infra-red" is becoming increasingly common in this age of rapid technological development. Infrared (IR) waves have been put to use in photography, aerial reconnaissance, and mapping for some time. Recently, the detection and measurement of IR waves has been given a growing variety of military applications. The purpose of this article is to examine the nature of IR waves, to mention some methods of detecting them, and to outline briefly some practical applications of IR detecting systems.

IR Wave Theory

Objects emit IR or heat waves by virtue of their temperatures. These waves, just like radio waves, are electromagnetic in nature. Electromagnetic waves are transverse waves which have varying electric and magnetic components, normally perpendicular to one another, and also perpendicular to the direction in which the waves are travelling.

Radio energy, light, and heat energy are propagated by means of these waves, which travel through free space at about 300 million metres per second. If one could imagine this energy travelling through space in waves, with the crests of the waves representing peak concentrations of energy, the mental picture would be much the same as the pattern formed on the surface when a pebble is dropped into a pool of water. The distance between successive crests is called the wavelength. The electromagnetic spectrum is comprised of a continuous range of wavelengths extending from radio waves, which can be several miles in length, to gamma rays, which are fractions of a millimetre in length.

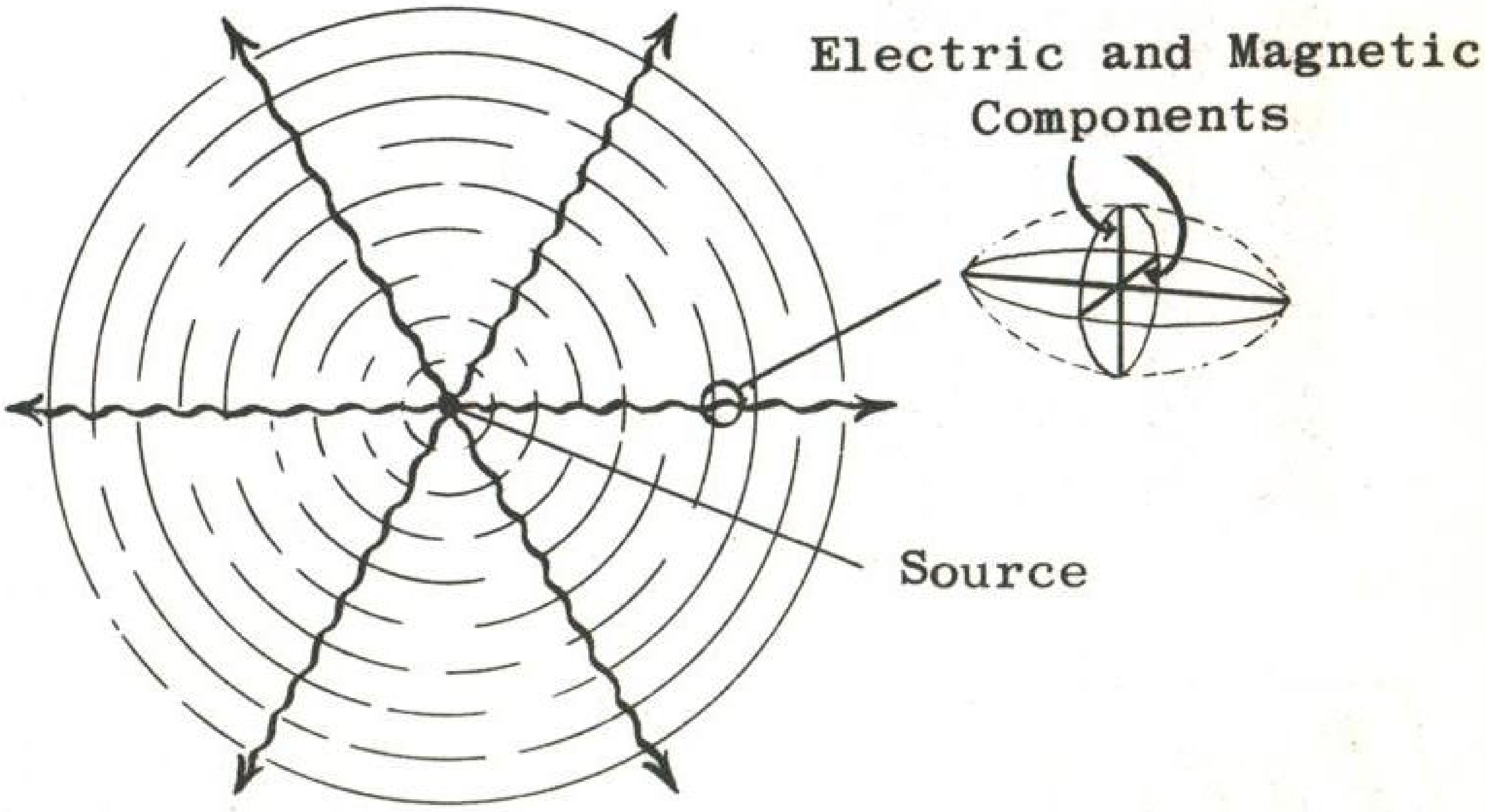
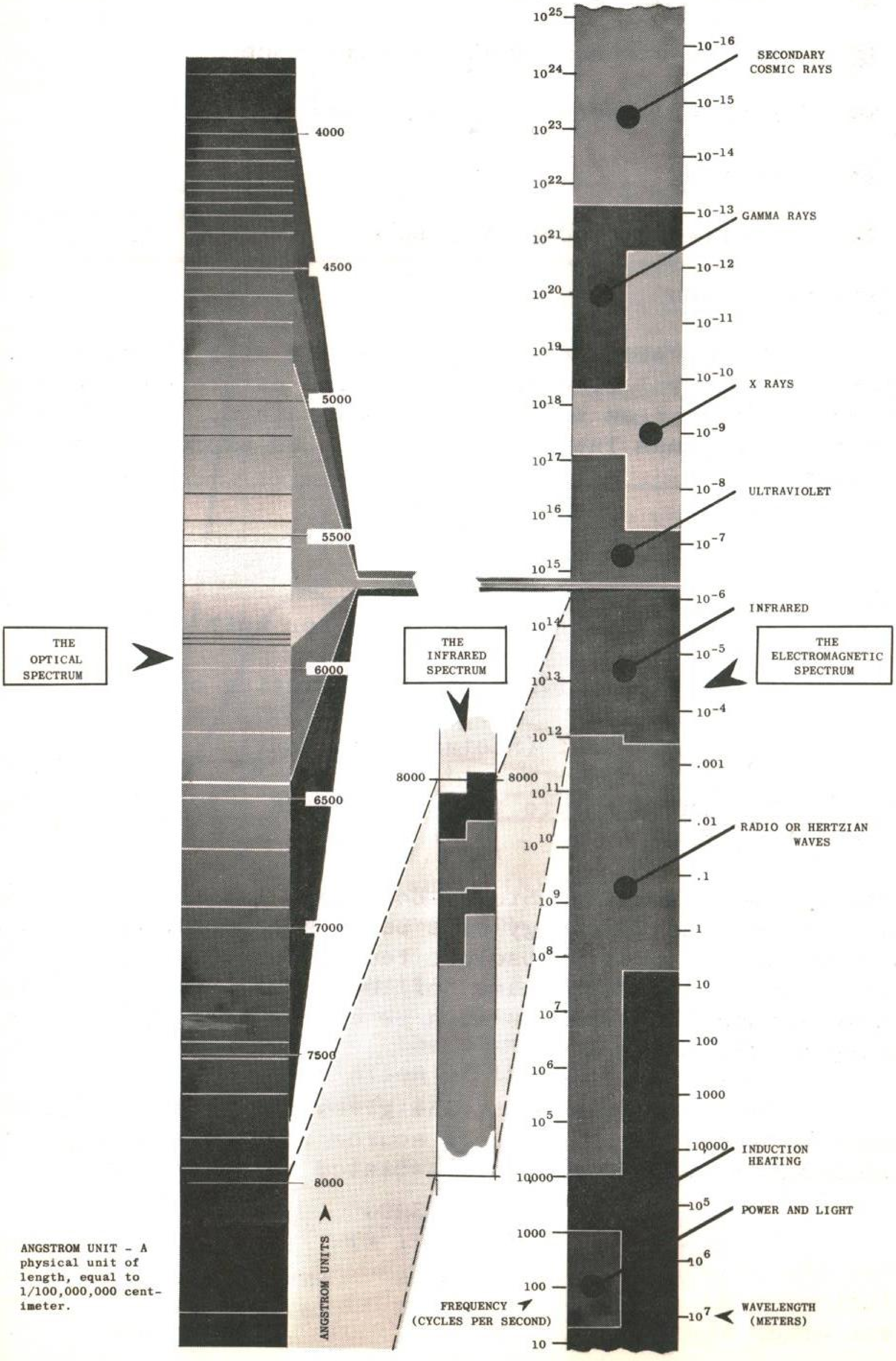


Figure 1 - Electro-Magnetic Waveform

The IR portion of the electromagnetic spectrum overlaps the high frequency end of the radio wave spectrum and the low frequency (red) end of the visible light spectrum. Radiations falling within this band of wavelengths are emitted from bodies as a result of their temperatures.

Work on the measurement of infra-red wavelengths was pioneered during the 1900s by H. Reubens and R.W. Wood, but it was not until after World War I that work was begun on the detection of objects by their infra-red emissions. At that time the General Electric Company was experimenting in the United States with infra-red for aircraft detection, with considerable success. The successful development of radar in the 1930s, however, turned interest of companies such as General Electric away from infra-red. During World War II some work was done on active IR surveillance systems by the Germans and the Allies, and devices such as the Sniperscope, Felix glide bomb, and Wasserfall anti-aircraft missile were developed.

Since World War II, and particularly during the 1950s, the detection of infra-red has begun to receive the attention it deserves. Today IR systems have been developed, or are under development, for the following purposes:



ANGSTROM UNIT - A physical unit of length, equal to 1/100,000,000 centimeter.

- Night photography
- Air-to-air homing missile guidance
- Stellar-supervised navigation
- Mapping
- Short-range communications

Thermal Radiation

The quantity of IR energy which will be emitted by a body in a given time depends on the nature and surface area of the body, as well as its temperature, according to the Stefan-Boltzman law. This law can be expressed mathematically as:

$$E = \epsilon \sigma T^4$$

Where:

E = Emissive power in units per unit of area,

ϵ = the emissivity of the radiating object

σ = a constant (Stefan's constant)

T = the absolute temperature (°K = 273°+°C) of the body

It can be seen from the Stefan-Boltzman law that the emissive power of the IR energy of a body is proportional to the 4th power of the body's absolute temperature. For example, a jet engine at a temperature of 1000°K will emit IR energy with more than 250 times as much power as a kettle of water boiling at 373°K.

Wien's Displacement law gives the relationship between the temperature of an IR source and the wavelength at which maximum radiation occurs. Stated approximately:

$$\lambda_{max} = \frac{3000}{T(^\circ K)}$$

Where: λ_{max} = wavelength of maximum radiations in microns

(1 micron = $\frac{1}{10,000}$ centimetres)

T = the temperature of the source of radiation in degrees absolute.

Figure 3 shows a graph of frequency of emission versus emissive power for a perfect emitter.

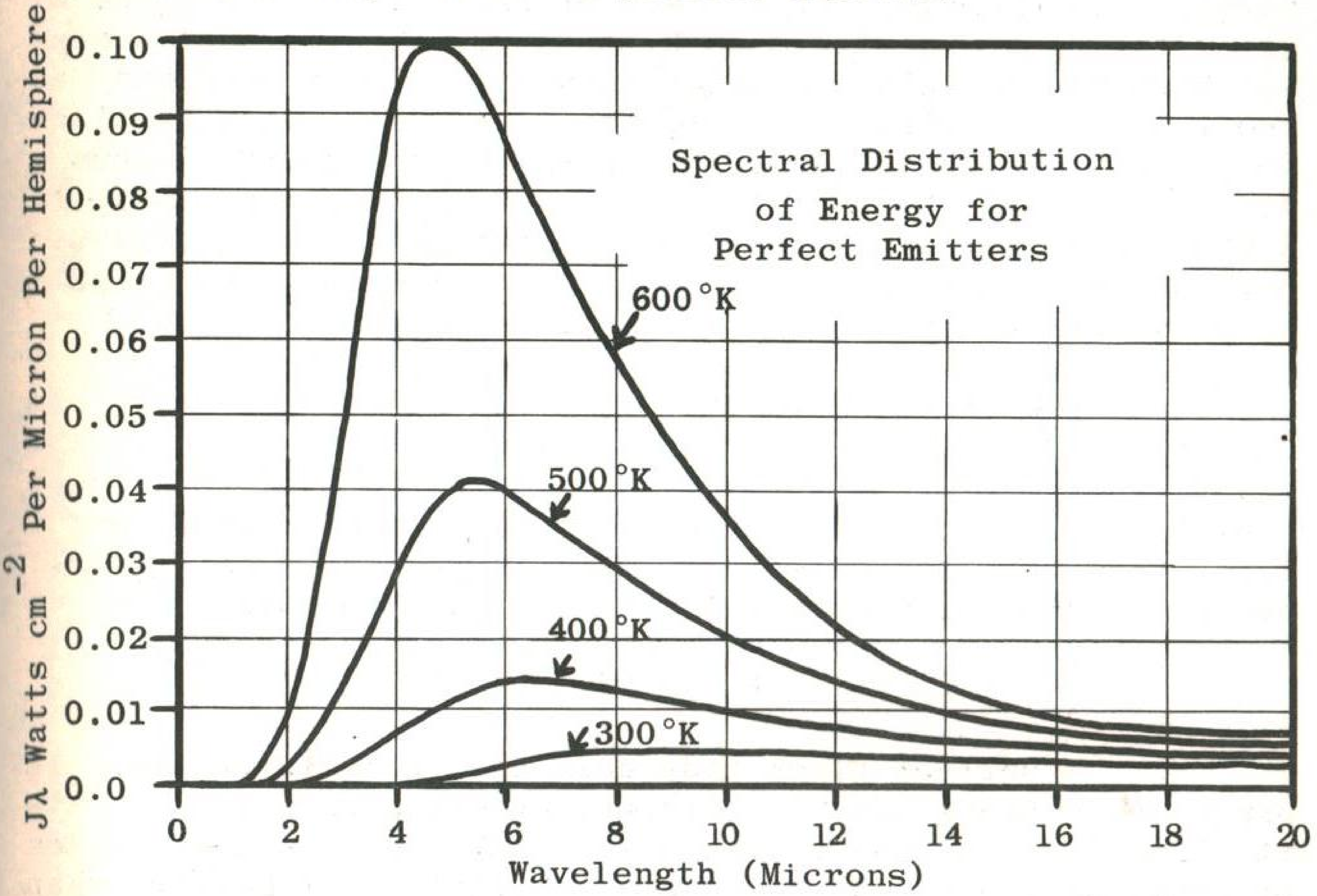


Figure 3 - Emissive Power for Perfect IR Emitter

Thus if a device for detecting IR energy can determine the wavelength at which it is detecting maximum radiations, it will give a rough idea of the nature of the source of these radiations from a calculation of the source temperature. A few results of such a calculation would be:

	λ_{max}	temperature
Sun	0.5 μ	6000 °K
Jet engine	3.0 μ	1000 °K
Piston Engine	4.0 μ	750 °K
Boiling Water	8.0 μ	375 °K

Human Body	10.0 μ	300°K

(μ = 1 micron)

In any discussion of infra-red, the mysterious term "black body" is always encountered. A brief explanation of this term is necessary before continuing.

In 1859, Kirchoff found that a body will emit light and heat energy equal to the amount of energy it absorbs. For example, if a piece of iron wire and a piece of glass tubing are heated side by side in the flame of a bunsen burner, the glass, which cannot absorb as much heat as the iron, will glow less brightly. By definition, a black body will absorb all the IR energy striking it. Thus a black body will be a perfect emitter of IR energy as well. A black body will also absorb all energy from the visible portion of the spectrum, and it will therefore be visible only by contrast with its surroundings.

The Stefan-Boltzman equation contained the term "emissivity", which can now be defined as "the ratio of the quantity of radiation a source will emit to the quantity of radiation a black body of the same temperature will emit". This means that the emissivity for a black-body source will be unity, and the equation for a black body becomes:

$$E = \sigma T^4$$

A perfect black body does not occur in nature. In practice, a black body is obtained by using an enclosed cavity lined on the inside with a material such as smoke black or platinum black, which have emissivities of better than 90%. Radiations which are admitted to such a cavity through a small aperture will be absorbed by means of multiple reflections and absorbtions on the inner walls of the cavity. Since virtually all the incident light or IR energy is absorbed inside the cavity, it is in effect a black body. When such a cavity is heated, radiation emitted through the aperture is the same as from a black body at that temperature.

Conclusion

This first article has given a brief introduction to infra-red wave theory. The second article, which will appear in the July issue of the OBSERVER, will describe IR detectors, and their capabilities.

The opinions expressed in the contributions to the RCAF OBSERVER are those of the writers and do not necessarily represent official RCAF views. The Editor reserves the right to make any editorial changes in manuscripts which he believes will improve the material without altering the intended meaning.

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