JENKINS

Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard Air Force Base, Texas

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Student Study Guide
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DAY 39

MISSILE AIRFRAME

OBJECTIVE:

To become familiar with weapon system development and missile airframe components, and construction.

INTRODUCTION

During the development of any missile, periodic reports are published giving new developments and the results from tests made on current models. By reading these reports you would realize the complexity of the problems that confront designers in the development of new missiles. Payload capability, range, production time, speed, and control configurations are but a few of the problems discussed in these reports. You can readily see that considerations given to missile design are many and varied, and no one problem stands alone when a new missile is being developed.

In this Study Guide, we will discuss the development cycle, airframe design considerations, airframe components, construction and maintenance techniques.

DEVELOPING A WEAPON SYSTEM

The first recognized ballistic missile effort for this country started in 1946, when the Air Force began an orderly and systematic missile development program. Contracts were negotiated for Rocket Propulsion Systems and a long range missile development program to include studies of missile guidance, flight control, rocket engine gimbaling and lightweight missile structures.

The Air Force Ballistic Missile Program benefited during these post war years from other Air Force Guided Missile programs such as Matador, Snark and Navajo, and from the Air Defense Missile Development program. All contributed to the solution of ballistic missile propulsion, guidance, control, and structural problems. However, the ballistic missile program was kept at a relative low level until 1950 because more conventional guided missiles appeared to offer the best and easiest solution to the range, payload, and accuracy program which faced long range strategic missile designers. In particular, two inhibiting factors were the lack of attractive, payload in terms of weight versus yield, and concern over protection of the payload on re-entry. The re-entry problem was an extremely difficult one and was not solved until a much later date.

By 1950, Air Force agencies felt that enough progress has been made in these areas to warrant study and limited design of an ICBM. A contract was awarded in 1951 for the development of the ICBM. This was the original Atlas Program, in which conservative development policies were followed, due to technical problems still to be solved. By 1953, the impending solutions to most of these problems, allowing design and initial construction of the Atlas, was near.

In 1953 the Atomic Energy Commission announced a thermonuclear breakthrough that pointed the way to design and production of small high-yield warheads. Also in 1953, the Department of Defense conducted a thorough examination of all long-range missile programs. The "Teapot" Committee was formed, composed of outstanding scientists and engineers. Their report made possible the recommendations that an accelerated Atlas program be established.

These recommendations were approved and in August 1954 the Western development Division later designated AFBMS and now the Ballistic Systems Division of AFSC was established. In early studies of the type organization to be set up to manage and direct the program it was decided that there be centralized control and a highly qualified staff for technical direction and system engineering. The decision was made that the Air Force would retain overall system responsibility, and contract for technical and scientific staff.

The decision was made to discard the then current procedure of new weapons buildup, that is, building a proto-type before venturing into production. Instead, it was decided to attack all areas of assignment concurrently, thus the "concurrency concept" presently used on all missile and rocket development was born. The primary objective and result of simultaneously conducting the many management activities is the reduction of leadtime by some three or more years.

Another unique aspect of Air Force ballistic missile program is the participation of industry on an "associate contractor" basis. Each operation is conducted as a prime contract to the USAF for the development and production of a particular major assembly or portion of a weapon system. The responsibility for overall systems engineering and technical direction, is carried out by the Space Technology Laboratories, Inc., a non-hardware-producing corporation under contract to the Air Force.

An equally important new concept was employed in the production and test phase. In order to reduce production lead time it was decided to take calculated risk of fabricating development test vehicles and subassemblies on the same production lines which later would be accelerated to produce the operational inventory. This procedure also allows demonstration of reliability of production hardware at the earliest possible date. This development concept has been applied to all three of the liquid propellant Air Force ballistic missiles (Thor, Atlas, and Titan)..

Development of the Atlas Intercontinental missile was the initial mission assigned to the Air Force Ballistic Missile Division (AFBMD). The first Atlas was test launched on 11 June 1957, less than three years after establishment of the AFBMD. Despite the fact the full programmed flight was not completed, this launching was a significant accomplishment particularly in view of scientific and technical challenges which were considered greater than any previously faced in a major weapon system development, including the Manhattan project. Subsequent tests of more advanced models have more than confirmed the total full-range capability of the Atlas as America's earliest available intercontinental ballistic missile.

In May 1955, based upon the recommendation of the Air Force Scientific Advisory Committee, a second ICBM program was authorized in order to provide a dual approach to the difficult technical problems of ICBM development.

As the Atlas successfully matured, the need for Titan as "backup" disappeared, and the Titan proceeded as an independent weapon system, making an indispensable contribution to the total ICBM inventory programmed for the near years. An excellent example both of program management flexibility and Titan contributions to the Atlas exists in the reorientation of the Arma-Bosch all-inertial guidance system from its Titan role to its use in the Atlas. This change has provided the capability of fully "hardening" later Atlas Squadrons.

Unprecedented success has marked the inception of the Titan flight test program. No previous ballistic missile had flown successfully on its initial launch from Cape Canaveral. In contrast the first four Titan launches were completely successful in satisfying test objectives. It is also noteworthy that the first Titan flew only three years after ground-breaking for the assembly plant.

The mission of developing the Thor Intermediate Range Ballistic Missile was assigned to the AFBMD in the late fall of 1955. Within ten months after signing the airframe and missile assembly contract the first test missile was delivered to Cape Canaveral for the initial test flight. Three months later, on 25 Jan 1957, the first Thor was launched.

This highly compressed development time cycle was made possible in great measure by the use of assemblies previously designed for the Atlas ICBM. A high degree of initial confidence could be placed in the performance of these assemblies under the less rigorous IRBM flight conditions.

Although hardening and dispersal of the earliest available U.S. ICBM's, Atlas and Titan, is well warranted, the Minuteman is the product of our search for a weapon system of the highest possible cost-effectiveness. This fourth USAF ballistic missile program is made possible by technological advances achieved during the progress of Atlas, Titan, and Thor. The greatly reduced weight, size and the cost of the Minuteman, its simplicity and adaptability to remotely controlled, automated monitoring, and its near-instantaneous reaction time gave promise of a reversal in today's trend of ever-increasing costs of modern weaponry.

Atlas and Titan will not be outmoded upon the availability of Minuteman. Aside from need for these "heavy" ICBM's in the years prior to deployment of the Minuteman "medium" ICBM, their appreciably greater yields and range potentials should ensure their retailiatory value against certain targets throughout the 1960's.

What will have been achieved upon reaching the desired goal - when each of the ICBM's and IRBM's have become a reliable operational weapons system produced in quantity? Paradoxically, the best that can be hoped for is that they never be fired in anger - that our ballistic missile capability will be so highly respected by all potential aggressors as to indefinitely deter them from attacking us.

When Atlas and Titan boosters can be diverted from the overriding requirement to increase our operational ICBM inventory, they can be utilized to place larger payloads in terrestial orbit, or for flights to nearer planets.

This should not imply that the ICBM and IRBM are "ultimate weapons" as they are frequently called, nor that the ballistic missile will replace the manned intercontinental bomber; but that it will become one of the most potent and convincing arms in our arsenal of strategic weapons.

MISSILE AIRFRAME DESIGN CONSIDERATIONS

The airframe provides the missile with the necessary aerodynamic profile for flight. It represents a compromise between air worthiness and strength to weight considerations and is subjected to violent stresses from the engines and the atmosphere.

An airframe is designed to support, contain, and protect the missile components. Aerodynamically the airframe should be slender to enable minimum drag. However, it must have great strength along the thrust line and the lateral axis. Aerodynamic cleanliness is considered a secondary factor since the missile will spend little of its total flight time in the atmosphere; therefore, missiles are constructed rather short and wide with some external plumbing and equipment.

The system requires a stable unit with the ability of mounting sensitive components and shielding them from outside influence of shock, vibration and electrical noise. A radio guidance system must also have some method of passing information from the missile guidance set to the ground guidance system.

The propulsion system must be capable of supplying sufficient thrust to enable the desired range of the missile to be obtained. To the manufacturer, a simple vehicle capable of being built and repaired in the minimum time with the minimum tools is desired. It is obvious that some sort of compromise must be made to incorporate the essential features of each of these considerations.

One of the prime considerations in design and construction of a missile is weight. Each increased pound in missile weight will result in a decrease in the range of between 1 and 10 miles. In order to increase aerodynamic efficiency a sacrifice in strength and an increase in bending moment will be experienced by the missile. This makes the missile difficult to construct and hard to control in flight.

Two methods of obtaining maximum strength to weight ratio have been employed in missile construction, full and semi-monocoque. The full monocoque (Figure 1) approach resembles an eggshell, a container with no internal

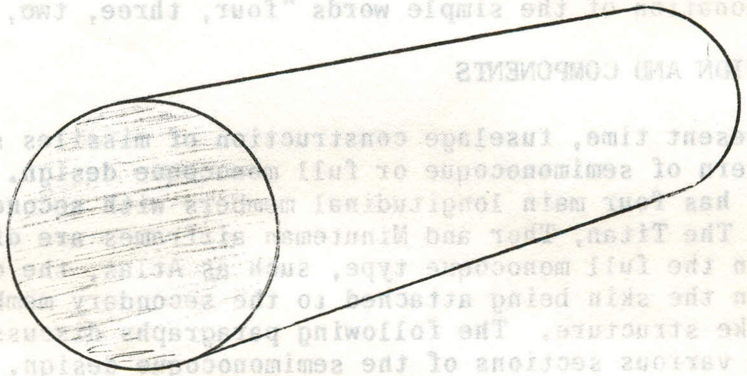

Figure 1
Full Monocoque

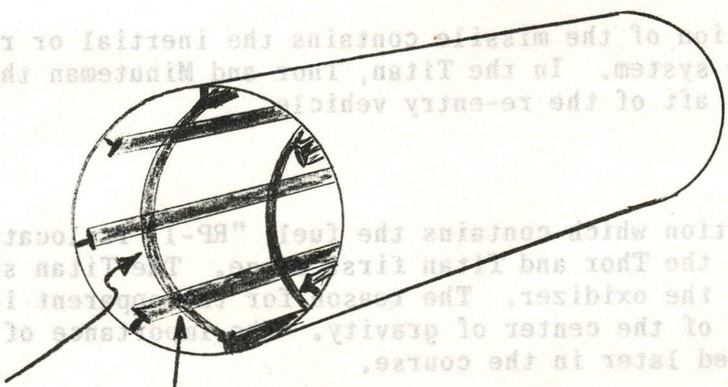

Figure 2
Semi-Monocoque

stress members. This unified concept saves considerable weight over the semi-monocoque, (Figure 2) which like an aircraft is constructed of skin braced with bulkheads, stringers and formers. The latter is easier to build and maintain but has a weight penalty whereas the former is light in weight but has the problem of retaining its own shape. The full monocoque vehicle must be pressurized to maintain strength and retain its shape.

This object that we call a missile is of many ideas and modifications of diverse approaches. It is small wonder that, as we watch the gleaming hardware which is the result of all these labors, there is terrific tension during the controlled intonation of the simple words "four, three, two, one....."

AIRFRAME CONSTRUCTION AND COMPONENTS

Up to the present time, fuselage construction of missiles seems to be following the pattern of semimonocoque or full monocoque design. A semimonocoque type usually has four main longitudinal members with secondary members attached to them. The Titan, Thor and Minuteman airframes are of the semi-monocoque type. In the full monocoque type, such as Atlas, the construction depends entirely on the skin being attached to the secondary members, thus forming a shell-like structure. The following paragraphs discuss the location and purpose of the various sections of the semimonocoque design.

Re-Entry Vehicle Section

The re-entry vehicle is a system in itself. It is considered a basic section of the missile airframe only because it completes the aerodynamic profile of the missile. The re-entry vehicle will be discussed in a separate study guide.

Guidance Section

The guidance section of the missile contains the inertial or radio components of the guidance system. In the Titan, Thor and Minuteman the guidance section is located just aft of the re-entry vehicle.

Fuel Tank Section

The fuel tank section which contains the fuel, "RP-1" is located above the oxidizer section in the Thor and Titan first stage. The Titan second stage has the fuel tank below the oxidizer. The reason for the apparent inconsistency is due to the placement of the center of gravity. The importance of center of gravity will be explained later in the course.

Center Body Section

The Titan and Thor have a center body section which is located between the fuel and oxidizer tanks. This section is used to join the two tanks and

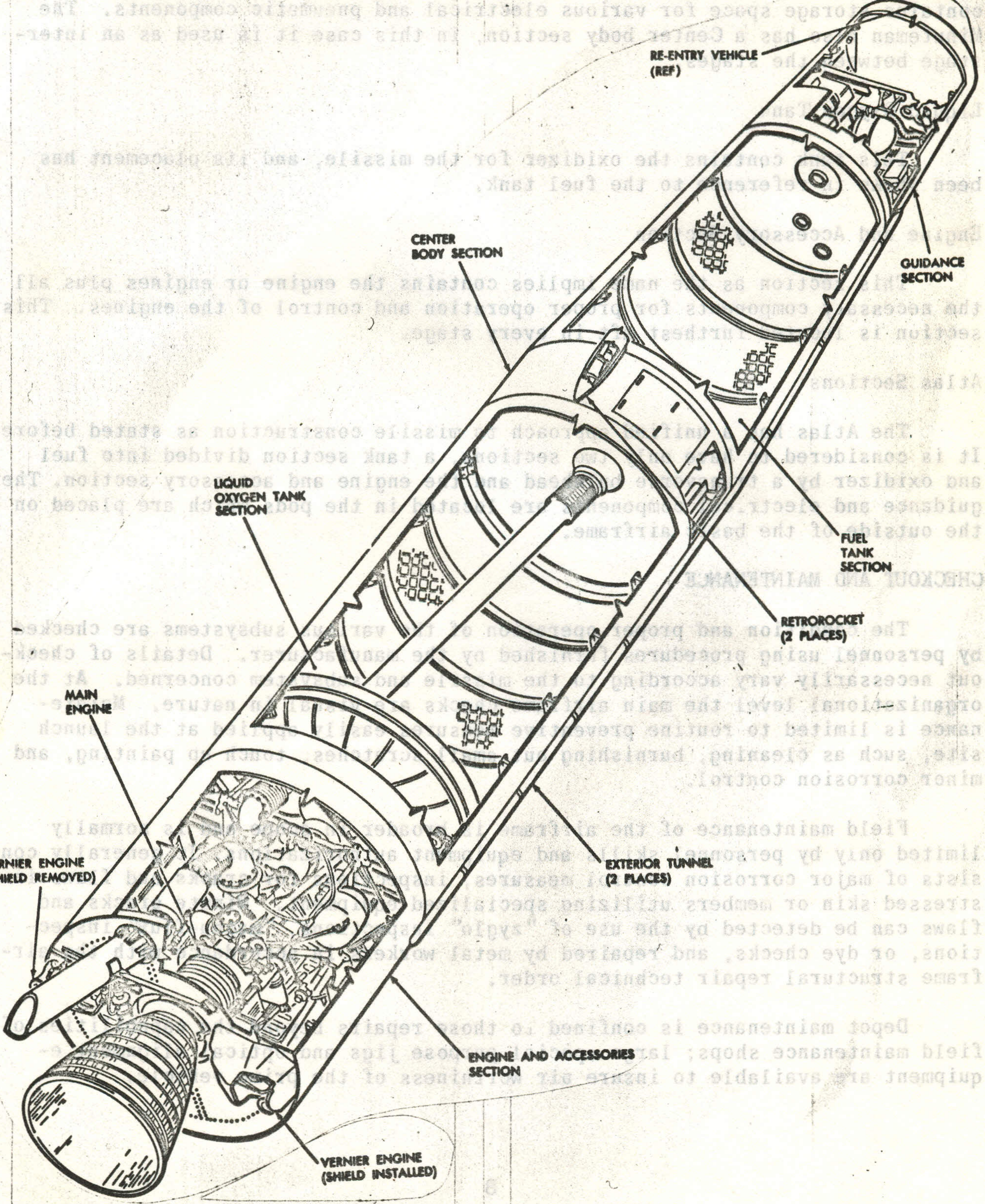

Figure 3 - Sections

contains storage space for various electrical and pneumatic components. The Minuteman also has a Center body section, in this case it is used as an inter-stage between the stages.

Liquid Oxygen Tank

This tank contains the oxidizer for the missile, and its placement has been shown in reference to the fuel tank.

Engine and Accessory Section

This section as the name implies contains the engine or engines plus all the necessary components for proper operation and control of the engines. This section is located furthest aft in every stage.

Atlas Sections

The Atlas has a unified approach to missile construction as stated before. It is considered to have only two sections, a tank section divided into fuel and oxidizer by a transverse bulkhead and the engine and accessory section. The guidance and electrical components are located in the pods which are placed on the outside of the basic airframe.

CHECKOUT AND MAINTENANCE

The condition and proper operation of the various subsystems are checked by personnel using procedures furnished by the manufacturer. Details of checkout necessarily vary according to the missile and subsystem concerned. At the organizational level the main airframe checks are visual in nature. Maintenance is limited to routine preventive measures easily applied at the launch site, such as cleaning, burnishing out small scratches, touch up painting, and minor corrosion control.

Field maintenance of the airframe is broader in scope and is normally limited only by personnel skills and equipment authorizations. It generally consists of major corrosion control measures, inspections for cracks and flaws in stressed skin or members utilizing specialized equipment. Minute cracks and flaws can be detected by the use of "zyglo" inspections, "magna-flux" inspections, or dye checks, and repaired by metal workers in accordance with the airframe structural repair technical order.

Depot maintenance is confined to those repairs beyond the capabilities of field maintenance shops; large special purpose jigs and optical alignment equipment are available to insure air worthiness of the prime vehicle.

MISSILE SPECIFICATIONS

The following chart shows salient features of US made ballistic missiles:

	THOR	ATLAS	TITAN I	TITAN II	MINUTEMAN
LENGTH	63'	71'	86'	90'	56'
WEIGHT					
Gross	109,800#	264,000#	224,000#	320,000	65,000# 70,000#
Empty	11,800#	20,000#	16,500#	25,000	N/A
THRUST					
Booster	N/A	330,000#	300,000#	430,000#	170,000
Sustainer	150,000#	57,000#	80,000#	100,000#	65 50,000
Vernier	1,000#	1,000#	1,000#	1,000#	35,000 N/A
STAGES	1	1½	2	2	3
MANUFACTURER	Douglas	Convair	Martin	Martin	Boeing
GUIDANCE	Inertial	Inertial	Radio	Inertial	Inertial

SUMMARY

Although the basic principles used in ICBM's are old, the necessary design and manufacturing skills have only recently enabled the developmemt of practical long range ballistic missiles. The technique of concurrency shortens the time from inception of a weapon system to its initial operational capability, but carries with it many knotty problems such as tremendous expense, need for competent critical judgement and adverse public reaction to test flight failures of a weapon system already substantially in being. Improved reliability resulting from experience in design and manufacturing, reduced unit cost, and hardening of sites should go far towards improving the nation's ballistic missile effort.

Present missile designers are using both the semimonocoque and the full monocoque design in airframe construction. The semimonocoque type is constructed like an aircraft with internal bracing and can be divided into various sections. The pure monocoque type of construction has almost no internal bracing. Checkout and maintenance procedures vary with each missile, but must be accomplished according to the applicable technical order to insure reliability.

QUESTIONS

1. How is the re-entry vehicle attached to the Airframe?
LATCHS OR BOLTS

2. What is the largest basic section of the missile?
PROPELLANT TANKS

3. Why is the forward part of the missile tapered?
AERODYNAMICS

~~4.~~ In which year did the actual design of ICBM begin? Which year was it completed?
WHO KNOWS!

5. What were the largest problems in early design of a missile?
RE-ENTRY
WEIGHT OF WARHEAD

6. What is the concurrency concept?
DEVELOPE EVERYTHING AT THE SAME TIME

7. List the phases in missile development.
DESIGN, TEST, PROCURE, PRODUCTION, OPERATION

8. What are the major problems associated with choosing an airframe?
WEIGHT VS STRENGTH

9. What is the most important consideration in missile design?
WEIGHT

10. Name and explain the types of construction of missile airframe.
MONOCOQUE - ONE PIECE CONST.
SEMI MONOCOQUE - INTERNAL BRACES

REFERENCES:

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2. TO 21-SM75-1, General Manual

3. AFM52-31, Guided Missiles Fundamentals

DAY 40A

RE-ENTRY VEHICLE

OBJECTIVE

To familiarize you with the re-entry vehicle (RV) its aerodynamic characteristics and the types of vehicles.

INTRODUCTION

"Re-entry" is the term used to describe the final portion of a ballistic trajectory in which a long-range missile or satellite plunges back into the atmosphere at speeds of 10,000 to 20,000 miles per hour. To the designer, re-entry is of great significance because of the tremendous heating and structural loading which result. The heating is caused by friction between the object and air particles of the atmosphere.

RE-ENTRY VEHICLE PROBLEMS

Before considering the physical processes of re-entry, a brief review of the physical environment above the earth is provided. The blanket of air surrounding the earth is relatively thin. Traveling outward the pressure of the air drops rapidly. Atop Mt Everest, which is only 6 miles high, the atmospheric pressure has fallen to only 1/3 of the sea level value. At 20 miles, the pressure is only 1/100 of that which we normally breathe. Further out into space, the absolute pressures approach those of a complete vacuum. Molecules of air which at sea level traveled only 1/10,000 of a millimeter before colliding with another molecule, 250 miles out must traverse about 5 miles before bumping into another particle.

Aerodynamic heating was no design problem with aircraft until after World War II when supersonic aircraft were built. It will be recalled that after the so-called "sonic barrier" was broken, the phase "thermal barrier" or "thermal thicket" loomed as the next major design problem. In manned supersonic aircraft a relatively large heat load is imposed at high speeds.

This heat load requires high capacity air-conditioning equipment to keep temperatures tolerable in the pilot's cockpit. The heat is caused simply by the frictional forces resulting from the flow of air molecules past the aircraft.

In the case of re-entry of long range ballistic missiles, the aerothermal effects are many and of greater magnitude. The RV of an IRBM, containing the warhead, re-enters the atmosphere from altitudes of 300 to 400 miles, traveling at about 10,000 miles per hour. In the case of an ICBM, the peak altitude may be 600 to 800 miles, the nose cone plunging toward the earth at 15,000 miles per hour. On the way up, there is essentially no frictional heating problem of magnitude in the case of an ICBM powered by liquid-propellant rocket motors. In the case of a solid-propellant powered ICBM, the burning rate of the propellant charge is higher, resulting in shorter burning periods of higher acceleration values. Thus, there may be ascent-heating problems requiring nose heat-shielding protection.

Things are very different when the RV returns. As it streaks down toward the atmosphere it picks up speed and strikes molecules more frequently as the atmospheric density increases. Since the air becomes more dense, the particles pile up ahead of the nose cone, and the familiar shock wave appears at about 60 miles altitude. Behind this shock wave gas temperatures as high as 15,000 degrees F or more are generated. This temperature is higher than the radiant surface of the sun. Deceleration forces of 20 to 30 g's may also be imposed on the structure as atmospheric drag increases.

The duration of the heating and deceleration periods for ballistic missiles, entering at fairly steep angles, is fairly short. In fact, the heat shock is almost explosive. This is very different from a satellite re-entry, where the vehicle is traveling initially along a path nearly parallel to the earth's surface. The re-entry speed may be as high as 17,000 miles per hour. However, in order to hold the peak re-entry temperatures and g-loading to a minimum, the angle of re-entry will probably be held to less than 5 degrees from the horizontal. This will result in a significantly longer heating period but much lower maximum temperatures and deceleration forces. Accordingly, the designer is mainly concerned with insulation of the interior, but the temperature and structural loads will be much easier to handle.

The designer of nose cones might be compared to the designer of brake linings. He has three objectives; namely, to keep as much heat as possible out of the RV, to take what heat he must accept and distribute it uniformly to prevent "hot spots", and to select a material that can absorb the amount of heat required. The braking action of the air on an incoming 15,000 mile per hour RV has been compared to the force necessary to stop a one-hundred-car freight train traveling at 70 miles per hour..

There are several design techniques for handling the heat problem. One method is to use a material to absorb the necessary heat in a straight-forward fashion (a <u>heat sink</u>). Another is to select a material which will melt or vaporize. In the process of vaporization, heat is absorbed and swept away from the nose cone in the flow of air. This is known as ablation. A third way to dispose of heat is by radiation. It might also be accomplished by transpiration or "sweat" cooling, in which a cooling fluid is forced through a porous material and evaporates on the surface. Several of these techniques may be combined in a particular design application.

The problems of designing a RV for an ICBM are much the same as for an IRBM except that temperatures and g-loading conditions are much greater for the larger, longer-range missile. In the case of the IRBM, the peak temperatures reached are just beginning to become really difficult. For the ICBM the problems are much worse. A rule of thumb relationship is that the heat "flux increases as the cube of the velocity".

HEAT SINK RE-ENTRY VEHICLES

The easiest, fastest cone to develop was the "heat-sink" type, made of thick copper. (See figure 1)

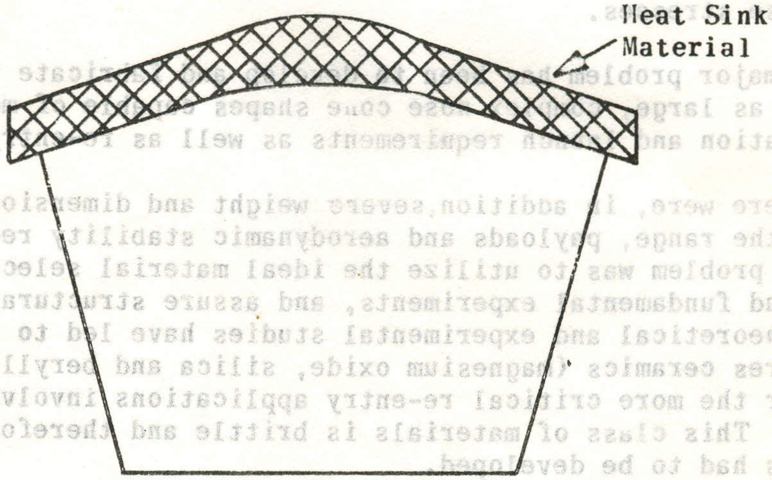

Figure 1
Heat Sink Re-Entry Vehicle

Since copper is an excellent conductor of heat, the cone's front surface could stay solid until the whole mass was near the melting point. To many, it seemed obvious that a nose cone should be made slim and sharp-pointed, capable of piercing the atmosphere with low resistance. But the contrary proved to be the case, for a blunt nose was better for the heat-sink cone. The snub nose would help pile up in front of the cone a high pressure layer of air that would itself act as a potent insulator. That way, most of the immense heat would be swept off the edge of the cone into a long tunnel of air.

Most of the early re-entry vehicles were built along such relatively simple lines and were successful enough in the first Thor and Atlas missiles. But they were heavy and in an ICBM, every ounce of RV takes away from the warhead. The blunt-nosed cones also began slowing down while still high in the atmosphere, making them more vulnerable to anti-missile missiles as they descended toward earth. Thus, even while the heat-sink cones were still being tested, work was begun on a new type of cone.

ABLATING RE-ENTRY VEHICLES

Heat shield requirements for re-entry application are indeed severe, and would cause melting or evaporation of most materials. We are thus led to the problem of finding ablating materials which will absorb a high energy per ablated mass and which simultaneously possess a low thermal conductivity to prevent the deep penetration of heat beneath the ablating surface. The combination of high heat transfer rates and low thermal conductivity then causes large temperature gradients and severe induced thermal stresses. Thus new fabrication techniques are required to enable materials to withstand these stresses.

A major problem has been to develop and fabricate these heat shield materials as large, complex nose cone shapes capable of meeting the handling, transportation and launch requirements as well as re-entry conditions.

There were, in addition, severe weight and dimensional limitations defined by the range, payloads and aerodynamic stability requirements. The materials problem was to utilize the ideal material selected by theoretical studies and fundamental experiments, and assure structural reliability. Extensive theoretical and experimental studies have led to the choice of high temperatures ceramics (magnesium oxide, silica and beryllium oxide) especailly for the more critical re-entry applications involving turbulent heat transfer. This class of materials is brittle and therefore new fabrication techniques had to be developed.

The ablating nose cone is the design of the present. It is longer and more pointed than its heat-sink predecessor. It can slice more deeply through the atmosphere before it slows down, giving it greater protection against defensive missiles fired from the ground. Better still, it is comparatively light.

Much work remains to be done. Re-entry vehicles can be made still lighter, thus adding to the missile's payload. This is particularly important to the solid-fuel, Minuteman, a fine but small missile with definite payload limitations. Extensive development work now under way on new graphite materials and structures may soon lead to radically new ballistic

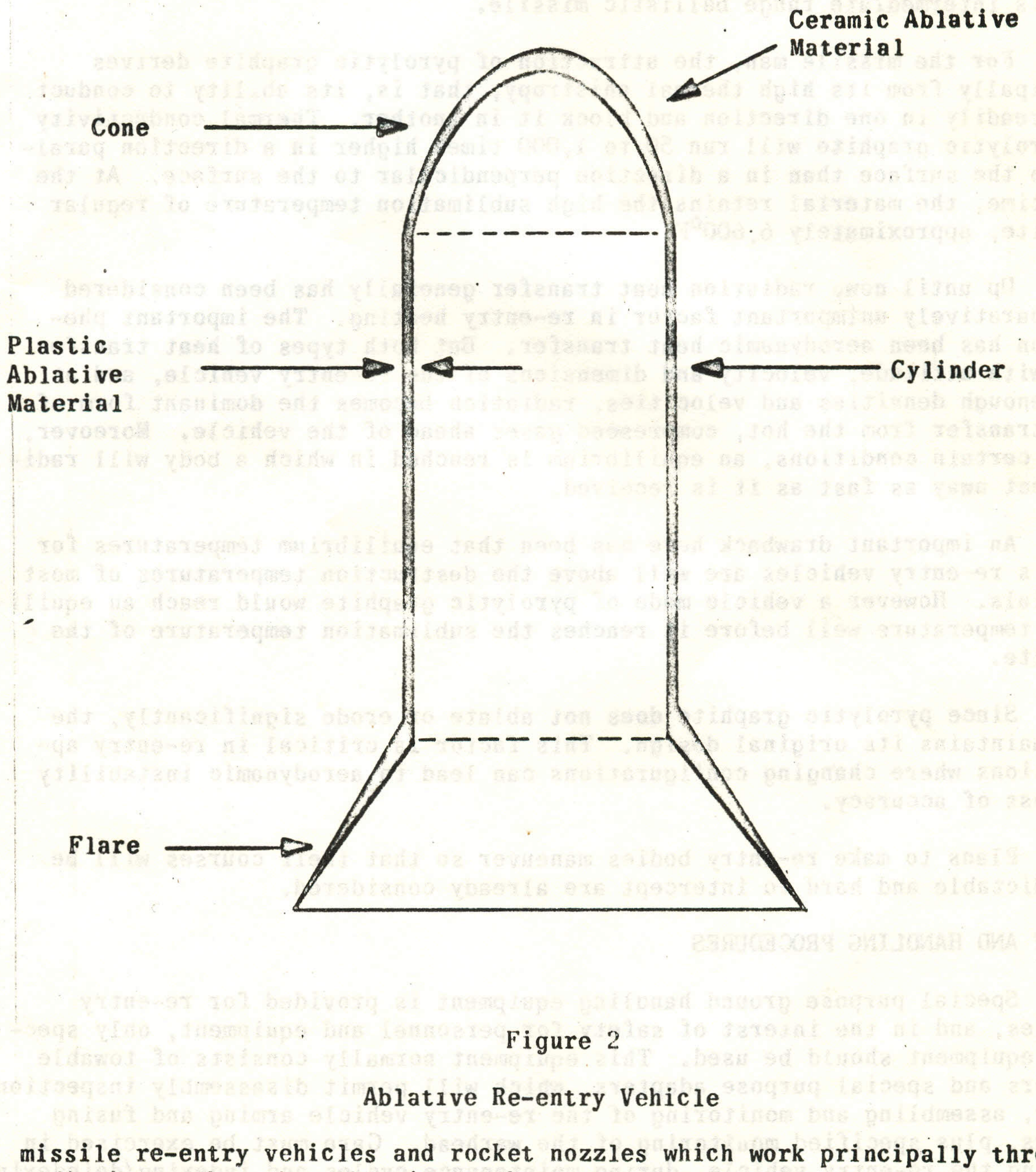

Figure 2

Ablative Re-entry Vehicle

missile re-entry vehicles and rocket nozzles which work principally through radiation rather than ablation or heat storage.

One scientist estimates that new graphite re-entry structures will weigh only one-tenth as much as the newest ablation re-entry vehicles, will come in on target one-third faster, and will also be more accurate.

Currently, most interest is centered on pyrolytic graphite a highly oriented crystalline material. First major applications of this material are expected to be in the rocket nozzles and re-entry vehicle of an improved 1,500 MI. Polaris intermediate range ballistic missile.

For the missile man, the attraction of pyrolytic graphite derives principally from its high thermal anistropy, that is, its ability to conduct heat readily in one direction and block it in another. Thermal conductivity of pyrolytic graphite will run 50 to 1,000 times higher in a direction parallel to the surface than in a direction perpendicular to the surface. At the same time, the material retains the high sublimation temperature of regular graphite, approximately 6,600^{o}F.

Up until now, radiation heat transfer generally has been considered a comparatively unimportant factor in re-entry heating. The important phenomenon has been aerodynamic heat transfer. But both types of heat transfer vary with altitude, velocity and dimensions of the re-entry vehicle, and at high enough densities and velocities, radiation becomes the dominant form of heat transfer from the hot, compressed gases ahead of the vehicle, Moreover, under certain conditions, an equilibrium is reached in which a body will radiate heat away as fast as it is received.

An important drawback here has been that equilibrium temperatures for today's re-entry vehicles are well above the destruction temperatures of most materials. However a vehicle made of pyrolytic graphite would reach an equilibrium temperature well before it reaches the sublimation temperature of the graphite graphite.

Since pyrolytic graphite does not ablate or erode significantly, the cone maintains its original design. This factor is critical in re-entry applications where changing configurations can lead to aerodynamic instability and loss of accuracy.

Plans to make re-entry bodies maneuver so that their courses will be unpredictable and hard to intercept are already considered.

SAFETY AND HANDLING PROCEDURES

Special purpose ground handling equipment is provided for re-entry vehicles, and in the interst of safety for personnel and equipment, only specified equipment should be used. This equipment normally consists of towable trailers and special purpose adapters, which will permit disassembly inspection, repair, assembling and monitoring of the re-entry vehicle arming and fusing systems, plus specified monitoring of the warhead. Care must be exercised in handling the re-entry vehicle, during maintenance cycles and indexing/deindexing cycles, to prevent damage to the heat shielding or heat absorbing surfaces, as minor scratches on these surfaces may be cause for rejection of the vehicle.

Personnel must be cognizant of, and well trained in radiation characteristics and radiation safety, as there are certain devises in the arming and fusing systems that contain "Kryptan 85", which is radioactive. In addition to radiation, the re-entry vehicle release mechanism must be handled with care. The release mechanism generally contains an explosive squib, therefore, only qualified personnel, trained on the specific system are to be responsible for installation, check out or removal of the release mechanisms.

Each type and series re-entry vehicle will have peculiar safety factors. You will be primarily concerned with the type assigned a particular weapon system, and will get the more specific details in the OZR course. However, "an ounce of prevention is worth a pound of care", is an excellent quideline.

SUMMARY

The future is filled with exciting problems. But the present is reality, and the basic re-entry problem has been solved.

QUESTIONS

1. What are the two main problems which are encountered during re-entry?
HEAT SHOCK

a. Steep angle MAX HEAT SHOCK MIN TIME

b. Shallow angle MIN HEAT SHOCK MAX TIME

2. What effect does the angle of a re-entry have on the problem?

3. What is the relation between vehicle velocity and heat?
HEAT IS PROP TO CUBE OF VELOCITY

4. What role does the shock wave play in re-entry?
INSULATE RE-ENTRY VEHICLE

5. Name the different ways of dissipating heat during re-entry and explian the principle of operation of each.

a. HEAT SINK - CONDUCTION
b. ABLATION - CONVECTION
c.
d.

6. What does the phrase "thermal barrier" mean?
HEAT PROBLEM

7. Is ascent-heating a problem with missiles? Explain.
YES - SOLID FUEL ACCELERATE FAST

8. What are the objectives of the designer of nose cones?
PROTECT THE WARHEAD
MAX HEAT + SHOCK WITH MIN WEIGHT

9. What does the term "anistrophy" mean?
GREATER CONDUCTION IN ONE DIRECTION THAN THE OTHER

10. What type of nose cone is presently used on our ICMB's?
ABLATIVE
What are its advantages and its limitations?

11. List an advantage and a disadvantage for the following ablative substances:

a. Ceramic

Advantage: HIGH ABLADIVE QUAL

Disadvantage: EXPENSIVE
BRITTLE

b. Plastic

Advantage: LIGHTER, WORKABLE, CHEAPER

Disadvantage: LOW ABLAPIVE QUAL

c. Metal

Advantage: SHOCK

Disadvantage: HEAVY

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Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard Air Force Base, Texas

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DAY 40B

PROPELLANT LOADING

OBJECTIVE:

To familiarize you with the basic characteristics of propellants, the equipment necessary for transfer and the hazards involved.

INTRODUCTION:

Before World War II propellants had been established mainly in the field of small arms. During peacetime they were studied at a low level, chiefly for use as sporting powders for civilian use. The advent of rockets in World War II and the use of extruded propellants changed the whole outlook on solid propellants. Also the work on liquid propellants culminating with the V-2 made the world aware that the rocket was a major factor in warfare. Recent developments in the long range missiles have made it clear that the space age is here.

With the tremendous growth in the rocket propulsion field it behooves us to have a basic understanding of the nature and characteristics of liquid and solid propellants. The safety of propellants is a particularly important subject since they are in general highly reactive chemicals. Consequently the propellants and their reaction products possess certain hazardous properties which must be fully understood by all who are required to handle them.

HISTORY OF PROPELLANTS

Propellants have as their major objective to impart motion to an object. They are usually associated with missiles and rockets, yet their origin is actually buried in antiquity. The Chinese are credited with the discovery.

The oldest of the propellants is gunpowder. It is a mixture of charcoal, sulfur and potassium nitrate, the composition of which has varied little since it was first devised. The first use of liquids as propellant material is not well known, but the first published scientific experimentations were those of Goddard in 1919. He is generally recognized as the pioneer in the field. As a result of increased activity on rocket propellant research and development during World War II there emerged a group of solid propellants called composite propellants. These are similar to black powder in that they are mixtures rather than homogeneous compounds like nitrocellulose. The first composite rocket appeared about 1945. The time since then has seen this group of propellant assume a major role in the propellant field.

PROPELLANT CHARACTERISTICS

Conventional aircraft engine uses fuel and air for its operation. The rocket on the other hand, does not need air because the necessary oxidizer supply is contained within the propellant. Therein lies the difference between propellants and fuels. A propellant or propellant system can be described as a balanced source of potential energy containing the necessary ingredients for conversion to useful kinetic energy to propel a vehicle. A fuel is one of the ingredients, the other material being the oxidizer in a chemical propellant. When the propellant contains all of the ingredients in one single molecule, this is termed "mono-propellant". In a "bipropellant" the fuel and the oxidizer are separate distinct entities stored in different places.

The two main classes of propellants are based on their physical character; solid propellants and liquid propellants. The solid propellants can be arbitrarily divided into two groups. The first group being the homogeneous propellants examplified by nitrocellulose-containing compositions. The second group consists of those compositions which are mixtures of fuel and oxidizer. The oxidizer is a finely ground inorganic crystalline material while the fuel is of a plastic nature, acting as a binder to hold the mixture in a uniform structure. This group of propellants is called the "composite" or "heterogenious" type.

Homogeneous propellants are thermoplastic, that is they soften with increasing temperature, have smooth, almost waxy appearance. They usually possess an odor characteristic of the plasticizer used. This type of propellants is processed into the desired shape by two methods - extrusion and casting.

In the composite solid propellants the oxidizer is the major constituent; therefore, it contributes most of the burning characteristics. Physical properties, however, are largely influenced by the binder. The most common oxidizers are potassium perchlorate, ammonium perchlorate and ammonium nitrate. A great variety of materials are used as binders, such as asphalt, phenolic resin, polystyrene, and synthetic rubbers. On the basis of the oxidizer type, composite propellants are divided into sub-groups. Potassium perchlorate compositions are characterized by relatively high burning rates and high flame temperatures and produces a very dense smoke. Formulations containing ammonium perchlorate have somewhat lower burning rate and flame temperatures and produce relatively little smoke. Propellants made with ammonium nitrate have the slowest burning rates and lowest flame temperature with little smoke production. To compensate for the low flame temperature aluminum powder is added.

There are two main groups of liquid propellants, mono and bi-propellants. There are two conflicting requirements for monopropellants, namely, that they be stable for storage yet readily combustible without added oxidizer. This has limited the number of materials suitable for such use.

There are many stable materials for bipropellants, and innumerable combinations of oxidizers and fuels have been utilized. It is generally conceded that there are a number of suitable fuels but no really ideal oxidizers.

A monopropellant is a substance which does not need the addition of another ingredient to bring about the release of its thermochemical energy. These materials are stable at ordinary temperatures and pressures, but react when heated, under pressure or in the presence of a catalyst to give hot combustion gases. Since there is only one liquid involved, the feeding system for a monopropellant engine is relatively simple.

In a bipropellant system, the fuel and the oxidizer are stored separately in the missile and the mixing takes place in the combustion chamber. For convenience, bipropellants are often classified as "hypergolic" spontaneously ignited, or "non-hypergolic" not spontaneously ignited.

Although all propellants undergo combustion and are transformed into gaseous products, the mechanism by which this is accomplished differs for each class and type of propellant. In the liquid propellants, droplet formation, vaporization, and flow rates are important factors. For solid propellants, the propellants, the propellant surface conditions, propellant composition, and the mechanical structure of the propellant grains are of importance. Mixing is important for liquid bipropellants but not for liquid monopropellant.

TRANSFER EQUIPMENT

Liquid propellant fuels and oxidizers are, in general, highly reactive chemicals, therefore, special equipment must be provided for their storage and transfer. The transfer equipment usually consists of an oxidizer transfer subsystem, a fuel transfer subsystem, electrical and pneumatic supply equipment and associated ground support equipment required for operation, control, and maintenance of the system. There is, exclusive of some support equipment, a complete propellant transfer system for each missile emplacement.

A basic propellant transfer subsystem consists of the storage tank, transfer lines, umbilicals, valving (pressure regulating, flow regulating, relief, vent and drain) and a high-pressure pneumatic bottle manifold. See figure 1. The transfer subsystem stores, controls, and regulates the flow of gaseous nitrogen and propellant to the missile.

If liquid oxygen were used as the oxidizer, the storage tank must consist of two cylindrically shaped tanks, one within the other, similar to a vacuum bottle. The inner tank is made of stainless steel and the outer tank of reinforced aluminum. To provide insulation of the inner tank the annular space between the tanks is evacuated of air and filled with a dry powdered material. The fuel tank, on the other hand, is not insulated as the liquid oxygen tank, because most of the common fuels being used today have a relatively high vapor pressure thereby obliviating the problem of "boiloff". However, if a cryogenic fuel is used, insulation must be provided the same way as for the liquid oxygen.

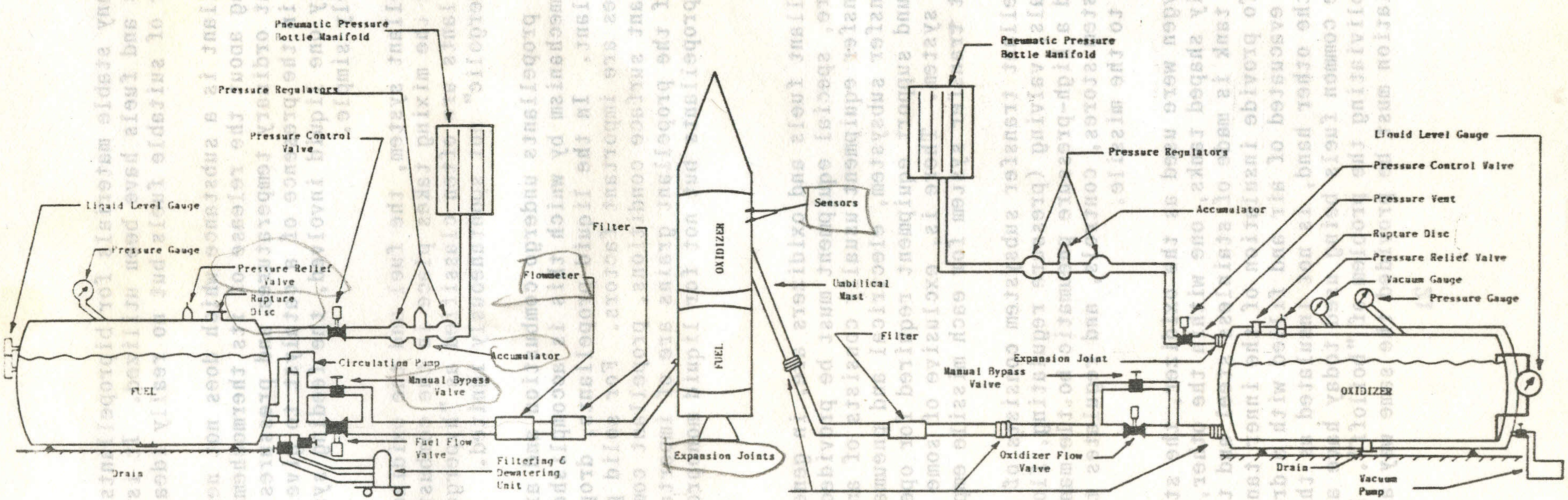

Figure 1
Basic Propellant Transfer System

Fire and explosion hazards have an important influence on the design of main storage units and on their location with respect to each other and to populated building and areas. Fuel and oxidizer must be separated by distance or barrier. Storage tanks should be diked and protected from effects of direct sunlignt, and ventilation should take advantage of prevailing winds and natural terrain. Ample water for fire fighting, and decontamination must be provided. Ready storage quantities of fuels and oxidizers should be the minimum quantity required for the operation. Emphasis should be placed on approved safety devices, equipment and material. Material for construction of valves, lines, etc is selected so that they are compatible with the propellant being transferred.

SYSTEM OPERATION

The transfer system stores and automatically loads the propellants and compressed nitrogen gas into the missile upon command. During launching countdown, the control manifolds are pressurized; the storage tanks are pressurized, the propellants are regulated, controlled, and simultaneously pressure-loaded into the missile; and the missile bottles are pressurized. Countdown operations for propellant transfer and subsequent missile launch are initiated, controlled, and monitored from the launching countdown group. Propellant transfer system operation is possible in three different environments: dry exercise countdown, launching countdown, and wet exercise countdown.

Prior to a launching countdown the propellant transfer system must be in a ready condition. During a ready condition the fuel, oxidizer, and pressurized nitrogen are stored in sufficient quantities and the pneumatic, solenoid and manually operated valves are in normal position. Checkout, servicing, and adjustment procedures have been performed and dry nitrogen purge pressure of a few psi is maintained in the transfer lines, missile, and ground storage tank.

A dry exercise countdown is accomplished to verify that maintenance functions have been properly performed and to verify weapon system readiness. During this exercise, the automatic sequencing of the propellant transfer system valves is verified by simulating propellant loading.

Prior to initiating a dry exercise countdown certain manually operated valves are closed to prevent propellant transfer. The complete propellant loading operation sequence is simulated by positioning switches on the propellant transfer system checkout panel and the rocket engine checkout control monitor in the missile checkout station. The propellant flow is simulated by positioning the sensor switches on the propellant transfer system checkout panel.

During the dry exercise countdown any malfunction is isolated by utilizing troubleshooting procedures. Malfunctioning components are repaired or replaced as required.

During the launching countdown, the entire propellant transfer operation is is automatically sequenced. The automatic sequence is a series of events in which the initiation of a function depends on the successful completion of the preceding function. The completely automatic operation of the propellant transfer system during countdown excludes any checkout or troubleshooting procedures. The launching countdown is initiated on the launch officer missile control panel. From the start to end, the functioning of the propellant transfer system is completely automatic.

A wet exercise countdown (with propellant flow) is accomplished to verify weapon system operational readiness. The wet exercise countdown differs from a launching countdown due to the following conditions: a wet checkout kit is installed in the fuel transfer line which routes the fuel to a fuel servicing trailer rather than the missile fuel tank and the engine igniter circuitry is disconnected.

CHECKOUT AND MAINTENANCE

Checkout of the entire propellant transfer system is possible only during a wet exercise countdown. However, checkout of propellant transfer subsystems or components can be performed at any time. Valve position checks, pneumatic and solenoid valve functional checks, subsystem leak checks, and computer checks are performed at regular intervals to insure operational readiness. Checkouts are accomplished at the launch emplacement utilizing the necessary ground support checkout equipment.

Propellant transfer system troubleshooting is accomplished as required at the launch emplacement during the pneumatic and solenoid valve functional check. Two or more men are required to perform the troubleshooting procedures.

The propellant transfer system regulators are adjusted at regular intervals and during subsystem leak check procedures to insure that they are set at correct operating pressure. The regulators are adjusted in groups according to the subsystem in which they are contained. During adjustment procedures, the electrically controlled valves throughout the propellant transfer system are positioned by signals from equipment in the checkout station. Shutoff and bleed valves are used to provide a controlled flow of gaseous nitrogen through the regulators during adjustment procedures.

Servicing procedures are performed at the launch emplacement to insure that adequate supplies of contaminate-free propellant and pressurized gas are stored and are available at all times. Each of the propellant tanks must at all times contain a supply sufficient to load, unload, and reload the missile. In the case of liquid oxygen, the volume of the liquid is constantly diminisning as a result of boiloff, therefore, a constant monitoring of the storage tank is necessary to insure an adequate volume of the oxidizer.

SUMMARY:

Propellants are used to impart motion to vehicles. A propellant system may be described as a balanced source of potential energy containing the necessary ingredients for conversion to useful kinetic energy. Propellants are divided into two main groups by their physical nature - solids and liquids. Solid propellants are again divided into sub-groups of homogeneous type and composite type depending on their composition. There are two main types of liquid propellants, mono- and bi-propellant; the main difference being the former requires no addition of an oxidizer.

Due to the hazardous properties of the chemicals being used as propellants, extreme care must be taken in their storage and handling. Special equipment and tools must be used which are compatible with the chemicals and their reaction products.

QUESTIONS:

1. What is the definition of propellant?
POTENTIAL ENERGY TO KENTIC

2. What is the difference between homogeneous and composite solid propellants? HOMO- COMPOUND
COMPOSITE- MIXTURE

3. In a composite solid propellant what determines the burning characteristics? OXIDIZER

4. How is low flame temperature compensated in a solid propellant?
AL POWDER

5. What is a monopropellant?
OX + FUEL IN ONE COMPOUND

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STUDENT NOTES

DAY 41-42

MISSILE ROCKET PROPULSION

OBJECTIVES:

To provide you with information pertinent to missile propulsion.

INTRODUCTION:

Understanding of missile fundamentals includes a study of the operations and theory which propel the missile. A firm knowledge of this is an important factor in the performance of an individual's functions. Information provided in this text includes a brief history of rocket propulsion, theory, related terminology, and practical application both present and future.

ROCKET HISTORY

The first known source of rocketry was its use by the Chinese as early as 1232. The Chinese had a weapon called the "arrow of flying fire". This was a small package of incendiary powder which on being ignited produced the propelling force for an arrow. The powder was believed to come from a Greek invention called wildfire.- a combustible mixture of various ingredients.

The idea reached the Arabs a few years later and by 1250 the concept had spread to Europe. The Germans, Italians, and French all came up with formulations concerning rocket development. The real boom, however, was brought about in Great Britain by Sir William Congreve in 1800. Congreve experimented with solid propellants and actually developed working models. He believed that his new invention would prove to be an excellent weapon replacing their artillery. The stabilization of the Congreve rocket was poor and inadequate, but through the efforts of William Hale, another Englishman, the stabilization problems were overcome and rockets had a tremendous role during the wars of this period.

The first liquid rocket invention is claimed by Pedro E. Paulet a South American engineer from Peru. Paulet made a successful test using Nitrogen peroxide and gasoline as propellants. His test stand and equipment resembled many later inventions but he failed to publish his works for some twenty-five years. In Europe the Germans pushed ahead under the direction of a young engineer, Wernher von Braun. The Russians made a definite stab at liquid rockets with a proposal for an oxygen and hydrogen propelled vehicle. The French came up with a unique rocket powered aircraft developing 10,000 lbs thrust using liquid propellants. In America, Professor Robert H. Goddard was hailed as the American father of rockertry. He first experimented with solid propellants and later liquids. Goddards experiments in liquid rockets led to working models and many refinements involving stabilization. His work can truly be said to be the ground work for our present liquid rockets.

PHYSICS OF ROCKET PROPULSION

Consideration of the theory of propulsion is made possible by the work of Sir Isaac Newton. In 1687 Newton formulated a series of laws of motion which are universally accepted. By applying these laws to the concept of rocket propulsion we are able to mathematically compute and analyze rocket engine operation.

Rocket propulsion is based on the reaction principle. This principle states that for every action there is an equal and opposite reaction. This is Newton's third law. In a rocket engine, propellants are injected into the combustion chamber and burned. The hot gases are then accelerated and ejected through the exhaust. The force which pushes the gases out of the nozzle is the action force according to Newton's second law. This states the rate of change of momentum in any direction is proportional to the force acting in that direction. The resulting reaction is the thrust which propels the missile. This is Newton's third law. A common example of the reaction principle might be a water hose. There is a tendency for the hose to move in a direction opposite the stream of water. This movement is the reaction to the action force of the expelled water.

If we were to take a closed cylinder which contained a combustible mixture and ignited it, the pressure would rise and probably cause a rupture in the cylinder. However, if one end was opened, the expanding gases would exhaust, causing a force in the opposite direction. The Force formula can be mathematically stated by the relationship $F=PA$, where P is the pressure in the cylinder and A the area of the exit.

Greater force may be obtained if we can further reduce pressure by increased gas expansion. To do this we add a nozzle to the exit of the cylinder. The amount of amplification this nozzle contributes to the original force is proportional to the value given to the nozzle coefficient (C_f). Thus, $F=PAC_f$. Since thrust is a "push" force we can call force and thrust the same. Now $T=PAC_f$.

A more practical method of computing thrust can be accomplished by means of the fundamental thrust equation. This equation provides a method of determining the thrust for a particular rocket engine. Since the engine being considered is a basic rocket engine with a combustion chamber and a nozzle at the exit, the thrust will be a result of the force accelerating the exhaust gases. The gases start at a low velocity at the combustion chamber and are accelerated to a high velocity at the nozzle exit. Assume the velocity at the exit remains constant and is termed V_e. This is the theoretical exhaust velocity and is the average velocity across the exit. The rate the propellant

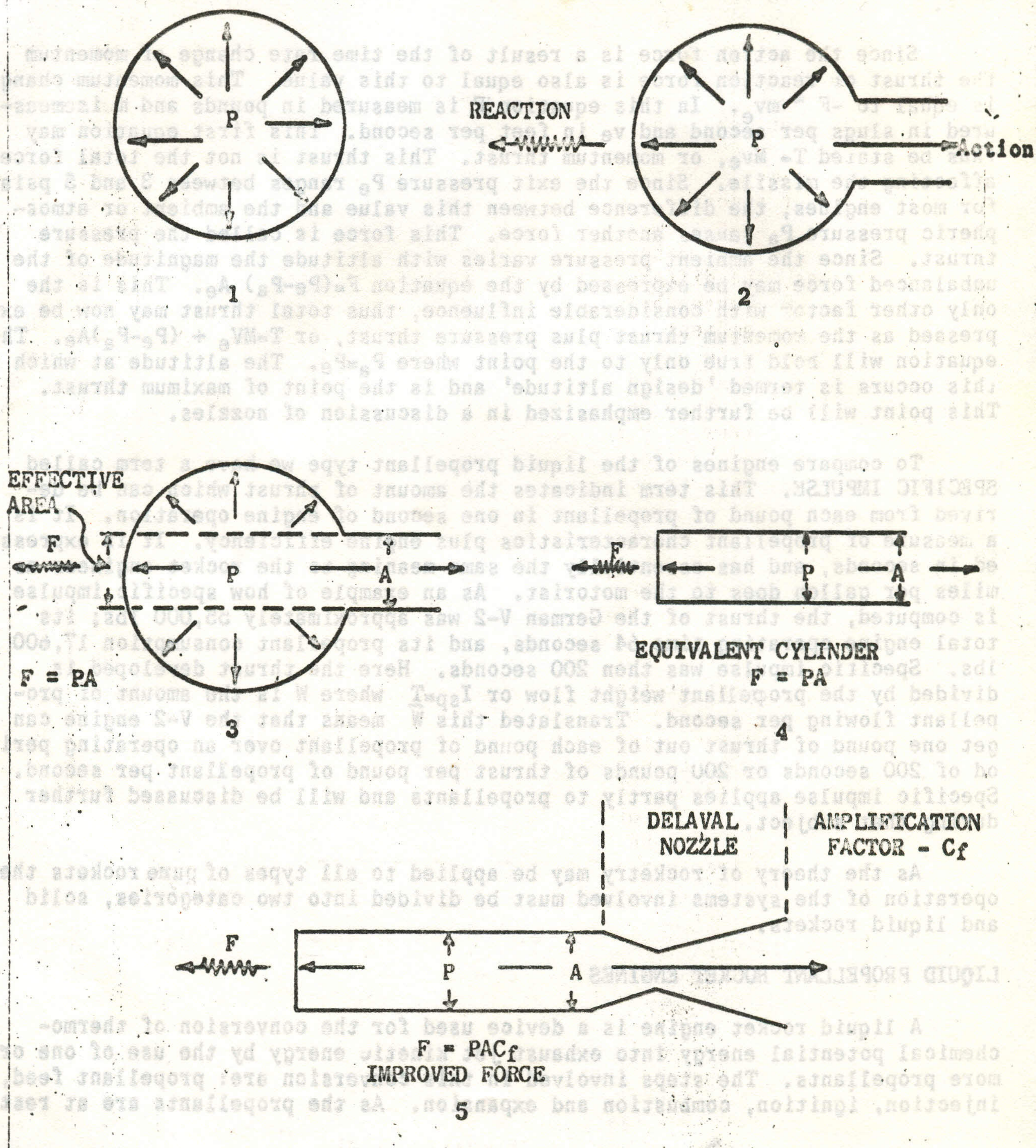


Figure 1
Rocket Propulsion Theory

Air Force-Jame

enters the combustion chamber and leaves the nozzle exit remains constant with time and is termed the mass rate flow or (M), called M dot. If the exit velocity is assumed constant the exit pressure may also be assumed constant. This pressure will be termed P_e and is the average static pressure across the nozzle exit.

Since the action force is a result of the time rate change of momentum the thrust or reaction force is also equal to this value. This momentum change is equal to $-F = mv_e$. In this equation F is measured in pounds and m is measured in slugs per second and v_e in feet per second. This first equation may thus be stated $T = Mv_e$, or momentum thrust. This thrust is not the total force affecting the missile. Since the exit pressure P_e ranges between 3 and 5 psia for most engines, the difference between this value and the ambient or atmospheric pressure P_a causes another force. This force is called the pressure thrust. Since the ambient pressure varies with altitude the magnitude of the unbalanced force may be expressed by the equation $F = (P_e - P_a) A_e$. This is the only other factor with considerable influence, thus total thrust may now be expressed as the momentum thrust plus pressure thrust, or $T = MV_e + (P_e - P_a)A_e$. This equation will hold true only to the point where $P_a = P_e$. The altitude at which this occurs is termed 'design altitude' and is the point of maximum thrust. This point will be further emphasized in a discussion of nozzles.

To compare engines of the liquid propellant type we have a term called SPECIFIC IMPULSE. This term indicates the amount of thrust which can be derived from each pound of propellant in one second of engine operation. It is a measure of propellant characteristics plus engine efficiency. It is expressed in seconds, and has essentially the same meaning to the rocket engineer as miles per gallon does to the motorist. As an example of how specific impulse is computed, the thrust of the German V-2 was approximately 55,000 lbs; its total engine operating time 64 seconds, and its propellant consumption 17,600 lbs. Specific impulse was then 200 seconds. Here the thrust developed is divided by the propellant weight flow or $I_{sp} = \frac{T}{W}$ where W is the amount of propellant flowing per second. Translated this means that the V-2 engine can get one pound of thrust out of each pound of propellant over an operating period of 200 seconds or 200 pounds of thrust per pound of propellant per second. Specific impulse applies partly to propellants and will be discussed further during that subject.

As the theory of rocketry may be applied to all types of pure rockets the operation of the systems involved must be divided into two categories, solid and liquid rockets.

LIQUID PROPELLANT ROCKET ENGINES

A liquid rocket engine is a device used for the conversion of thermochemical potential energy into exhaust jet kinetic energy by the use of one or more propellants. The steps involved in this conversion are: propellant feed, injection, ignition, combustion and expansion. As the propellants are at rest until they are required for use by the engine they need a means to be transferred to the combustion chamber. There are numerous propellant feed systems.

One of the simplest methods is that of using gas pressure to pressurize the tanks and force the propellant out. This is an excellent system for low thrust and short duration rocket units such as "ratio" units. The system includes a tank to supply pressure or some other innovation which produces a high pressure gas to pressurize the propellant tanks. The pressure is controlled and maintained by valves and regulators. This system is generally lighter than a turbopump system for the small rocket applications. For large intercontinental missiles the system would be much too bulky and heavy to supply the large quantities of propellants needed.

CHEMICAL PROPULSION SYSTEMS

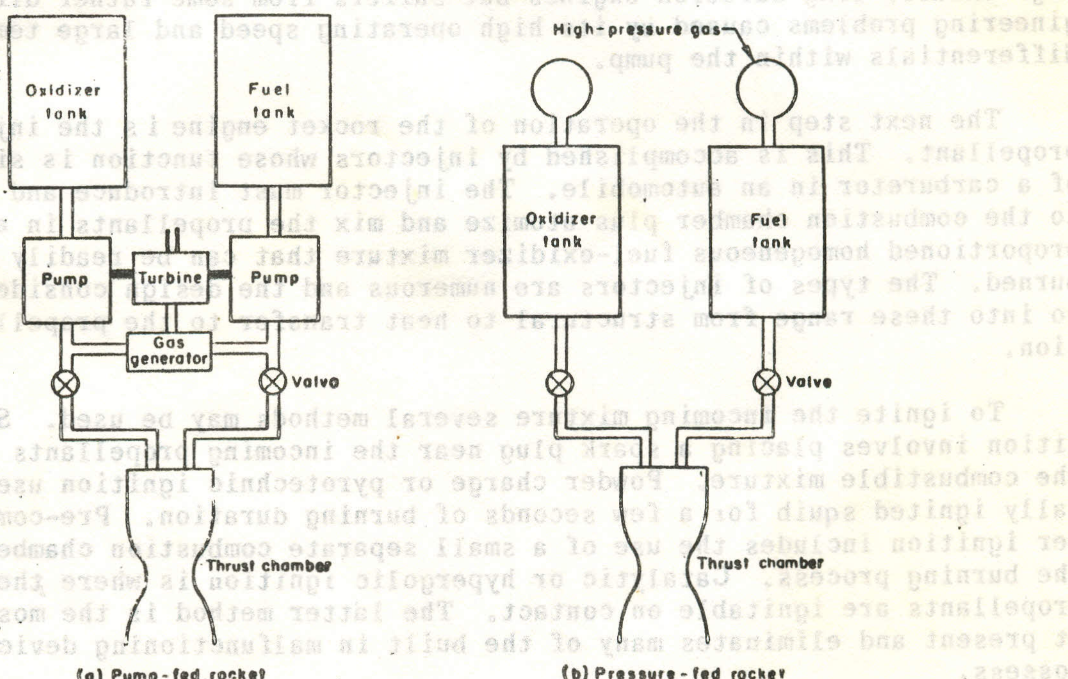


Figure 2
Schematic of liquid-propellant rocket

Its operation is simple. A propellant feed system is not necessary. Injection is also eliminated as the propellant is stationary. Ignition is accomplished by means of a pyrotechnic or powder charge device, which is generally located toward the forward portion of the combustion chamber. Solid rockets are also equipped with nozzles which provide for increased gas expansion.

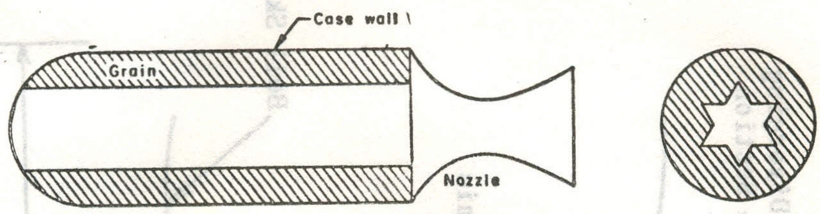


Figure 3

Schematic of solid-propellant rocket

In the solid propellant engine the combustion takes place throughout the engine. From this it can be said the solid rocket is one large combustion chamber. The liquid engine has a separate combustion chamber into which the propellants are injected and burned. Both engines produce hot gases in their chambers thus giving a high gas potential energy and a low kinetic energy. The resulting pressure and temperature are very high. To utilize these properties in the form of thrust we must convert the potential energy to kinetic energy and since kinetic energy equals $\frac{1}{2}Mv^2$, the objective is to obtain a high velocity value. This is done in most cases for both solids and liquids by the DeLaval nozzle.

The DeLaval nozzle is a converging - diverging type nozzle. Its operation is simple but unique. The expanding gases force the gas particles to the rear of the nozzle, increasing velocity and lowering potential energy. As the gases enter the converging portion of the nozzle the decrease in cross sectional area causes an increase in the velocity of the flow of gases. The maximum velocity that can be reached in this section occurs at the throat and corresponds to the local sonic velocity at this section. When the gases reach sonic velocity their flow properties reverse. Thus by addition of a diverging section the gases are further expanded and the velocity again increases. If a nozzle is to accomplish its goal of gas expansion certain conditions must be met. The first is that of reaching sonic velocity at the throat. To reach this velocity the ratio of the chamber pressure to throat pressure which is called the "critical pressure ratio", must be obtained. Once this critical pressure ratio is reached the velocity at the throat will always correspond to the throat sonic velocity regardless of any further pressure increases in the combustion chamber. When a nozzle reaches this condition it is said to be choked.

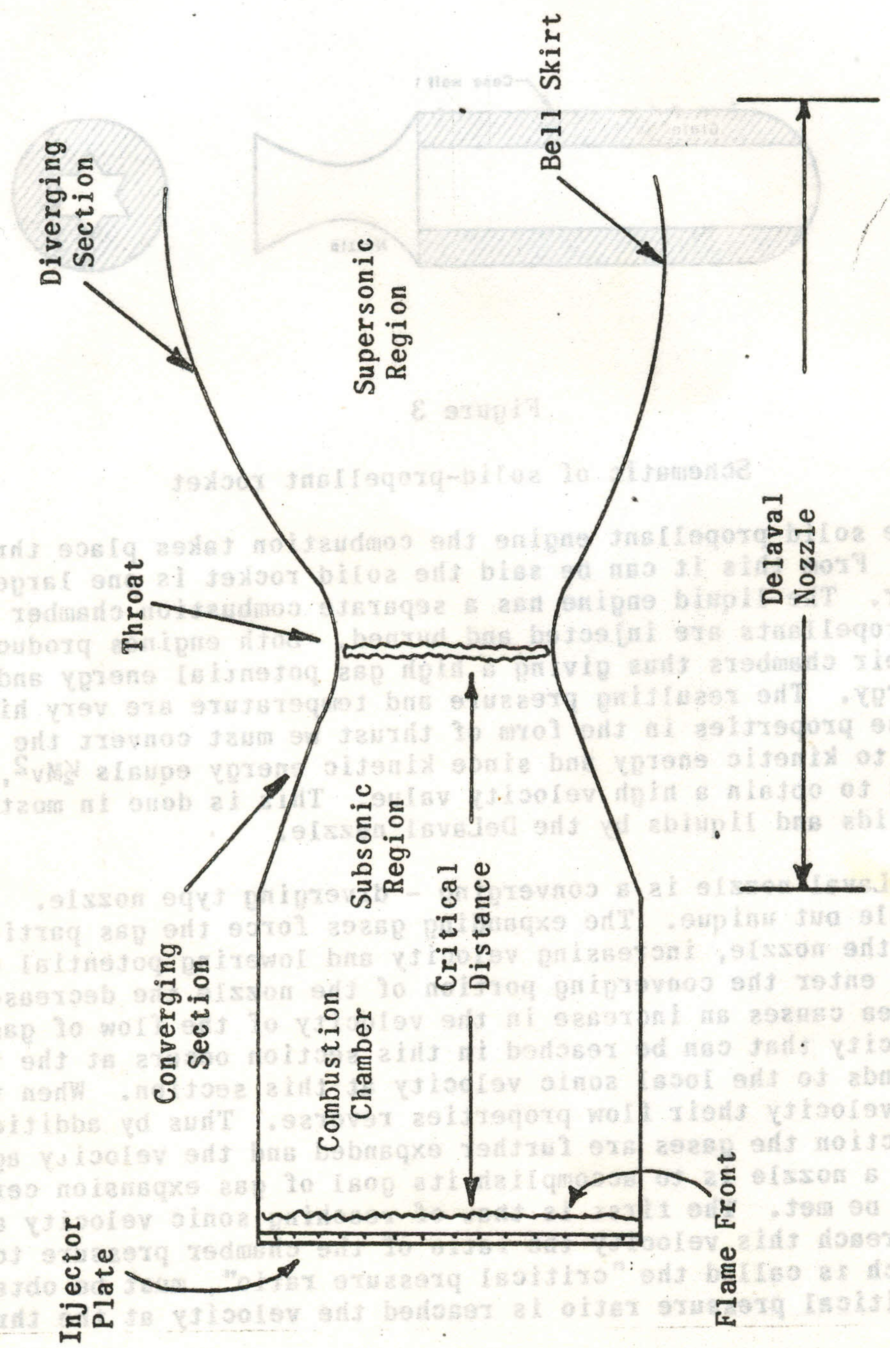


Figure 4
DELAVL NOZZLE and COMBUSTION CHAMBER
(LIQUID ROCKET)

Engine calibration must not be disturbed so we must rely upon the depot for replacement or repair of any component or part affecting this calibration. This would include such items as the turbopump assembly, gas generator, and orifices.

Documentary control of inspections and maintenance tasks completed is necessary for accurate engine history. Without accurate engine logs and records, such as replacement dates of parts subject to deterioration and parts replacement records, the efficiency of the maintenance concept would be impaired.

NEW DEVELOPMENTS

Chemical combustion is now used in rocket propulsion because no other means of accelerating mass to high exhaust speeds has been perfected. Other, more promising systems under study include:

Nuclear fission - In this power plant, the enormous heat energy of atomic fission is used to help create an exhaust thrust. Heat itself does not produce thrust, but a nuclear reactor can be used to heat some substance which, when channeled through a nozzle in conventional rocket engine fashion, produces a reaction. Among substances suggested as the "working fluid" are liquid hydrogen, helium and ammonia. Performance of a nuclear rocket would be limited by the energy content of the working fluid and temperature limitations of the reactor materials. Specific impulse estimates for nuclear rockets range from 600 to 1,500 seconds. Rocket engineers doubt that we will be able to achieve thrust through direct exhaustion of nuclear fission particles.

Nuclear fusion - The fusion rocket would use the force of the H-bomb, the energy created in the uniting or fusing of the lightest atomic nuclei into heavier nuclei. A likely fuel would be deuterium, a form of hydrogen, which is abundant in the oceans and hence a better long term fuel than the uranium used in atomic fission. Heating deuterium to very high temperatures would create a high speed plasma (hot gas) capable of specific impulse ratings in the millions of seconds. It is estimated that temperatures around 350 million degrees would be needed to sustain a fusion reaction. As solid walls would not stand up under such conditions, it has been proposed that exhaust masses be contained by magnetic fields shaped as nozzles. Before fusion can be applied to rocket propulsion, scientists must learn how to control fusion energy in the laboratory.

Ion Power - Ions, which are atoms unbalanced electrically by the removal of one or more electrons, are accelerated to high speeds by electrical fields. The ions can be formed by passing a "propellant" through an ionizing device. The source of electrical energy can be a nuclear reactor, battery, or a solar radiation system. Exhaust velocities would be very high, but due to the low mass of the ion particles, the ion rocket would have relatively little thrust and therefore would not be suitable for surface launch when strong gravity must be overcome. Chemical or nuclear rockets could boost ion vehicles into space, or the vehicles would be assembled and launched in orbit.

Arc Heating - An electrical arc is used to heat a working fluid which is expelled through a nozzle. Energy for the arc might be derived from nuclear reactor batteries or solar radiation.

Photon Power - A beam of light exerts pressure. Thus very high radiation of photons (light particles) could provide sufficient thrust to move a vehicle in space. Again, the low mass of photons would result in low thrust and low acceleration, but particle velocities would be 186,000 miles per second, the speed of all electromagnetic energy. Theorectically a photon-powered vehicle could accelerate close to the speed of light. However, no method of radiating tremendously intense beams of light is known.

SUMMARY:

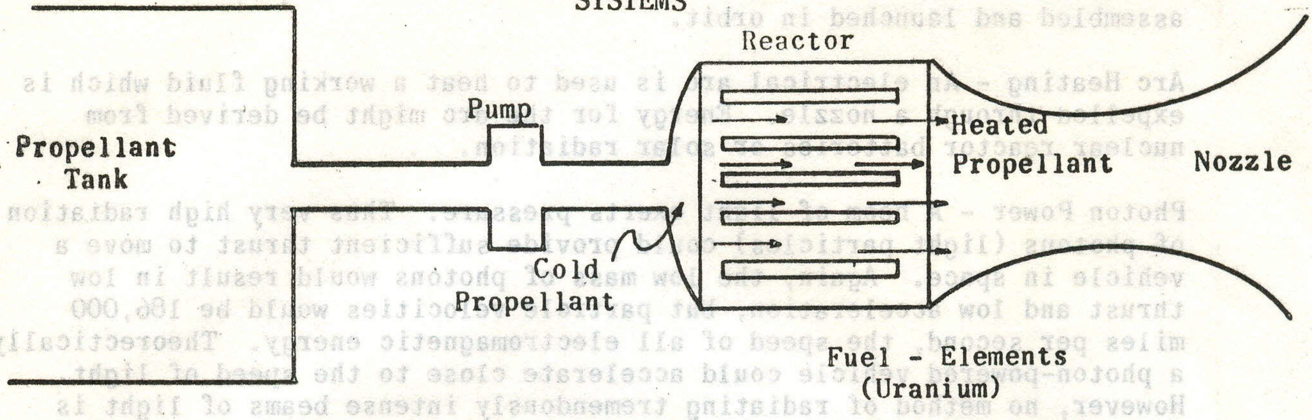
Since the early Chinese weapons of war to the far out dreams of Van Braun, have come theories and experiments related to the field of rocketry. From these, man has developed working systems based on the principle of rocket propulsion, thereby bringing him closer to his desires for an ultimate weapon and further enabling him to display his adventurous and exploring spirit.

Our present development is only a glance at things to come. The chemical propulsion systems in use at present represent one of the many methods available. Common to these systems is the DeLaval nozzle, which we accept as a standard for all engines. This however, is only one method of system design; new methods are now being developed.

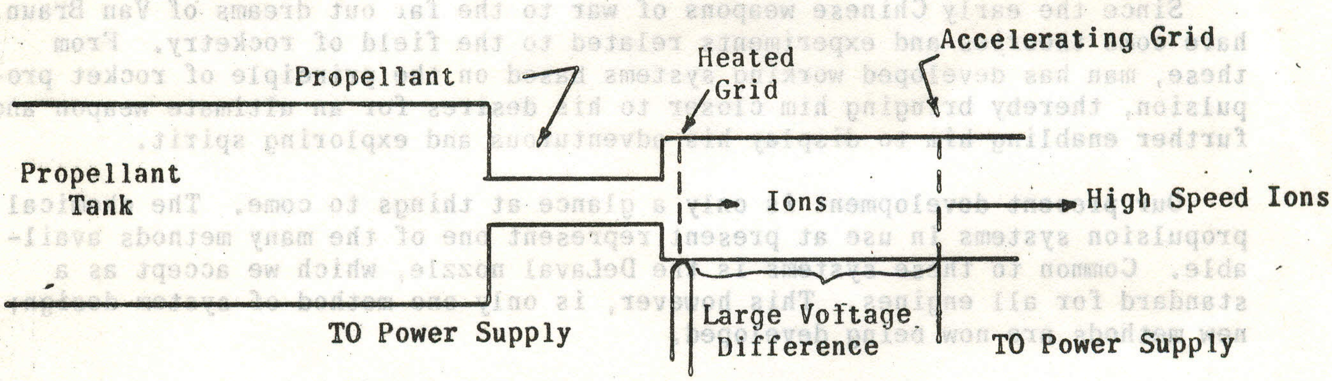
In our exploitation of the field of chemical rocket propulsion both solid and liquid systems have been used. Each has its advantages and disadvantages. The liquid system offers us the capability of powerful long range missiles, capable of carrying reasonably large payloads. This is accompanied by proportionally large problems, as the system is complex and bulky. Conversely, the solid rocket system presents considerably fewer problems. However, the solid rocket has limited capabilities, since large high thrust motors are currently in the development phase. Due to the relative simplicity of solid rocket systems, refinement in their present development may give the solid systems the leading role as future military and space boosters.

The advantage of a system with fewer parts is obvious. There would be less possibility of malfunction and the amount of maintenance required would be reduced considerably. The liquid system requires numerous daily and periodic inspections. This is complicated by the numerous parts that must be calibrated and properly adjusted. In a solid system much of this maintenance will be eliminated. There will, however, be a need for daily and periodic

FUTURE PROPULSION SYSTEMS



NUCLEAR ROCKET



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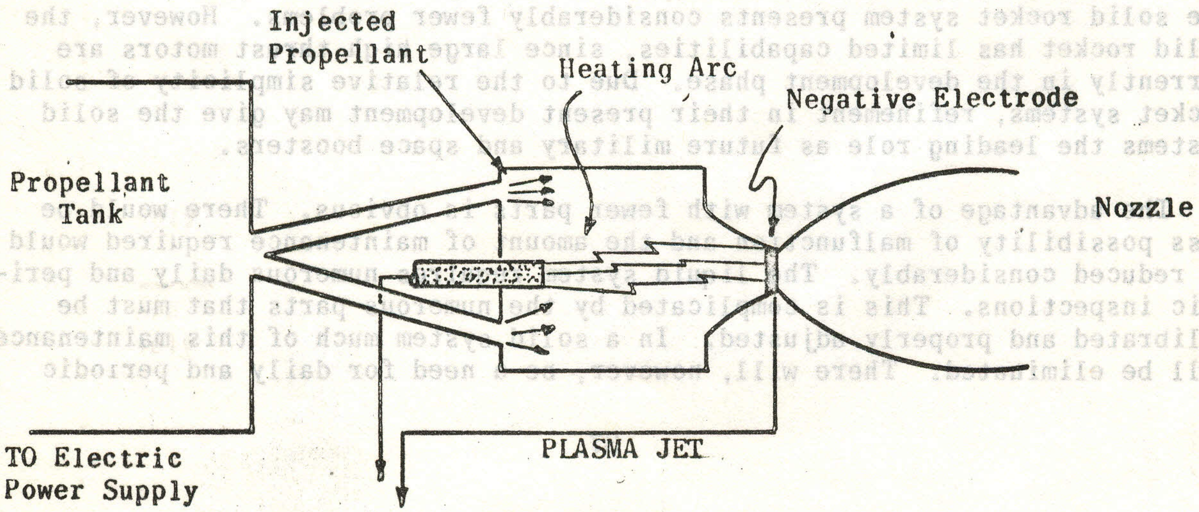

PLASMA JET

Figure 5

inspections and properly kept records.

In an attempt to increase thrust and overall performance all known methods of propulsion are under investigation. This includes methods involving all known sources of energy, coupled with an investigation of improving present methods of combustion and expansion.

QUESTIONS:

1. What is the purpose of a nozzle and how does it accomplish this purpose?
   1 EXPAND GAS TO GET HIGH GAS VELOCITIES
   2. CONVERGENT AND DIVERGENT

2. Why do we have such a term as specific impulse?
   EFFICIENCY OF PROPULSION SYSTEM

3. Why is the turbopump propellant feed system most commonly used today?
   EFFICIENT

4. ~~How have nozzles been adapted to solid propellant rockets?~~

5. What are some of the advantages and disadvantages to solid rockets?
   1. SIMPLE 1. LESS POWER
   2.

6. ~~What type of engine maintenance is carried out at the site?~~

7. What seems to be the next step in the future of rocket propulsion?
   NUCLEAR

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STUDENT NOTES

DAY 43

RADIO GUIDANCE SYSTEM

OBJECTIVE:

To acquaint you with radio guidance methods used in the ICBM.

INTRODUCTION:

In a discussion of guided missiles, perhaps the method of guidance most immediately though of by the layman is that of some form of radio or radar. This means of controlling the movement of an object through space has numerous historical precedence. Two of those are the radio controlled aircraft (drone) and the remote-controlled marine vessels. The development and refinement of existing radio guidance systems has proceeded through the years. The result has been an extremely sophisticated system capable of tracking and guiding an ICBM. This system functions effectively even at the extremes in speed and distance.

RADIO-INERTIAL GUIDANCE

As applied to missiles, radio-inertial guidance is simply a method of directing a missile into a trajectory by using radio signals to determine and control the missile position. The objective is to guide the missile onto a trajectory which includes the target.

Several methods of accomplishing this objective are available. In a previous lesson when the "beam-rider" principle was discussed, it was found that the ground radio equipment assumed a passive role and merely provided a radio beam coinciding with the desired flight path. The missile, provided with appropriate receiving equipment, remained oriented to the beam throughout the powered portion of its flight and ideally positioned itself on the beam to achieve the desired trajectory.

Another type of radio guidance system is that employed by the Air Force GAR I, an air-to-air missile. Here the missile is carried by an interceptor and is electronically linked to the radar system of the aircraft. The missile contains only a radar receiver, which is linked to a set of flight control surfaces capable of deflecting the missile's path when in flight. The radar system of the aircraft detects the target and alerts the missile receiver to the reflected signal. At a computed position and time the missile is fired, guided by the reflected energy of the interceptor radar and homes in to the target. The advantages and disadvantages of such a system are too technical for the purposes of this discussion. It can be seen, however, that we have effectively reduced the amount of guidance equipment required to be carried in the missile, thus saving space and weight.

Another refinement is employed in the radio-inertial guidance system of the ICBM. Here the command signal origination is transferred from the missile to the ground subsystem. The ground equipment is now charged with the additional duty of continuous tracking of the missile, as well as computing the position relative to the target and the trajectory.

The distinction between this and other remote-control methods is important. Other less sophisticated systems, merely provide a means of controlling the movement of an object. The movement can be made with reference to some visual purpose or the system may simply provide a means of control with respect to no specific reference. For example, the controls of a drone aircraft can be manipulated to direct the flight path in any given direction within the limitations of the system. The drone can also be made to fly along a specific track, but only is some means of observing the drone and the flight path is introduced to the system. This would close the loop of the guidance system by providing necessary feedback. This is the method actually used.

One might argue that the distinction drawn is really a specious one, since with the inclusion of performance feedback, the system of our example appears indistinguishable from that used in the missile. The difference is one of technique. In the drone example, we used two channels of communication. One was for performance detection (visual, radar or some other) and the other for commands. In this case, our command was the controlling radio frequency. In the missile, however, only one channel of communication is used. Let us consider a typical launch to see how this is accomplished. See Figure 1.

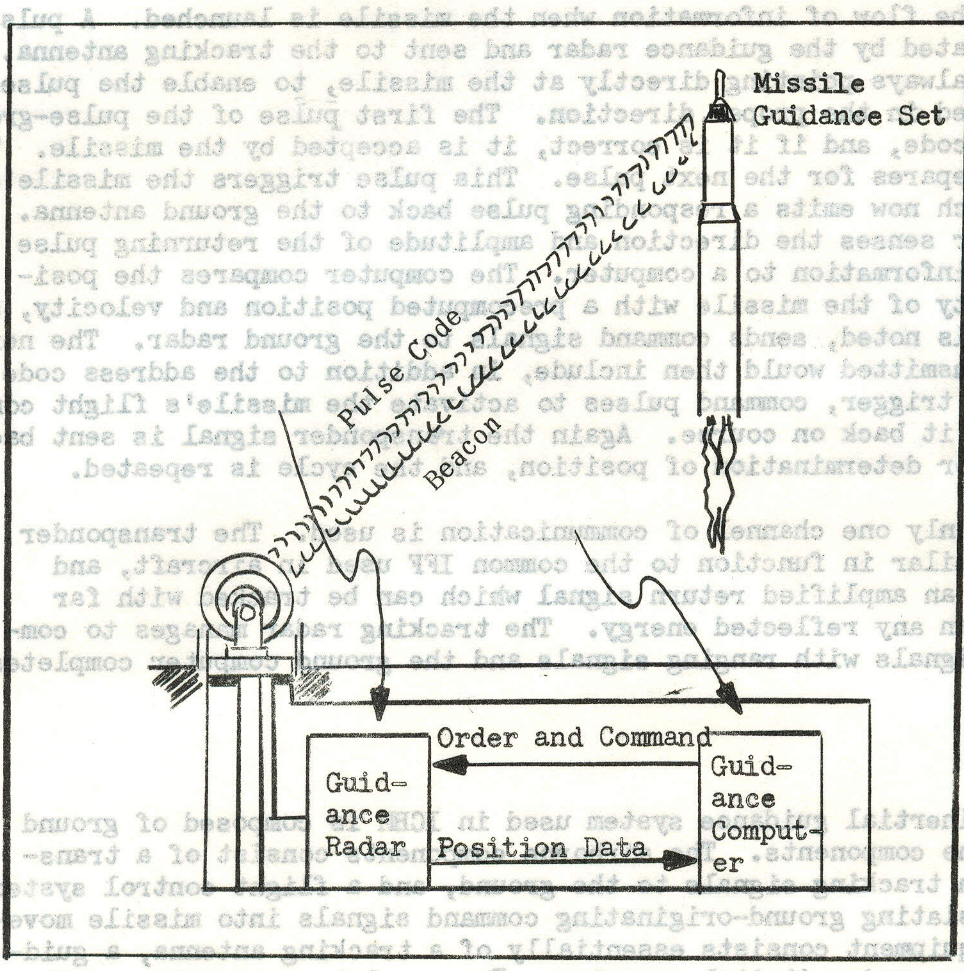


Figure 1 - Radio Inertial Guidance (Block Diagram)

At some time before launch the guidance radar is locked-on the missile. The directional antenna is aimed directly at the missile, but no command signals are transmitted. The guidance radar operates continuously at a fixed pulse repetition frequency (PRF) producing pulse-groups composed of individual pulses which perform three functions.

First - Signals are address-coded so the missile will respond only to the radar controlling it.

Second - Signals are coded to trigger an answering pulse from a transponder contained in the missile for tracking purposes.

Third - Signals are coded into pitch and yaw commands to control steering.

Consider the flow of information when the missile is launched. A pulse-group is originated by the guidance radar and sent to the tracking antenna. The antenna is always pointing directly at the missile, to enable the pulse to be transmitted in the proper direction. The first pulse of the pulse-group is the address code, and if it is correct, it is accepted by the missile. The missile then prepares for the next pulse. This pulse triggers the missile's transponder which now emits a responding pulse back to the ground antenna. The ground radar senses the direction and amplitude of the returning pulse and sends this information to a computer. The computer compares the position and velocity of the missile with a precomputed position and velocity, and if a deviation is noted, sends command signals to the ground radar. The next pulse-group transmitted would then include, in addition to the address code and transponder trigger, command pulses to activate the missile's flight controls and bring it back on course. Again the transponder signal is sent back to the ground for determination of position, and the cycle is repeated.

Note that only one channel of communication is used. The transponder used is very similar in function to the common IFF used in aircraft, and merely produces an amplified return signal which can be tracked with far greater ease than any reflected energy. The tracking radar manages to combeing command signals with ranging signals and the ground computer completes the loop.

SUMMARY:

One radio-inertial guidance system used in ICBM is composed of ground and missile-borne components. The airborne components consist of a transponder to return tracking signals to the ground, and a flight control system capable of translating ground-originating command signals into missile movement. Ground equipment consists essentially of a tracking antenna, a guidance radar system, and a digital computer. The complete system is capable of tracking and guiding the powered path of the missile throughout the speeds and distances normally encountered. It is considered particularly effective in that it has effectively reduced the weight and complexity of the load carried by the missile.

QUESTIONS:

1. What guidance equipment is carried in the ICBM discussed in this text?

2. Explain the coding of a typical pulse-group.

3. Where are the command signals originated?

REFERENCES:

1. TO 21-SM68-2F-7-1-1

2. AFM 52-31, Guided Missile Fundamentals

DAY 43A

PRINCIPLES OF MISSILE TRAJECTORIES

OBJECTIVE:

This text is to familiarize you with the basic principles of trajectories, the effects of earths rotation on a trajectory and variables affecting trajectories.

INTRODUCTION:

The process of moving from a known position to a desired position is a simplified definition for guidance. It would be expected that the known position for a missile would be the launch point and the desired position would be the target. However, this is not the case with ballistic missiles, where both the known and desired positions are points in space. A study of principles of missile trajectories will show that this is true.

MISSILE TRAJECTORIES

The type trajectory used by a missile depends upon the range and the capabilities of individual missile systems. Trajectories are distinguished by the phase of guidance system operation as shown in figure 1.

Midcourse guidance is a common type which allows the missile to be controlled during most or all of the flight path. Since the propulsion system must be operating to permit guidance to function, this method has limited application. This type of guidance would be unsatisfactory for any missile that was unable to maintain propulsion for a long duration. However, it is a suitable system for a missile such as Matador or Snark.

When the latter portion of a missile trajectory is controlled it is referred to as a terminal guidance. In this case, some sort of target measurement must be employed to lead the missile to the target. Such a system should be very accurate if allowed to operate unhampered. The Sidewinder missile, which homes on a heat source, is an example of a terminal guidance system; however, at present there are no long range missiles which use this method.

The remaining method is to employ guidance only during the initial phase of flight. Ballistic missile uses this approach. The idea is to submit the missile

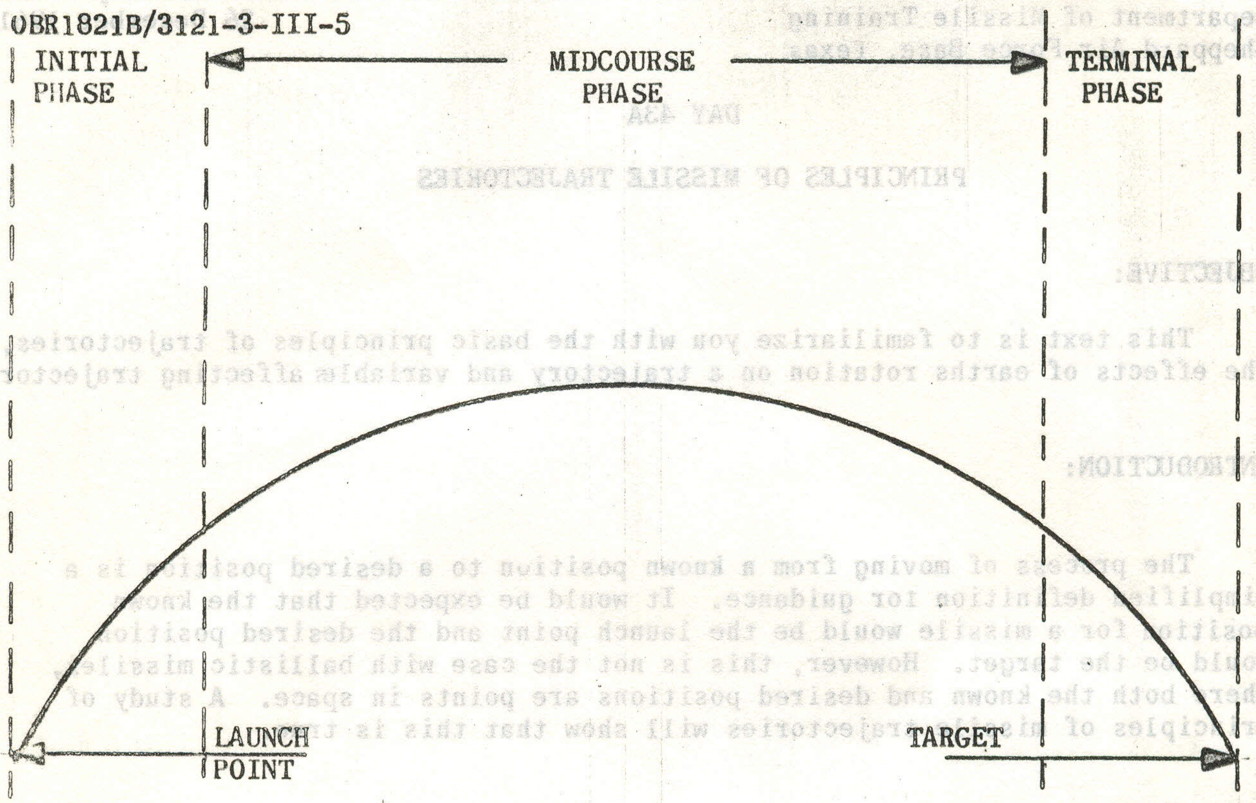


Figure 1
Guidance Phases

to very exact control during the first portion of flight. Then at some optimum point along the flight path the thrust and control are both stopped, the RV separates and follows a free fall path to the target. Long range missiles such as the Atlas, Titan and Minuteman have flight paths of this type.

BALLISTIC TRAJECTORY

A ballistic trajectory is the path followed by any rigid body which is given an initial velocity and allowed to free fall to the target. The path followed by a projectile after it leaves the muzzle of a cannon is a ballistic trajectory. The theory applied to a cannon projectile is identical to that of a ballistic missile.

To obtain a hit with a cannon the barrel must be aimed in the correct direction (azimuth and elevation) and the speed of the projectile leaving muzzle must be fixed. Once the projectile leaves the muzzle there is no further control exerted on its path. This means that both the ballistic trajectory and exact point of impact are determined by the muzzle conditions.

The missile, during powered flight, can be compared to the projectile in the cannon barrel. If the RV is traveling in the correct direction and at the right speed for its position at thrust cut-off it should hit the target. The purpose of the missile guidance system is to insure that these critical conditions have been attained. It would appear that the simplest approach for guidance control during powered flight would be to require the missile to follow a predetermined fixed path. Then at some exact point the powered portion would be terminated and the missile would follow a ballistic trajectory to the target.

A guidance system which would accurately accomplish these requirements is seldom used by ballistic missiles because of numerous variables that complicate the problem. The system which is actually used is based on the premise that an infinite number of ballistic trajectories exist to any target. Guidance must select the most satisfactory trajectory as influenced by the missile's position in space. This selection is continuous and is based upon the missile's capabilities and characteristics as it progresses along the powered portion of flight. However, when the missile reaches a position in space where the correct velocity (speed and direction) has been obtained, the guidance system stops missile power. The missile then follows the ballistic trajectory to the target.

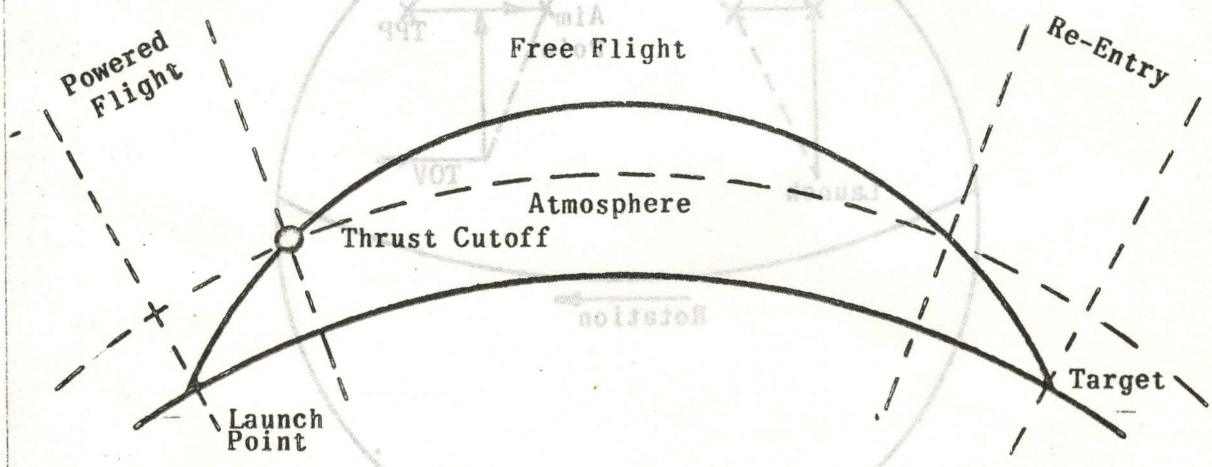


Figure 2 - ICBM Trajectory

EFFECT OF EARTH'S ROTATION

If the earth was a non-rotating body, the trajectory equations would be simplified due to the omission of the effects of Coriolis acceleration and rotation itself. Any point or object on the surface of the earth has an eastward velocity due to the rotation of the earth which amounts to 1044 mph at the equator and decreases to 0 at either pole. Two problems are caused by this - the movement of the target during the flight of the missile and the deflection of the missile.

During a 30 minute missile flight the target will have moved a certain distance which can be accurately computed from the target latitude and the flight time. The position the target will be at the end of the flight is called Targets Predicated Position (T.P.P.). In Figure 3 the left set of vectors illustrates this "lead" required to compensate for target travel during flight.

As a missile leaves the earth it will be deflected in an eastwardly direction due to the earths rotation. This is called throw out velocity (T.O.V.) and varies from 1044 mph to 0 according to the latitude of the launch point. The amount of error which would result may be computed from the latitude of launch and flight time. This error would place the re-entry vehicle many miles east of the targets predicted position. To eliminate this error the error distance is applied to the targets predicted position in a Westerly direction. The new position, called aim point, is shown in the right set of vectors in Figure 3.

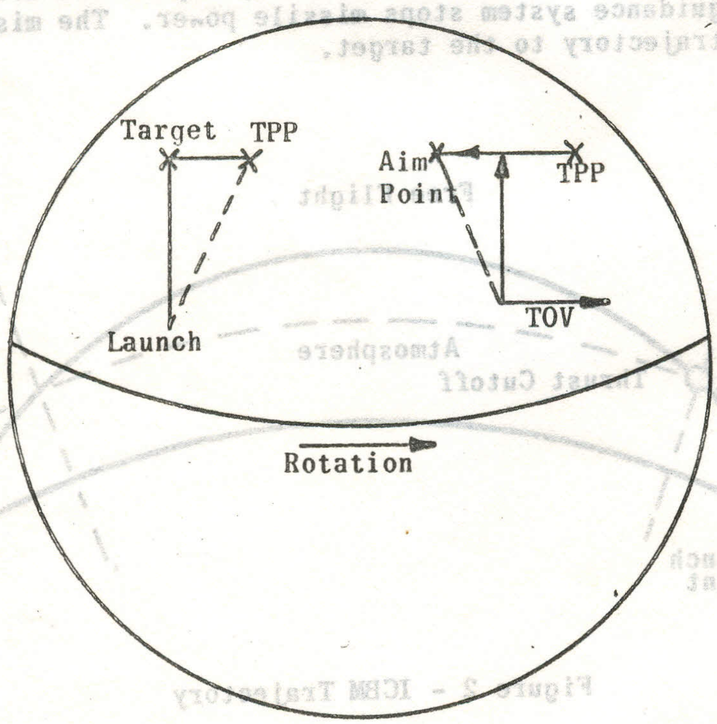


Figure 3 - Effects of Earths Rotation

Another effect of earths rotation is Coriolis acceleration or force. It is defined as a deflecting force acting on a body in motion, due to the earth's rotation which diverts horizontal motions to the right in the northern hemisphere and to the left in the southern hemisphere.

In figure 4 the impact points expected without Coriolis are marked X. The actual trajectories are deflected as shown due to Coriolis effect. A basic formula for Coriolis force would be:

Coriolis Force = 2 W V sin Ø

Where W = angular velocity of the earth

V = missile velocity

Ø = latitude at that moment

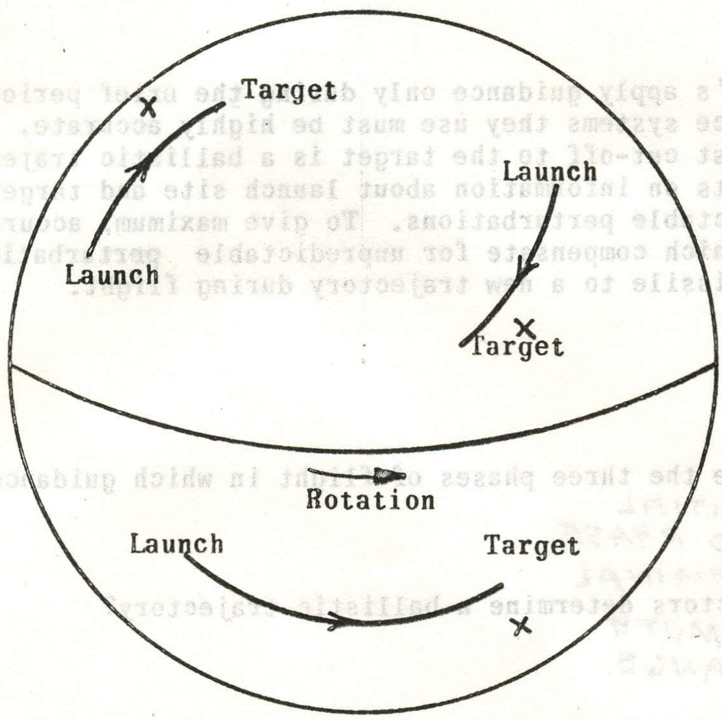


Figure 4 - Coriolis Effect

As latitude and velocity increase Coriolis effect will increase. It would be zero only for a missile flying along the equator.

TRAJECTORY VARIABLES

Forces affecting a trajectory other than earths rotation may be referred to as perturbations. In space flight, the resultant of all forces causing a disturbance on the orbit is known as a perturbative force. Perturbations make the navigational problem exceedingly complex. These perturbations may be classified as predictable and unpredictable.

Some predictable perturbations are: gravitational anomalies, the actual shape of the earth, factors bearing on the launch site and target such as altitude and weather at target. Some unpredictable perturbations are: missile drift, engine thrust variances, individual missile characteristics and gyro drift.

Predictable factors can be compensated for by pre-setting the information into the guidance system. Those unpredictable perturbations which occur prior to guidance, will be corrected by guidance providing certain requirements are fulfilled.

SUMMARY:

Because ICBM's apply guidance only during the brief period of powered flight, the guidance systems they use must be highly accurate. The actual path followed from thrust cut-off to the target is a ballistic trajectory. The guidance system acts on information about launch site and target positions, earths rotation and predictable perturbations. To give maximum, accuracy sophisticated systems are used which compensate for unpredictable perturbations by computing and steering the missile to a new trajectory during flight.

QUESTIONS:

1. What are the three phases of flight in which guidance may be applied?

   1. INITIAL
   2 MID PHASE
   3. TERMINAL

2. What factors determine a ballistic trajectory?

   AZIMUTH
   RANGE

3. Are predetermined flight paths normally used by ballistic missiles? Why? NO - UNPREDICTABLES

4. How is the velocity of a ballistic missile controlled?

   ENGINE CUT OFF

5. Give three ways in which earths rotation affects trajectory.

   1. CORIOLIS ACCL
   2. THROW OUT VEL
   3. TARGET MOVEMENT

6. What factors are used to determine targets predicted position?

   1. LAT OF TARGET
   2 TIME OF FLIGHT

7. Where would throw out velocity be greatest?

   EQUATOR

8. As velocity increases how will Coriolis force be affected?
IT WILL INCREASE

9. How can predictable perturbations be compensated for?
IN THE GUIDANCE SYSTEM

REFERENCE:

Dictionary of Guided Missiles and Space Flight

Webster's New Collegiate Dictionary

ACSP Student Study Guide

NOTES

Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard Air Force Base, Texas

OBR1821B/3121-3-III-6
Student Study Guide
20 December 1961

DAY 43B

POSITION AND RATE SENSORS

OBJECTIVE:

To familiarize you with position and rate sensor principles and their applications to Missile Guidance and Control Systems.

INTRODUCTION:

Operation of guidance and control systems depends heavily on sensing of position, speed and acceleration. Their accuracy can be no greater than that of the sensor devices which supply this information. There are two basic types of sensors - position and rate.

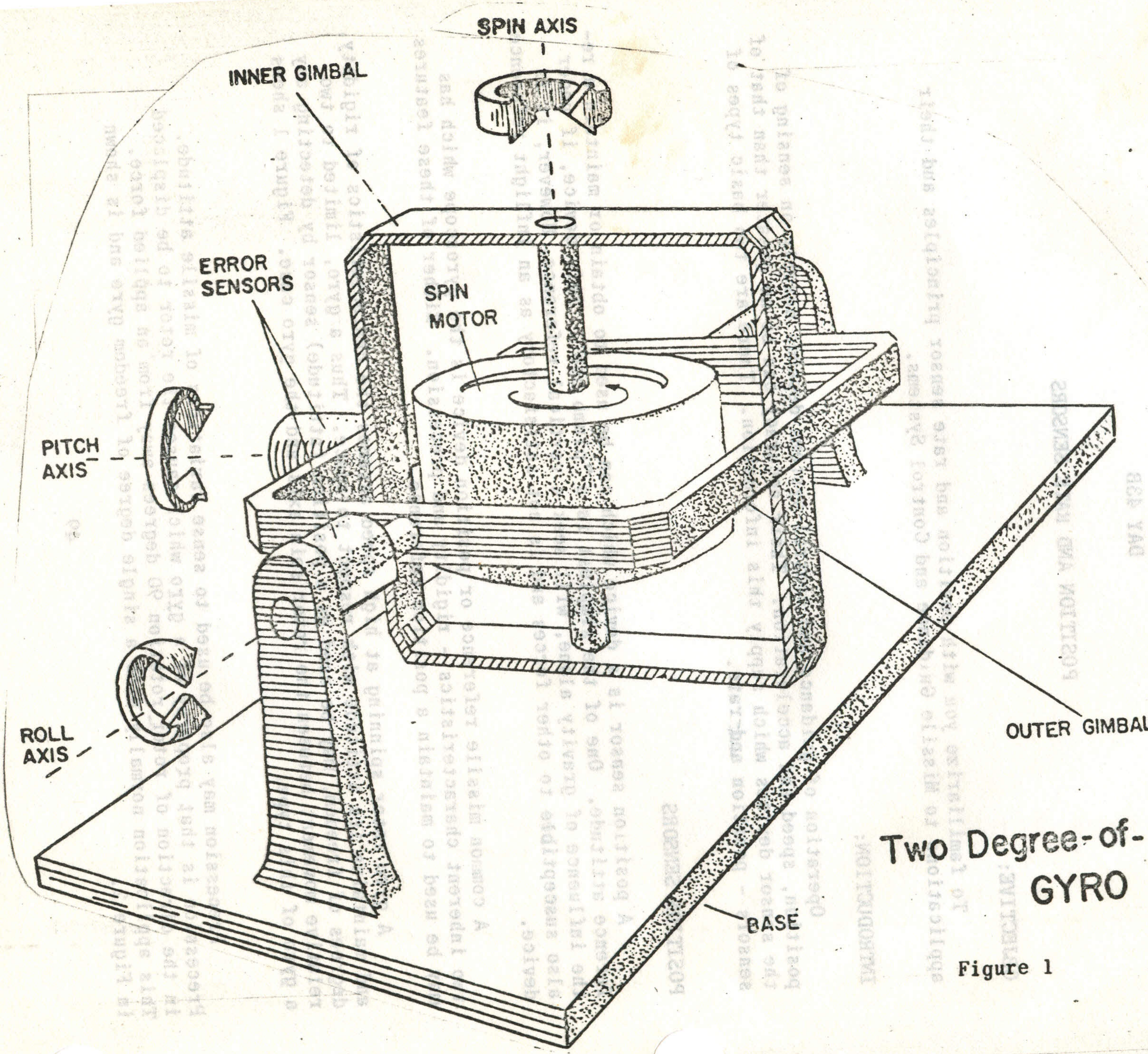
POSITION SENSORS

A position sensor is a device which can be used to obtain or maintain a reference attitude. One of the simplest is a "plumb bob". This device, if under the influence of gravity alone, will seek a vertical reference. However, it is also susceptible to other forces and is not satisfactory as an inflight reference device.

A common missile reference or position device is the gyroscope which has two inherent characteristics - rigidity and precession. Either of these features may be used to maintain a position reference.

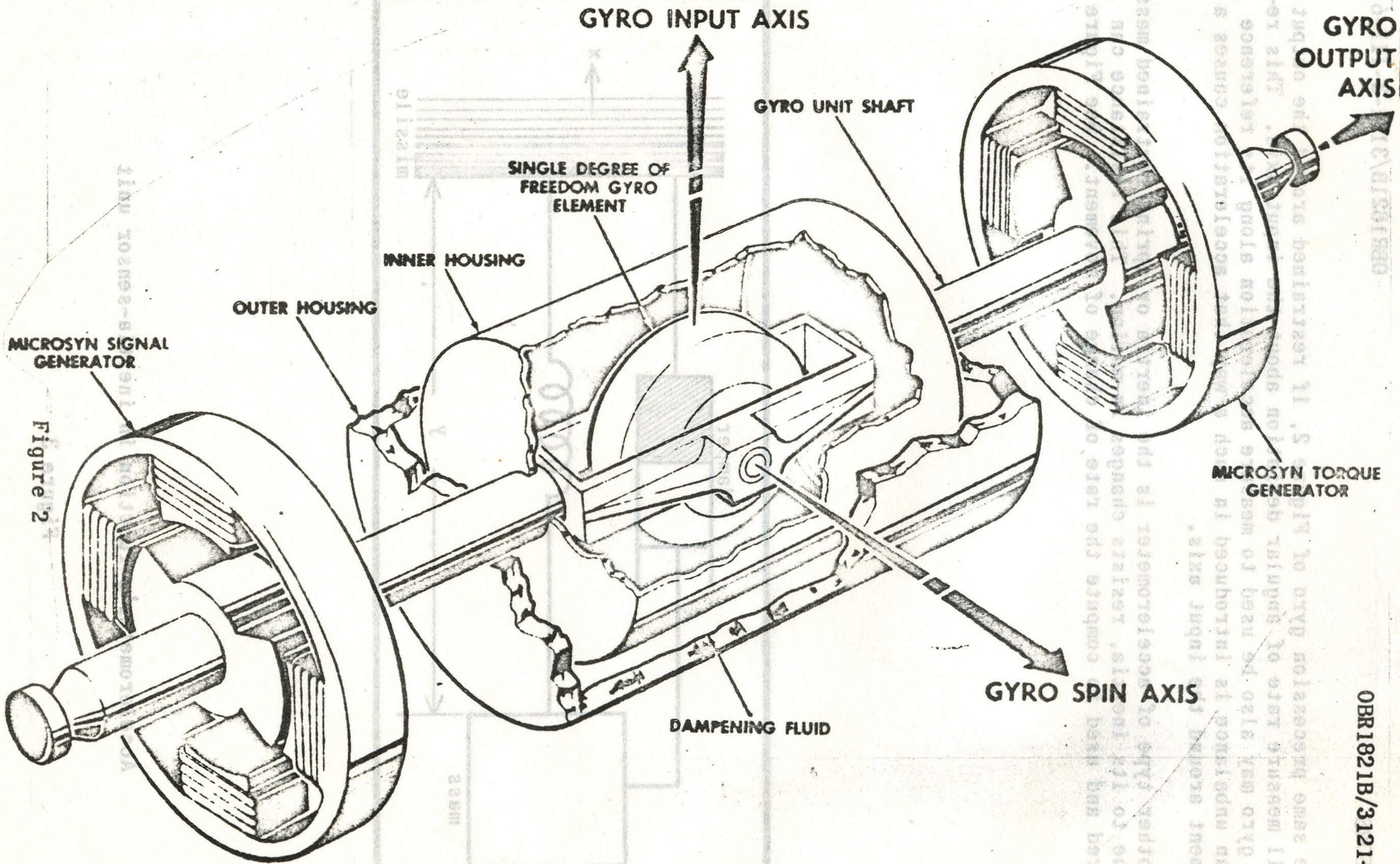
A gyro rotor spinning at high speed assumes the characteristics of rigidity, and maintains its attitude with respect to space. Thus a gyro, limited to two degrees of freedom, may be used as a position (attitude) sensor by detecting any relative movement between the rotor spin axis and the gyro case. Figure 1 shows a gyro of this type.

Precession may also be used to sense variations of missile attitude. Precession is that property of a gyro which causes the rotor to be displaced in the direction of rotor rotation 90 degrees away from an applied force. This application normally uses a single degree of freedom gyro and is shown in Figure 2.



Two Degree-of-Freedom GYRO

Figure 1

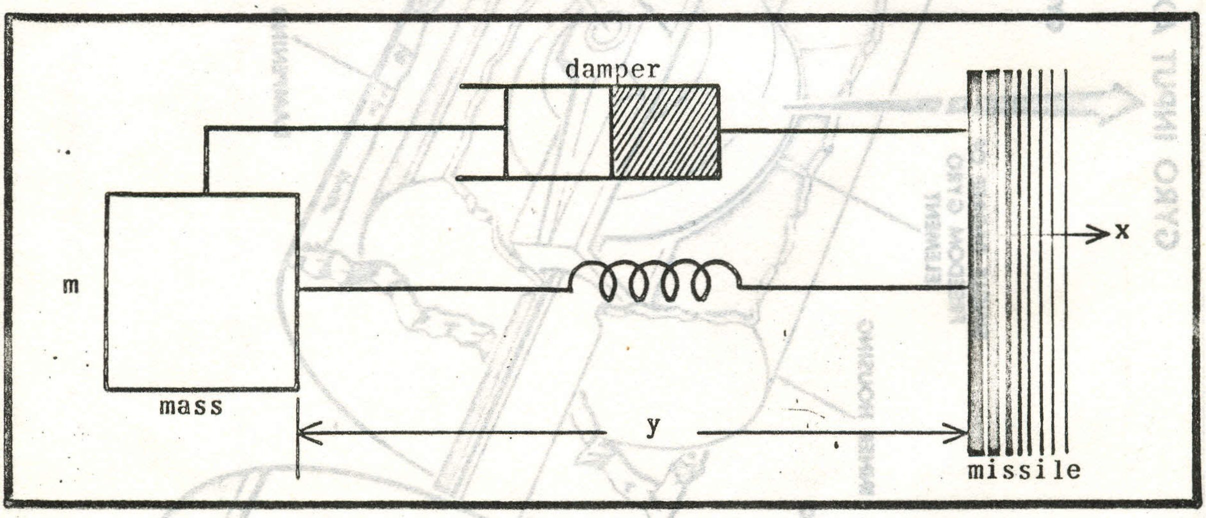


TYPICAL INTEGRATING GYRO

Figure 2

The same precession gyro of Figure 2, if restrained around the output axis, will measure rate of angular deviation about the input axis. This restrained gyro may also be used to measure acceleration along its reference axis if an unbalance is introduced in such a way that acceleration causes a displacement around the input axis.

Another type of accelerometer is the inertia or spring restrained mass which, due to its inertia, resists changes in motion. This resistance can be measured and used to compute the rate of change of movement. See Figure 3.



Accelerometer's function in inertia-sensor unit

Figure 3

In all of the sensing devices described above a signal pick off system is provided to convert mechanical movement into electrical signals, appropriately phased, which are utilized in guidance or control.

Although the sensors used in current guidance and control systems are more elaborate and sophisticated than the examples used here, the same basic principles apply.

SENSOR APPLICATIONS

Two degree of freedom gyros, utilizing the principle of rigidity, may be used to stabilize a guidance platform against all vehicular motion. This stabilized platform serves as a mounting pad for accelerometers.

Single degree of freedom gyros, utilizing the principle of precession are used in the flight control system to detect missile attitude deviations. This type gyro may also be used to stabilize a guidance platform if one is oriented on each axis.

The restrained (precession) gyro is used as an oscillation dampening device in conjunction with position gyros in the flight control system.

SUMMARY

The gyro, containing a rotor which can be rotated at high RPM, has inherent characteristics of rigidity and precession. Thus they are readily adaptable for detecting movement about their reference position, or measuring acceleration along a reference axis. Their output when converted to electrical signals by pick-off devices, provides essential information for guidance and control of an ICBM.

REVIEW QUESTIONS

1. How many degrees of freedom are required in the gyro mounting to utilize the principle of rigidity?

2. To utilize the principle of precession what degree of freedom will a gyro have?

3. What is the purpose of a stabilized platform?

REFERENCE: AFM 52-31

Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard AFB, Texas

OBR1821B/3121-3-III-7
Student Study Guide
3 January 1962

DAYS 44 AND 45

FLIGHT CONTROLS

OBJECTIVE:

To familiarize you with the basic operating principles and components of ballistic missile flight control systems.

INTRODUCTION:

The main purpose of the missile flight control system is stabilization of missile attitude about the roll, pitch and yaw axes during powered flight. In ballistic missiles it has the additional function of establishing the basic trajectory, although it neither monitors nor corrects for trajectory errors.

FLIGHT CONTROL SYSTEM PRINCIPLES

The principles of the missile control system are the same as in any automatic control system. Such a system constantly makes corrections of some controllable item, and then checks the results as a basis for further correction. This forms a cycle of interdependent action which is typical of a closed-loop control system.

There are four major requirements of any automatic control system:

1. The controlled item.

2. A means of detecting errors in the controlled item. (Sensor)

3. A means of using this error to decide upon a correction. (Control equipment)

4. A device for actually making the correction. (Corrector)

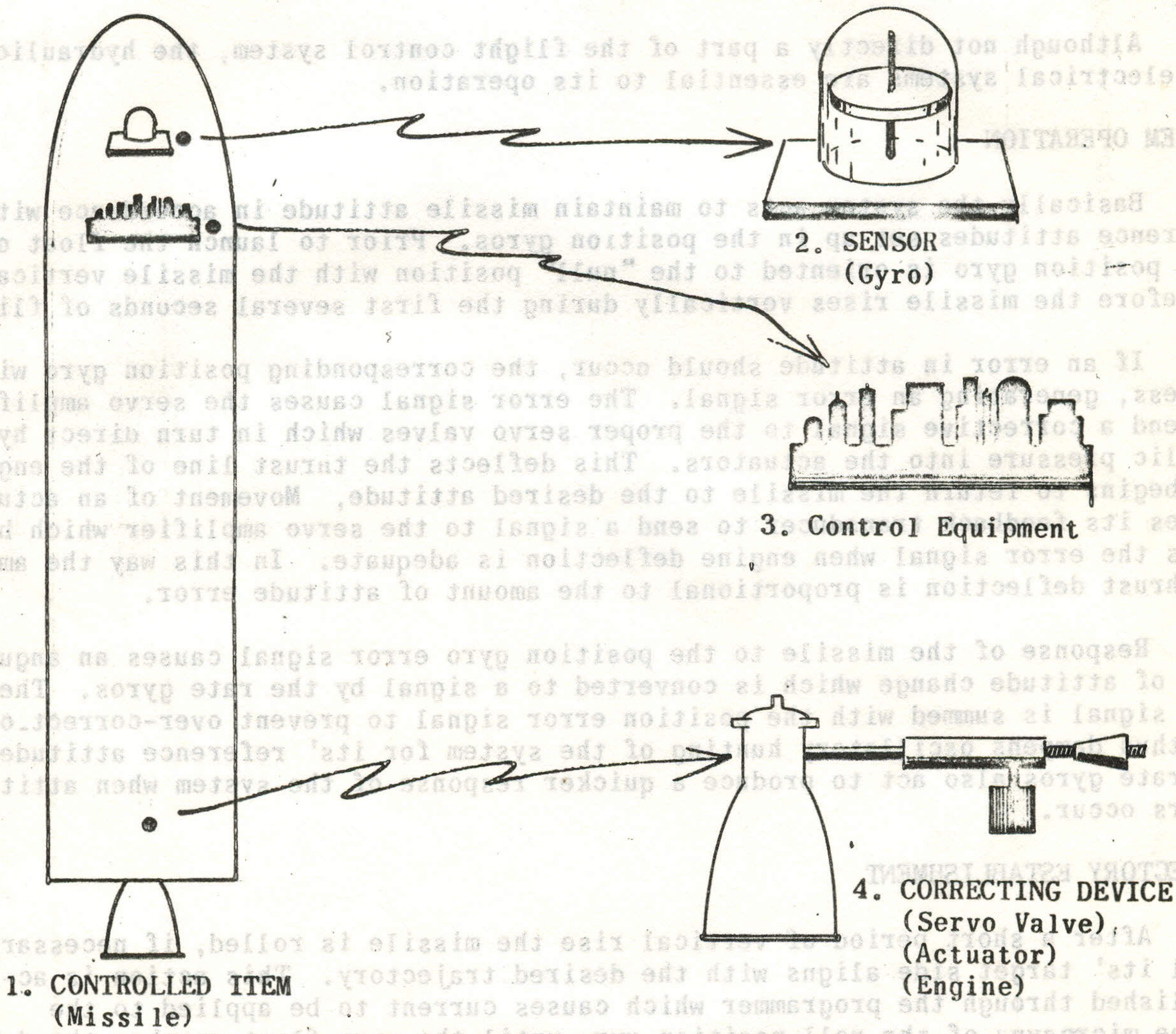
The controlled item is obviously the missile.

The sensing units are gyroscopes.

The correction <u>deciding</u> equipment consists of the electronic portion of the system.

The correcting device must be able to produce a force or moment to change the attitude of the vehicle.

Early missiles used aerodynamic control surfaces as a correction device. These are impractical for ballistic missiles since most of the powered flight is outside the atmosphere. Deflection of thrust is used to change attitude on present day ballistic missiles. Generally the engine thrust chamber is moved on a swivel joint (gimbal) by a hydraulic actuator. Figure 1 shows the basic units of a ballistic missile flight control system.



Four Principle Parts of Every Missile Control System

Figure 1

SYSTEM COMPONENTS

The airborne system is essentially a three axis autopilot and servo system made up of the following coordinated electrical, electronic and hydraulic components:

The flight controller is the principal component of the system. It contains position gyros, servo-amplifiers, a programming timer, target selection circuitry and control relays.

Three rate gyros are located in the center body section of the missile.

Two hydraulic actuators are linked to each engine; each actuator has a servo valve and a feedback transducer attached to it.

Although not directly a part of the flight control system, the hydraulic and electrical systems are essential to its operation.

SYSTEM OPERATION

Basically the system acts to maintain missile attitude in accordance with reference attitudes set up in the position gyros. Prior to launch the float of each position gyro is oriented to the "null" position with the missile vertical. Therefore the missile rises vertically during the first several seconds of flight.

If an error in attitude should occur, the corresponding position gyro will precess, generating an error signal. The error signal causes the servo amplifiers to send a corrective signal to the proper servo valves which in turn direct hydraulic pressure into the actuators. This deflects the thrust line of the engine and begins to return the missile to the desired attitude, Movement of an actuator causes its feedback transducer to send a signal to the servo amplifier which balances the error signal when engine deflection is adequate. In this way the amount of thrust deflection is proportional to the amount of attitude error.

Response of the missile to the position gyro error signal causes an angular rate of attitude change which is converted to a signal by the rate gyros. The rate signal is summed with the position error signal to prevent over-correction and thus dampens oscillatory hunting of the system for its' reference attitude. The rate gyros also act to produce a quicker response of the system when attitude errors occur.

TRAJECTORY ESTABLISHMENT

After a short period of vertical rise the missile is rolled, if necessary, until its' target side aligns with the desired trajectory. This action is accomplished through the programmer which causes current to be applied to the torque microsyn of the roll position gyro until the gyro float reaches the desired reference attitude. The resulting displacement of the signal microsyn causes an error signal which produces thrust deflection as needed to roll the missile. Achievement of proper roll alignment returns the signal microsyn to null in the new reference position. Attitude stabilization will continue to the new reference through the remainder of powered flight.

When the roll program has been completed the missile is pitched to the desired angle in a similar manner.

At the end of the programmed flight the programmer closes a relay which enables guidance signals to be applied to the control system through the torque microsyns of the yaw and pitch position gyros. If the missile is within a certain volume of space ("barrel in the sky") guidance steering signals will make small accurate changes in missile attitude as required to achieve a satisfactory trajectory.

MISSILE ELECTRICAL SYSTEM

The Missile electrical system consists of a main missile battery, a power changeover or transfer circuits, an inverter (motor-generator), AC and DC distribution busses and interconnecting wiring cables. The main battery and inverter combination provide the AC and DC voltages required by the missile system during flight. See figure 2.

The main missile battery is the only source of missile borne electrical power, excluding the Re-entry vehicle which is provided with individual batteries. In order to satisfy the power requirements a missile battery must meet the following specifications:

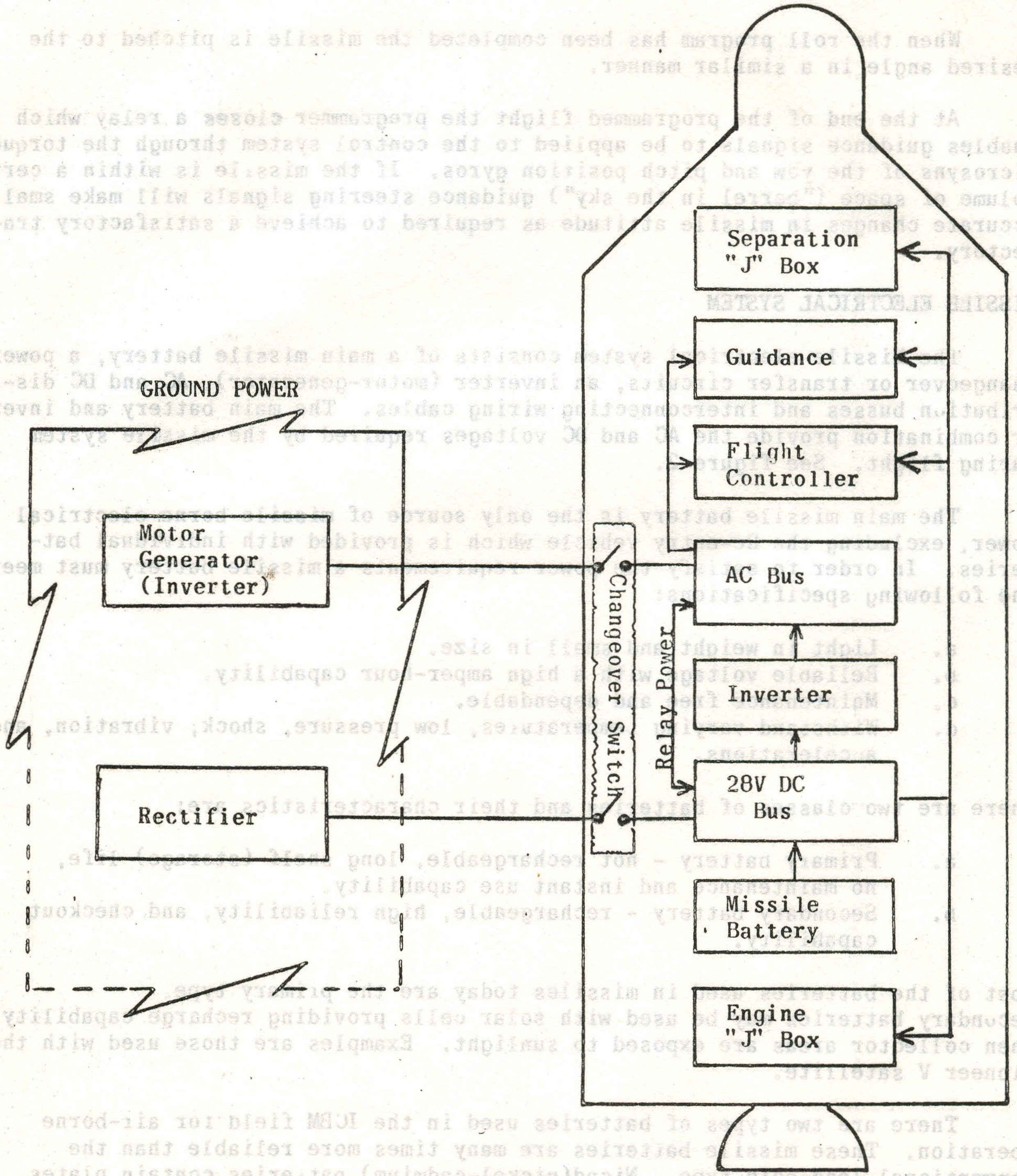
a. Light in weight and small in size.
b. Reliable voltage with a high amper-hour capability.
c. Maintenance free and dependable.
d. Withstand varying temperatures, low pressure, shock, vibration, and accelerations.

There are two classes of batteries and their characteristics are:

a. Primary battery - not rechargeable, long shelf (storage) life, no maintenance and instant use capability.
b. Secondary battery - rechargeable, high reliability, and checkout capability.

Most of the batteries used in missiles today are the primary type. Secondary batteries may be used with solar cells providing recharge capability when collector areas are exposed to sunlight. Examples are those used with the pioneer V satellite.

There are two types of batteries used in the ICBM field for air-borne operation. These missile batteries are many times more reliable than the conventional lead-acid type. Nicad(nickel-cadmium) batteries contain plates of nickel and cadmium separated by thin plastic sheets. Each plate is "sintered", a process which fuses a micro-fine powder onto a fine mesh screen. This leaves the plates about eighty percent porous, thus increasing the effective plate surface area many hundred times. The electrolyte used is generally thirty percent potassium hydroxide.



Typical Electrical System
Figure 2

Silver-zinc batteries are more widely used in the ICBM operations. They are dry charged, requiring only the addition of electrolyte for actuation. Compared to Nicad batteries, Silver-zinc batteries are only about one-third as heavy, yet their output on an equal weight basis is four times as great. See figure 3.

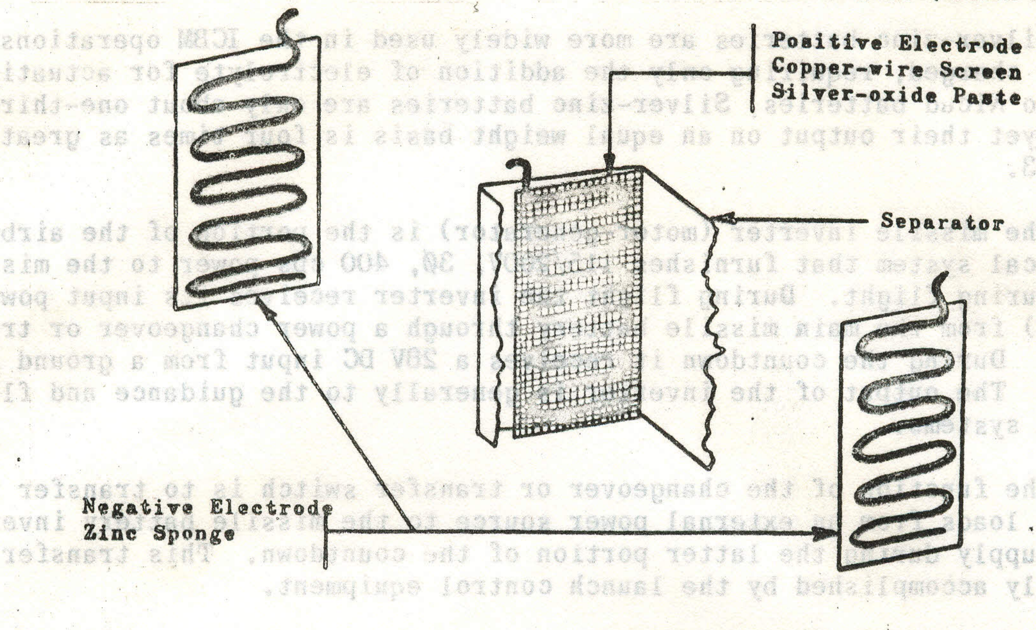
The missile inverter (motor-generator) is the portion of the airborne electrical system that furnishes 115/200V, 3Ø, 400 cps power to the missile loads during flight. During flight the inverter receives its input power (28V DC) from the main missile battery through a power changeover or transfer switch. During the countdown it receives a 28V DC input from a ground power source. The output of the inverter is generally to the guidance and flight control systems.

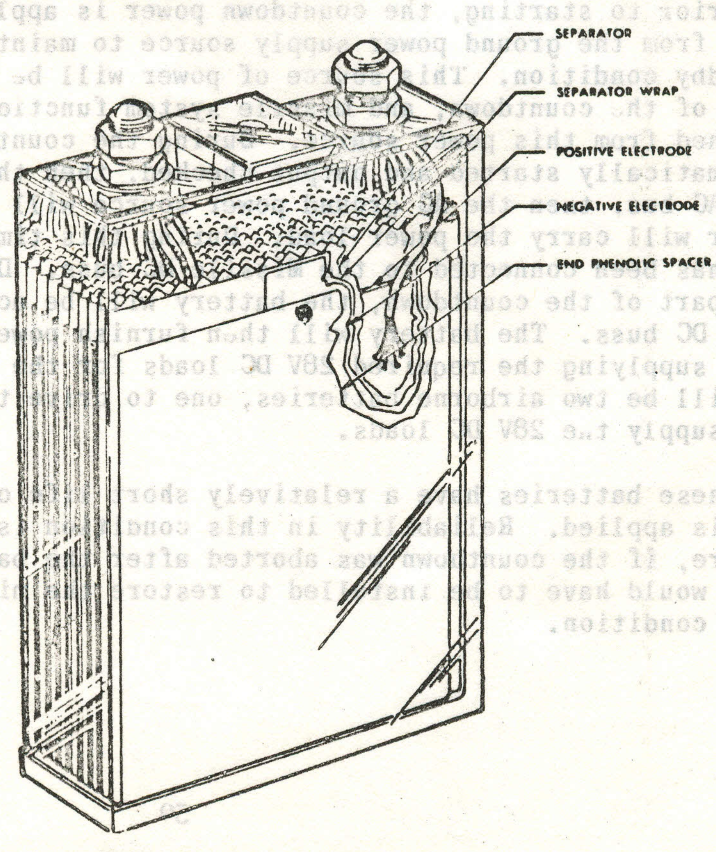
The function of the changeover or transfer switch is to transfer the missile loads from an external power source to the missile battery inverter power supply during the latter portion of the countdown. This transfer is automatically accomplished by the launch control equipment.

ELECTRICAL SYSTEM OPERATION

Prior to starting, the countdown power is applied to certain selected systems from the ground power supply source to maintain the systems in a ready or standby condition. This source of power will be used throughout the major portion of the countdown, and missile system functional checks will be accomplished from this power source. During the countdown, the inverter will be automatically started and output checked, then the output will be applied to the AC bus, then the AC ground power source will be disconnected and the inverter will carry the power load. During this time a 28V DC ground power supply has been connected to the Missile DC buss. During the "commit phase" or latter part of the countdown, the battery will be activated and applied to the missile DC buss. The battery will then furnish power to drive the inverter as well as supplying the required 28V DC loads for the missile. In some missiles there will be two airborne batteries, one to drive the inverter, and a separate one to supply the 28V DC loads.

These batteries have a relatively short life once they are activated and a load is applied. Reliability in this condition is limited to a few minutes, therefore, if the countdown was aborted after the battery is activated, a new battery would have to be installed to restore the missile electrical system to a ready condition.





Secondary and Primary Cell Construction

Figure 3

Hydraulic and Pneumatic System

A missile hydraulic system is basically very much like an aircraft hydraulic system. The primary energizing unit of the hydraulic system is the pump. A reservoir to store fluid, pressure relief valves, check valves, filters, accumulator and hydraulic actuators are necessary components for most hydraulic systems.

The hydraulic pump can be driven by an electric motor or by some other energy source within the missile. On liquid propellant missiles, the hydraulic pump may be driven by the turbo-pump which also drives the fuel pumps. Two types of pumps frequently used are the geared-type and the piston-type (reciprocating pump). The Vickers pump, commonly used on missiles, is a rotating piston type pump and can be either constant volume or constant pressure in operation. For operation, the intake port is connected to the fluid reservoir, and the output is connected to the high pressure delivery line. The hydraulic actuator and the load to which it is attached are displaced by the fluid being pumped into the system.

Fluid flows from the hydraulic reservoir to the pressurizing pump which forces fluid throughout the system. The reservoir also receives the returning fluid after it has performed the desired work on the hydraulic actuator piston.

Pressure relief valves are designed to limit the pressure in the hydraulic system to some maximum value and thus prevent damage to parts of the system. Some hydraulic systems used hydraulic pressure regulating switches instead of relief valves. Such switches control the power-pump operation in response to pressure changes within the system.

An accumulator acts as an auxiliary storage place for hydraulic fluid under pressure. In so doing, it tends to dampen out pulsations or pressure surges in the hydraulic system. Pulsating flow in a hydraulic system would cause vibration of components and unsteady operation of the control devices to which the actuators are linked. Accumulators may be of the floating piston type or the diaphragm type. In both types, the air chamber is charged with compressed air to a pressure corresponding to the line pressure desired in the hydraulic system.

One-way check valves are used to keep the fluid always flowing in one direction. This keeps system pressure from being dumped overboard and to restrain the fluid from reverse flow through the filters.

The purpose of a hydraulic actuator is to transform fluid pressure into mechanical force necessary for moving some type of control device. The fluid to the actuator is usually controlled by a hydraulic servo-valve connected to the actuator. The servo-valve receives the electrical signal from the flight control system, and meters the fluid to the hydraulic actuator to displace the actuator piston in the proper direction and proper amount.

Transfer systems that use air as the medium of energy transfer are referred to as pneumatic systems. Basically, the operation of a pneumatic system is similar to the hydraulic system just discussed. A pneumatic system cannot be used for engine actuators on missiles because of the slow response caused by compressability of the air. Pneumatics can be used on missiles to pressurize the accumulator, the hydraulic reservoir, the propellant tanks, and to operate the fuel valves. The most common pneumatic systems use helium or nitrogen pressures.

FLIGHT CONTROL CHECKOUT AND TEST

Flight control checkout may be accomplished by panels located at the complex or in the maintenance area. The checkout will usually include:

Power check of all units to determine voltage and frequency.

Gyro drift check to determine gyro condition.

Slew check to determine that command signal introduced through a position gyro will properly gimbal the engine.

Programmer unit check to simulate flight.

Gyro sensing check by introducing error signals to be electronically monitored.

If a malfunction is found, flight control test equipment for servo-valves, inverters, rate gyros and the programmer is used to further isolate the cause.

SUMMARY

The flight controller represents the link between the guidance (programmed or inertial) and the engines. By using the circuitry in the flight controller it can perform its mission. The mission or job of the flight controller can be simply stated as control and stability of the missile in flight. It uses the gyros, both position and rate, for information and converts this to data which is fed to the hydraulic system by way of the servo-valves to effect engine movements.

QUESTIONS

1. What is the relationship of the hydraulic system to the remainder of the flight control system?

2. What is the function of the flight control system?

3. Guidance signals enter the flight control system through what unit?

4. Name the major units of the flight control system.

5. What are the major requirements of any automatic control system?

6. What is the purpose of the position and rate gyros?

7. What is the function of the programmer?

8. How is a pitch change accomplished?

9. Name the major components of a missile electrical system.

10. What is the difference between the Nicad and Silver-zinc batteries?

11. Wnat is a primary class battery?

12. List the sequence of events that occur when changing from external to internal power.

13. Name the major components of a missile hydraulic system.

REFERENCES

TO-21 SM75-1

AFM 52-31

Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard AFB, Texas

OBR1821B/3121-3-III-8
Student Study Guide
3 January 1962

DAYS 46 & 47

INERTIAL GUIDANCE

OBJECTIVE:

To familiarize you with the fundamentals of an inertial guidance system and its components.

INTRODUCTION:

The function of an inertial guidance system is to direct a missile to a point in space where a re-entry vehicle is released and allowed to free fall to the target. An outstanding feature of the system is that it is completey self-contained, requiring no additional information after launch, and is virtually immune to countermeasures. Its accuracy compares favorably with other more sophisticated systems, while miniaturization of components has permitted construction well within the imposed parameters of size and weight. Inertial guidance systems are in use in the Atlas E and F, Titan II, Minuteman, and in IRBMs Thor, Jupiter and Polaris. With continuing research and refinement it is the guidance system of the forseeable future.

GUIDANCE PRINCIPLES

An inertial guidance system employs one of the oldest methods of navigation known to man; dead reckoning. Dead reckoning may be defined as the method of advancing from a known position to a later position by adding one or more vectors that represent known courses and distance. It is basic to all other forms of navigation. There are two basic problems in navigating by dead reckoning, one essentially the reverse of the other. In general terms they are:

1. Pre-planning a course from one known position to another by use of information about the route which will affect the course.

2. Use of observed data while enroute to effect corrections to the desired, pre-planned course.

The reliability of this system is heavily dependent upon the accuracy and detail of the information supplied it. For example, if it were possible to predict with all the variables which would affect a flight from New York to Chicago, (exact magnetic variations, each tiny gust of wind, etc) the navigation problem would be solved in its pre-planning phase and no in-flight corrections would be necessary. Aside from the objections which would be raised by the navigators' union, we realize that no such precision is possible and that the real solution to the problem emerges from in-flight observations and corrections. The accuracy with which these are performed will then be a direct measure of the overall accuracy of the entire flight.

Missile-borne inertial guidance systems employ the principles just discussed with several refinements. The pre-planning is accomplished by UNIVAC-type computers and a simplified digest of the solution is supplied to the memory circuits of the guidance system airborne computer. In-flight observations are performed by accelerometers, (devices which measure acceleration in a specific direction), and are correlated to the stored memory data in the computer to arrive at steering corrections.

This method of dead reckoning differs essentially from that previously discussed in that the in-flight observations are made internally - meaning that no information is available in flight from an external source. In addition, the entire operation of the system - observation, comparison, correction - is accomplished continuously, from instant to instant, rather than periodically or at the whim of a human navigator. Another major difference lies in the coordinates or reference system used. Aircraft navigation is usually performed in relation to latitude and longitude coordinates or some other earth-bound reference system. The missile inertial guidance system considers no external references other than its launch position and the target, and always determines its new position in terms of the position last computed. Since this is a continuous process, high degrees of accuracy are achieved and deviations from a desired course are minimal.

GUIDANCE PROBLEMS

One common difficulty experienced by many students in understanding the operation of an inertial guidance system is in interpreting the unfamiliar terms employed. Most of us are conditioned to think of navigation in terms of magnetic headings, knots and nautical miles travelled. The azimuth unit used by the missile has no apparent relation to true or magnetic north. It is merely an expression of the missile's position in relation to an imaginary plane which includes the launch position, the point of impact, and the center of the earth. This will be discussed later in greater detail. Velocity and distance are really only functions of acceleration, which is all that the system can sense.

A basic understanding of some elementary physics is required to grasp the fundamental operating principles whenever the velocity of a body changes, the motion is described as acceleration. Acceleration is defined as <u>the rate of change of velocity</u>, and is commonly expressed in units of feet per second per second. Acceleration can be determined mathematically by knowing the amount of change of velocity and the duration of time required to accomplish the change. Consider an automobile uniformly accelerated from 20MPH to 50MPH in ten seconds, The net change of velocity was 30MPH, and over the ten seconds during which this increase took place we discover a rate of change of velocity of 3MPH per second (30MPH divided by 10 seconds). Thus, at the end of one second the automobile would be traveling 23MPH; at the end of two seconds 26MPH, etc. If necessary to use common terms, we could have converted the 30MPH to 44 feet per second and the acceleration would then be expressed as 4.4 feet per second per second. What was stated here can be shown schematically as:

$$\text{acceleration} = \frac{\text{final velocity - initial velocity}}{\text{time}}$$

or algebraically as:

$$a = \frac{v - v_0}{t}$$

Expressed as a solution for final velocity (v):

$$v = v_0 + at$$

which states that the final velocity is equal to some initial velocity plus some change of velocity. It may be similarly shown that the initial velocity (v_0) was also the result of an acceleration acting through time, or, more generally, that any velocity is the result of some acceleration.

One further operation is possible, that of converting velocity to distance travelled. Distance is simply the result of velocity acting through time:

$$d = vt$$

Given missile acceleration and duration of time, we may convert this intelligence to more useful forms of velocity and distance.

The development of these computations may appear unfamiliar to the human navigator since he generally obtains a direct reading of vehicle velocity or distance travelled by reference to some external information. Since this is neither possible nor desirable in a jam-proof inertial guidance system, the problem of missile navigation is reduced to measuring accelerations and converting them to velocities and/or distances.

SYSTEM COMPONENTS

It can be seen from the forgoing discussion that the only essential components of an inertial guidance system must include some device capable of accurately measuring acceleration and a computer capable of translating that information into Missile steering and commands and engine cutoff signals. Let us consider some aspects of the first of these, the accelerometer.

The simplest form of accelerometer is the classical accelerometer which is shown in Figure 1.

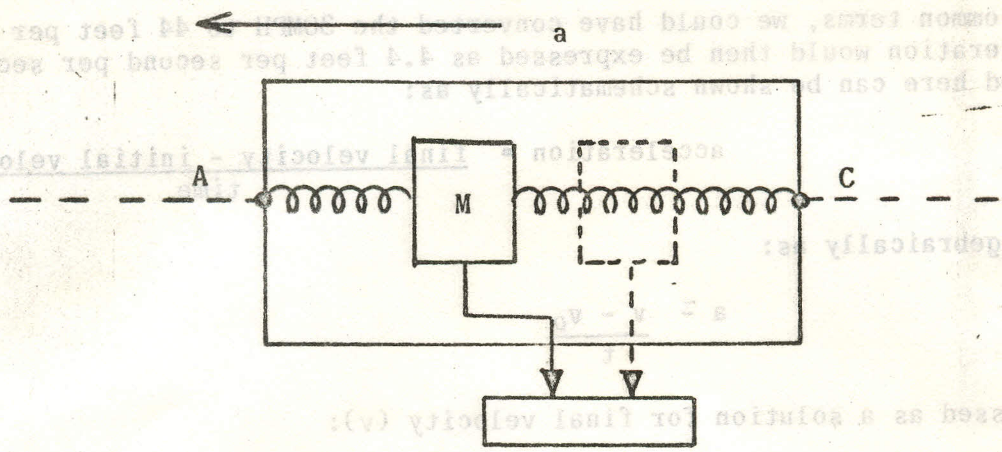


Figure 1 - Basic Accelerometer

This device consists of a mass (M) which is suspended by two springs in an enclosed case. When an acceleration is experienced along the axis AC, an apparent displacement of the mass occurs due to inertia. This is in accordance with Newton's First Law of Motion, which states in part that a body at rest tends to remain at rest unless acted upon by an external force. The displacement can be measured by an electrical pick-off as shown in Figure 1.

From Newton's Second Law of Motion we obtain the following relationship:

$$F = ma$$

where F is force, m is mass, and a is acceleration. Thus, if the mounting case is accelerated along axis AC by an amount (a) and the mass (m) of the suspended object is known, the force (F) acting on the mass may be determined. From physics we are able to establish another pertinent relationship:

$$F = kx$$

where k is a constant of spring restraint and x is the displacement of the mass. The force will thus be proportional to the distance moved by the mass.

Combining these two relationships:

$$ma = kx$$

or

$$x = \frac{ma}{k}$$

where k and m are fixed values. The movement of the mass is thus proportional to and an indication of the acceleration applied.

The operation of this simple device, while illustrative of the principles that apply to all accelerometers, cannot be made sufficiently sensitive for the high degree of accuracy required in missile systems. The devices actually used will be demonstrated in the classroom.

The second essential component of an inertial guidance system, the computer, can take many forms. Both analog and digital computers are in use. Both perform essentially the same functions:

1. convert acceleration values to velocity and/or distance expressions;

2. compare observed quantities with stored memory data;

3. originate steering orders and engine cutoff signals to achieve a suitable ballistic trajectory to the target.

A detailed analysis of one type of computer will be given in the classroom.

PLATFORM STABILIZATION

Two problems not previously discussed arise in the operation of the inertial guidance system:

1. the accelerometers must be maintained in a fixed orientation so that the values they transmit to the computer will always have the same meaning;

2. the effect of gravity (also an acceleration) must be considered and subtracted from the total values sensed in order to present a true picture of missile movement.

In actual practice, a solution to the first problem results in a partial solution of the second. Most systems use three accelerometers, each designed to sense acceleration in one direction only. These are oriented at right angles to each other to permit measurement of missile movement in any direction of three-dimensional space. The accelerometers are mounted on a system of gimbals positioned by three stabilization loops which maintain a fixed or stable platform for the accelerometers. Each loop contains a gyro, a servo amplifier and a servo motor which positions a gimbal. Any movement of the missile will be sensed by at least one stabilization gyro and will be countered by an equal but opposite movement of an appropriate gimbal. The accelerometers are thus always "pointed" in the same direction and are able to transmit signals to the computer that always have the same "meaning". At the instant of launch the stable platform becomes fixed in space and will maintain its orientation regardless of earth or missile movement. The effect of gravity on the accelerometers is noted and subtracted at launch and, once compensated for, will no longer influence the system.

PLATFORM ORIENTATION

The specific orientation given the platform will vary somewhat from system to system. In the particular system which we will examine in the classroom, the platform is aligned with respect to the horizontal and to a plane coincident with the planned impact point. Determination of the horizontal is accomplished by use of a vertical sensing element; the azimuth or reference plane is determined by electro-optical aiming instruments called electrotheodolites. Operation of these instruments will be discussed in greater detail in the classroom.

SYSTEMS OPERATION

At some time prior to launch the stable platform is erected by electrically positioning the gimbals. It is then closely aligned to the horizontal and reference planes by the instruments previously discussed. Power is then applied to the stabilization gyros to maintain this initial orientation. The accelerometers are mounted on the inner gimbal of the stable platform and are at right angles to each other. Since the platform is now oriented to a particular target, the sensing axes of the accelerometers are now in their final desired position. Additional ground equipment called an earth rate integrator compensates for apparent precession of the stabilization gyros due to rotation of the earth.

At the instant of launch the earth rate integrator is removed from the circuit and the platform is held in its final spatially-oriented position by the stabilization gyros. The accelerometers now sense missile acceleration as component forces of their three fixed sensing directions and transmit this information to the computer. The computer converts this information to velocity and distance values, compares them with information stored in its memory, and supplies corrections to reposition the engines. Steering corrections are applied until a position is reached which will provide a free-fall path to the target. At this time the engines are cutoff and the re-entry vehicle separated. The re-entry vehicle now has the proper velocity to follow a ballistic trajectory to the target.

CHECK-OUT, TEST EQUIPMENT AND PROCEDURES

Check-out of the guidance system, test equipment and procedures employed vary greatly from missile to missile. Essentially these consist of testing the proper operation of all equipment, checking on the correct alignment of the platform, and providing the computer with a sample problem before launch to ensure its reliability. In general, these procedures are of so technical and detailed a nature as to lie beyond the scope of this course of instruction. Sample check-out and test equipment will be demonstrated by your instructor to acquaint you briefly with the procedures involved.

COMPARISON OF SYSTEMS

Inertial guidance systems, while essentially similar in their approach to the problem, differ greatly in equipment used. There are no less than three distinct types of accelerometers used on today's ICBM's. Computers range from the relatively simple analog of the Thor to a much more complex digital type found in the Minuteman. Some differences are also introduced between "coffin" and "silo" missiles because of the erection of the former. Alignment problems are somewhat simplified in the silo missiles since the requirement for an alignment check after erection is eliminated. Physical location of the guidance components varies from one missile to the next due to airframe and other considerations. Ground equipment and test procedures, as noted, are designed for a particular missile and are often similar in only the broadest aspect. Classroom discussions will provide an examination of a typical system and will indicate the large differences between systems.

SUMMARY

With a fixed platform to measure from, the accelerometers originate acceleration values for the guidance system. These values are used to determine at any instant the velocity and position of the missile. The computer uses this information to originate the necessary commands for achievement of trajectory.

REVIEW QUESTIONS

1. Define acceleration.

2. Why are three accelerometers used to measure missile movement?

3. Why is a stable platform used in inertial guidance systems?

4. What effect do high velocities have on the operation of the system?

5. How does an inertial guidance system determine the missile's position?

REFERENCES:

1. Modern College Physics, HE White, pp34-40

2. Inertial Navigation Systems, Autonetics

3. Student Study Guide, TP-ACC 31150P-3

NOTES

DAY 49

POWER GENERATION AND DISTRIBUTION

OBJECTIVES:

To familiarize you with power generation and distribution.

To familiarize you with power output and utilization.

INTRODUCTION:

Every system on the missile and its associated support equipment requires electrical power for operation. This day's instruction deals with the production and distribution of electrical power to the launch complex and missile.

POWER GENERATION AND DISTRIBUTION THEORY:

A theoretical power generation and distribution system is shown in Figure 1.

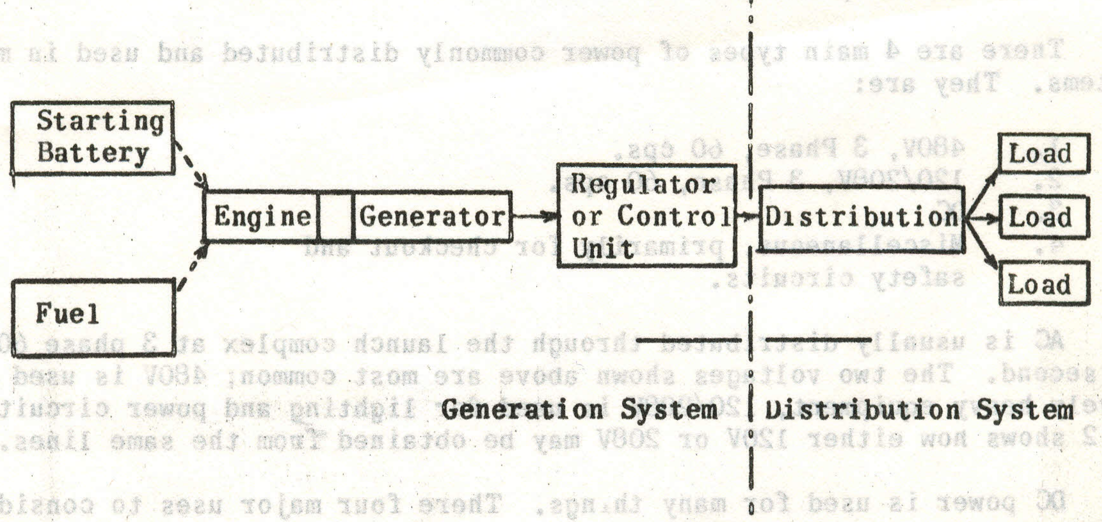


Figure 1

The three basic parts of a power generation system include the engine, generator, and regulator. The engine may operate on gasoline or diesel fuel; however, present missile systems use diesel fuel exclusively. The engine provides mechanical power which the generator converts into electrical energy. The regulator, or control unit, is the "brain" of the power generation system. It consists of units to monitor and control the form of the electrical power. This includes frequency, voltage, and phase control for each generator. In addition, synchronizing devices and paralleling devices are provided for use when two or more generators must be on the line simultaneously. Fuel, and a start system (usually based on batteries) are also present.

A distribution system, primarily switching units and connections, is also needed, as shown in Figure 1. It should be realized that the separation between them is not always as clear-cut as shown. For example, transformers and rectifiers are sometimes considered part of distribution and sometimes part of the regulator.

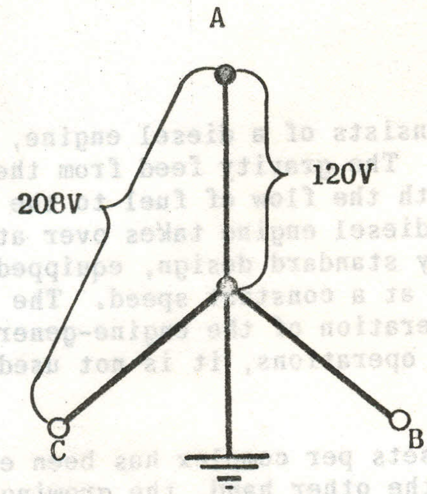
Usually, this system is entirely self-contained. This is true at all Complexes and at most Maintenance Areas. Because failure of the electrical power can prevent launch, the missile system must be able to function without commercial power which is less reliable because it is not under military control. This does not mean that commercial power is never used. On the contrary, in many areas commercial power is more economical. Where it is both available and more economical it will be used. However, it is never used in a way that would allow its failure to halt the count-down. The power requirements of the Complex change with changing weather conditions and at various points in the count-down. All of these facts, along with power availability, must be known to and considered by the LCO.

There are 4 main types of power commonly distributed and used in missile systems. They are:

1. 480V, 3 Phase, 60 cps.
2. 120/208V, 3 Phase, 60 cps.
3. DC
4. Miscellaneous, primarily for checkout and safety circuits.

AC is usually distributed through the launch complex at 3 phase 60 cycles per second. The two voltages shown above are most common; 480V is used for relatively heavy equipment, 120/208V is used for lighting and power circuits. Figure 2 shows how either 120V or 208V may be obtained from the same lines.

DC power is used for many things. There four major uses to consider. First, all relays work on DC. Secondly, some panel lights may work on DC to provide malfunction isolation in case of a power failure. If these lights were on AC, a power failure would prevent malfunction isolation and analysis to correct the power failure. However, the DC is from batteries and would not be affected.



Three Phase Diagram Showing 120/208V AC Power

Figure 2

As seen in the theoretical system (Figure 1), a third DC use is for starting the diesel engines. The last major use we will consider is generator excitation. The generator is composed of electro-magnets. Prior to the introduction of current into its windings, an electro-magnet is simply a bale of wire. The first jolt of current must come from somewhere - DC batteries are normally the source.

The miscellaneous power consists mainly of 3 phase 400 cps used for checkout and ground operation of missile borne equipment. It is generated near the using equipment by a motor-generator operated from 60 cps power.

It is interesting to note a major difference between different weapon systems. Some systems have more than one missile per complex (Atlas D, Titan I). In such a case, the generation equipment (along with other equipment common to all the missiles of that complex) is located at some area away from any one missile (usually this area is near the Control Center). This complicates distribution. On the other hand, some complexes have only one missile per complex (Titan II, Atlas F). In this case, the generators will be within the silo, and distribution is simplified.

SYSTEM COMPONENTS

Fuel Tanks

Fuel supply for the generator sets is kept in a large diesel fuel tank. The tank contains approximately a 30 day supply in case re-supply problems make it necessary to operate the Complex in an isolated condition. The fuel is usually gravity fed to the generator sets.

Generator Sets

The generator set consists of a diesel engine, generator, day tank, and local control console. The gravity feed from the large tank is to the day tank which is used to smooth the flow of fuel to the diesel engine. A standard diesel fuel system on the diesel engine takes over at this point. The diesel is a large engine of fairly standard design, equipped with a governor so that it will turn the generator at a constant speed. The local control console is provided to allow local operation of the engine-generator combination for maintenance. Under normal operations, it is not used because operation is remote.

A minimum of 2 such sets per complex has been established because of the need for back-up. On the other hand, the growing complexity of gear also put a practical maximum limit on the number of sets. At some point it becomes easier to use larger sets than to add more sets of the same size. In present missile systems, this limit is 4 - thus, the number of sets per complex may be 2, 3, or 4.

Switchboards

The primary switchboard combines the electrical power obtained from all the generators and commercial power. It acts as a fuse box, monitoring station, combining unit, regulator, and distribution device. In combining the power, care must be taken to equal the load (paralleling), and to synchronize the phases.

In addition, secondary switchboards are used to distribute power within localized areas. They receive power from the primary, and may sometimes transform or otherwise process it before distribution.

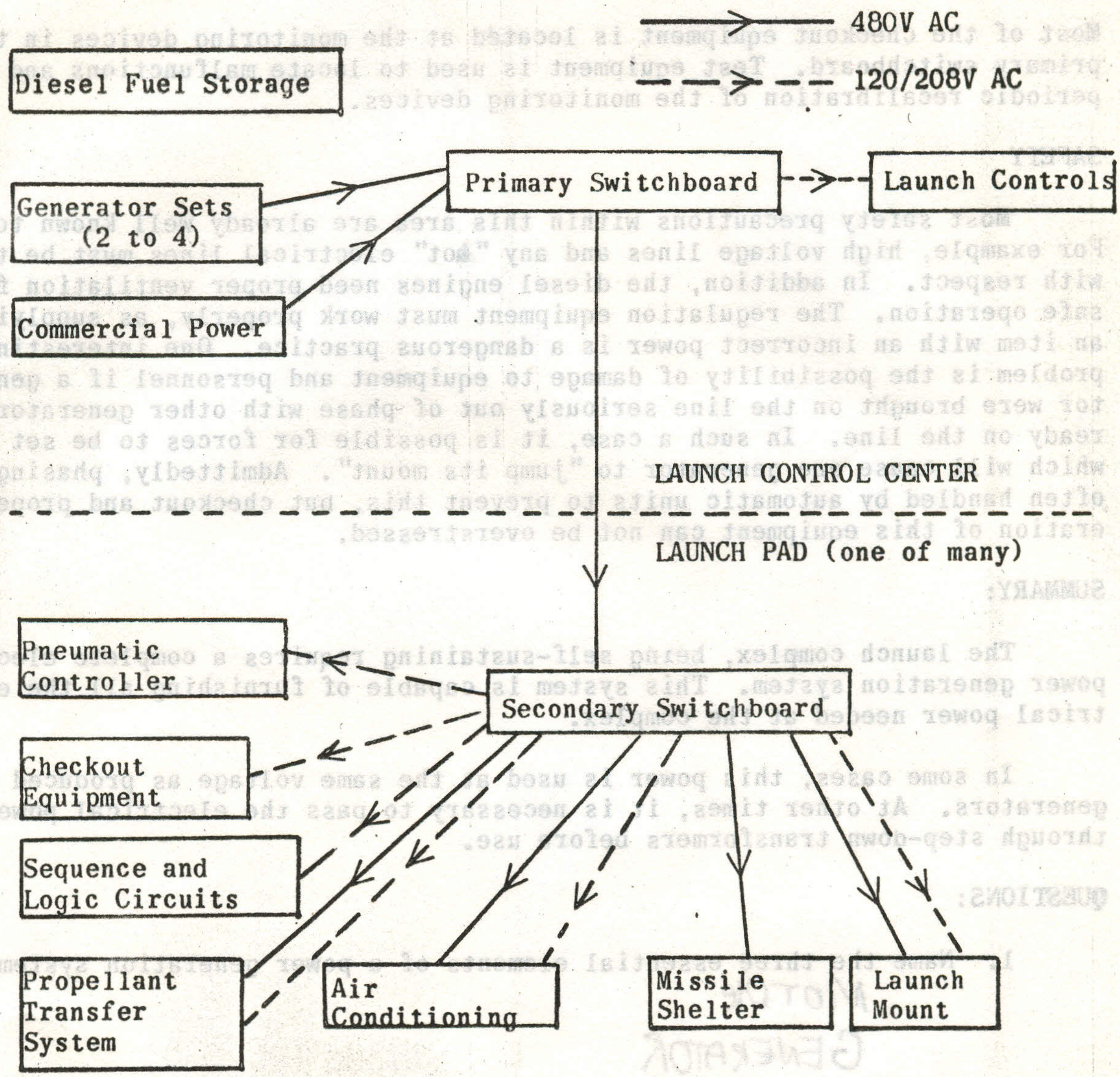
POWER DISTRIBUTION SYSTEM

The distribution system consists of the switchboards discussed above, interconnecting lines, and the using units. It is best understood by reference to Figure 3, which also shows some of the equipment making up the complex which uses the electrical power. Also, notice that long distance transmission is done by high voltage AC. Very little DC distribution is done, although much DC is used. The reason is that batteries (all provided with a rectifier and trickle charge device) are located at many convenient locations.

CHECKOUT AND TEST REQUIREMENTS

Checkout of power systems consists of such functions as:

- Power availability check
- Emergency start system check
- Regulator check



DISTRIBUTION SYSTEM IN A MULTI-MISSILE COMPLEX
Figure 3

Most of the checkout equipment is located at the monitoring devices in the primary switchboard. Test equipment is used to locate malfunctions and for periodic recalibration of the monitoring devices.

SAFETY

Most safety precautions within this area are already well known to you. For example, high voltage lines and any "hot" electrical lines must be treated with respect. In addition, the diesel engines need proper ventilation for safe operation. The regulation equipment must work properly, as supplying an item with an incorrect power is a dangerous practice. One interesting problem is the possibility of damage to equipment and personnel if a generator were brought on the line seriously out of phase with other generators already on the line. In such a case, it is possible for forces to be set up which will cause one generator to "jump its mount". Admittedly, phasing is often handled by automatic units to prevent this, but checkout and proper operation of this equipment can not be overstressed.

SUMMARY:

The launch complex, being self-sustaining requires a complete electrical power generation system. This system is capable of furnishing all the electrical power needed at the complex.

In some cases, this power is used at the same voltage as produced by the generators. At other times, it is necessary to pass the electrical power through step-down transformers before use.

QUESTIONS:

1. Name the three essential elements of a power generation system.

   MOTOR
   GENERATOR
   REGULATOR

2. Why is an internal power generation system necessary?

   SECURITY

3. List some of the factors affecting the power requirements of the complex.

4. What are the 4 types of power utilized at the complex?

1. 480V - 1+3 P
2. 208V 1+3 P
3. 120V 1+3 P
4. DC

5. What are the LCO's duties with respect to power generation overload?

TITAN II - PERMISSIVE LOADING
OTHERS - UNDEFINED

REFERENCES:

1. T.O. 21-SM75-1, General Manual
2. T.O. 21-SM75-1F-2-6, Function Manual-Launch Position Power Generation and Distributing System Analysis and Maintenance.

Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard Air Force Base, Texas

OBR1821B/3121-3-III-11
Student Study Guide
8 November 1961

DAY 50

ENVIRONMENTAL CONTROL

OBJECTIVES:

To become familiar with the needs for ballistic missile environmental control systems.

INTRODUCTION:

Missiles are designed with highly sophisticated units and therefore the environment for such systems must be controlled to enable the specialized equipment to function properly. Specific temperatures are maintained within limits by an air conditioning unit, located at the launch pad and in the maintenance area. In addition to missile environment control, personnel work areas must also be air conditioned.

THEORY OF ENVIRONMENTAL CONTROL

An environmental control system is designed to maintain correct temperature, humidity, and filtered condition; however, this test covers only the temperature control system. The cooled air is supplied by the refrigerative process in most systems. The refrigerative system is composed of a compressor, condenser, liquid receiver and evaporator and utilizes freon gas as the cooling agent. Figure 1 shows the compressor producing a high pressure vapor which is sent to the condenser to dissipate heat and return to the liquid state before entering the receiver. The liquid then goes to the evaporator where heat is absorbed from the air in changing the liquid into a gas. The process of absorbing heat from the air as it passes over the coils produces the required cooling effect.

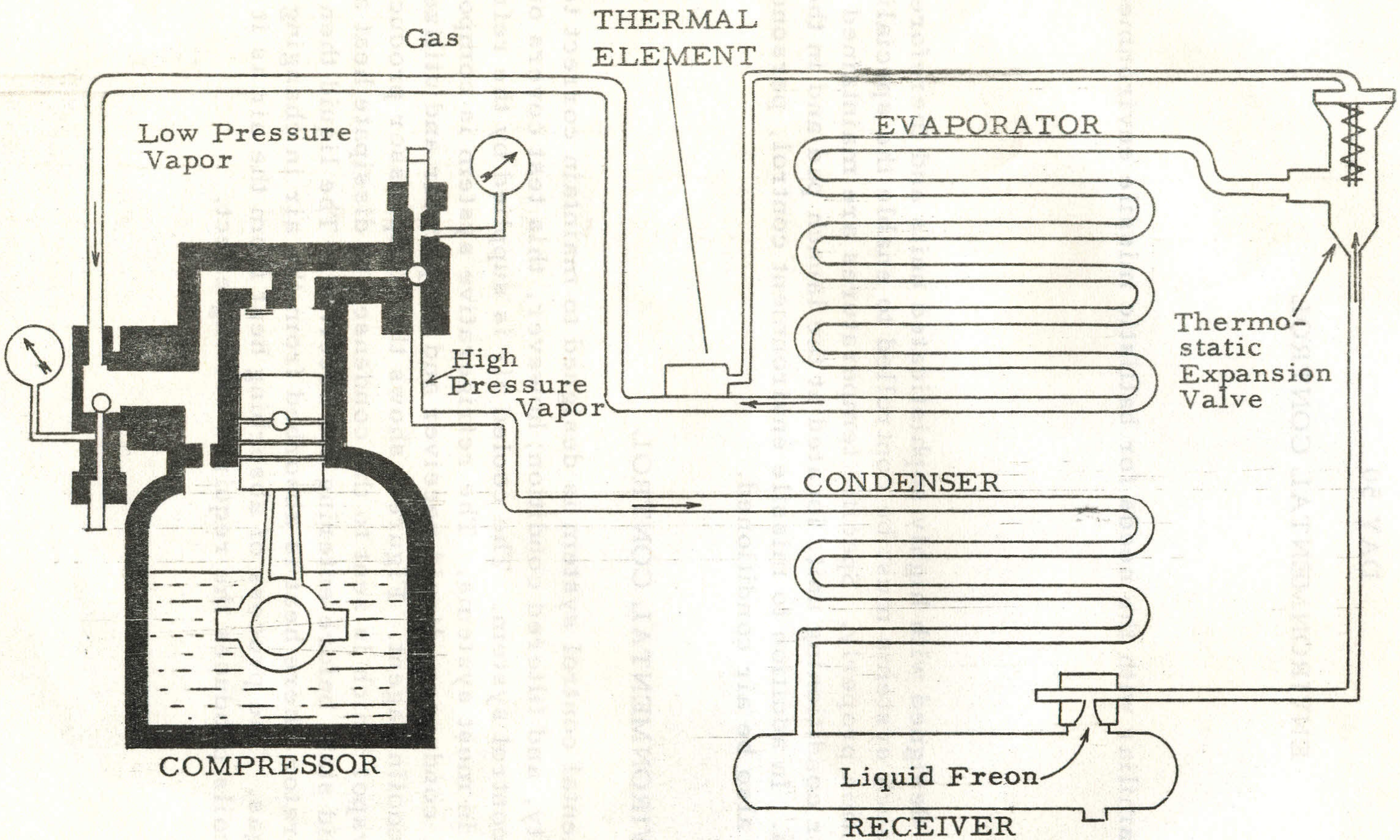


Figure 1 - Typical Cooling System

Warm air is obtained from hot water which is heated by electric probes as shown in Figure 2 or by the diesel engines. The hot water is circulated through heat exchangers where heat is absorbed by air passing over coils. This warmed air is often combined with cooled air to maintain the close temperature tolerances required of missile air conditioning.

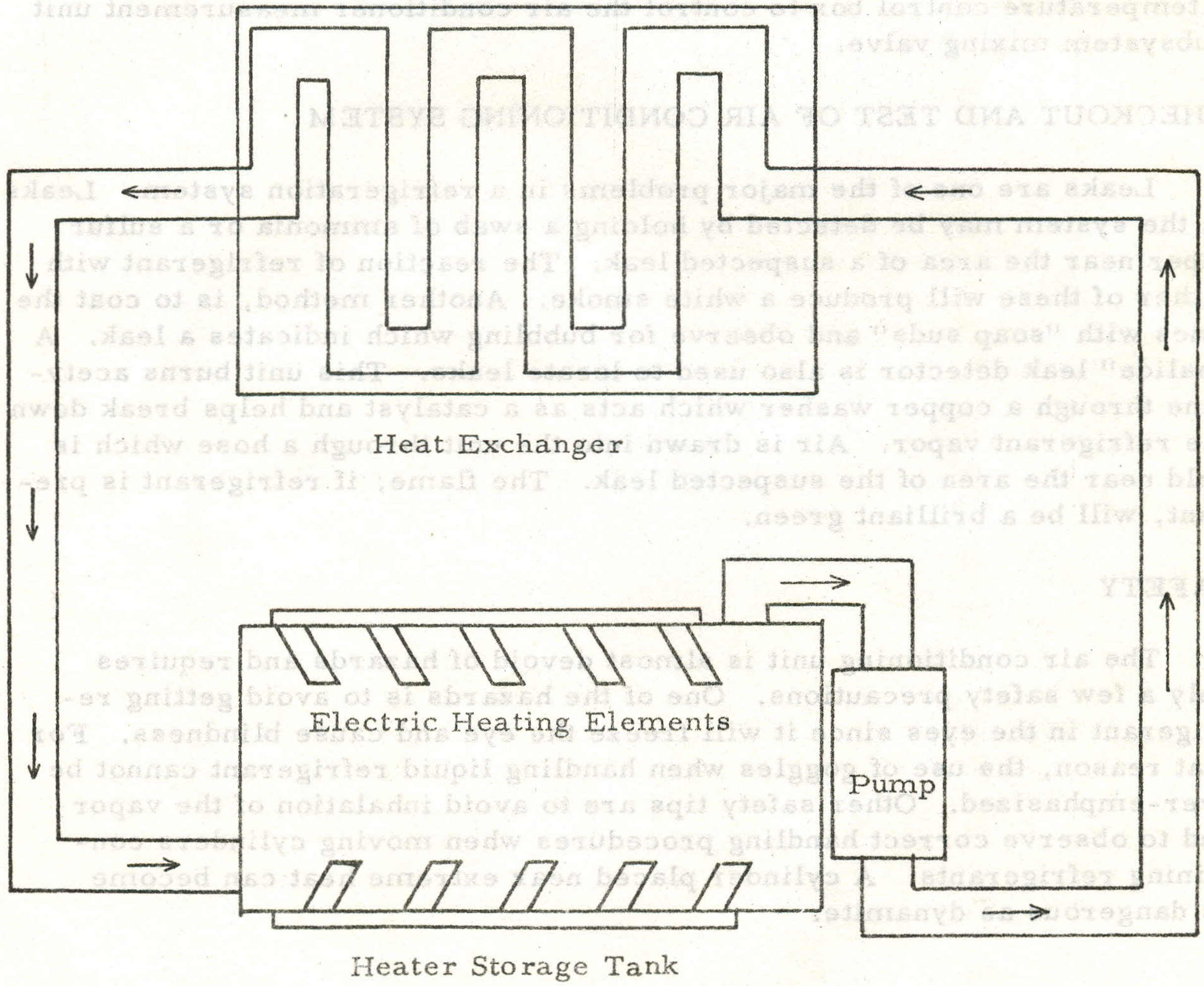


Figure 2
Heating Cycle

A typical schematic of a missile air conditioner is shown in Figure 3. The three subsystem unit supplies conditioned air to meet missile requirements, in specific areas, such as the guidance section. This section requires hot and cold air as determined by the mode of system operation. The engine section receives only heated air which may include gaseous nitrogen to serve as a fire suppression agent during the liquid oxygen loading and firing sequences.

Control of the missile temperatures is maintained by one or more sensing devices. Since the outside temperature must be considered in maintaining the desired tolerance for the guidance measurement unit, two sensing devices in the air conditioning duct and another at the outlet side of the measurement unit are required. All three devices send signals to a temperature control box to control the air conditioner measurement unit subsystem mixing valve.

CHECKOUT AND TEST OF AIR CONDITIONING SYSTEM

Leaks are one of the major problems in a refrigeration system. Leaks in the system may be detected by holding a swab of ammonia or a sulfur taper near the area of a suspected leak. The reaction of refrigerant with either of these will produce a white smoke. Another method, is to coat the lines with "soap suds" and observe for bubbling which indicates a leak. A "halide" leak detector is also used to locate leaks. This unit burns acetylene through a copper washer which acts as a catalyst and helps break down the refrigerant vapor. Air is drawn into the unit through a hose which is held near the area of the suspected leak. The flame, if refrigerant is present, will be a brilliant green.

SAFETY

The air conditioning unit is almost devoid of hazards and requires only a few safety precautions. One of the hazards is to avoid getting refrigerant in the eyes since it will freeze the eye and cause blindness. For that reason, the use of goggles when handling liquid refrigerant cannot be over-emphasized. Other safety tips are to avoid inhalation of the vapor and to observe correct handling procedures when moving cylinders containing refrigerants. A cylinder placed near extreme heat can become as dangerous as dynamite.

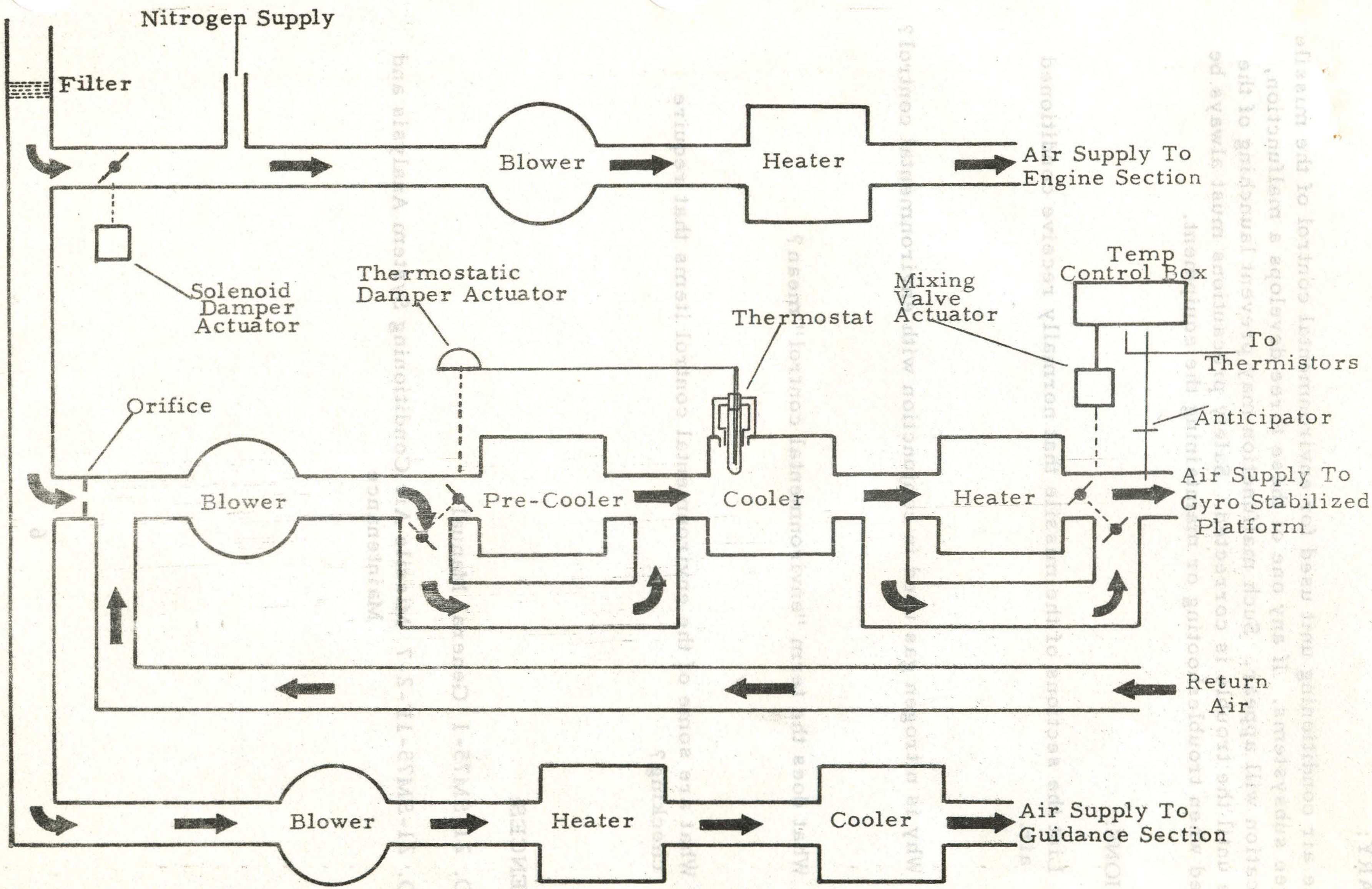


Figure 3 - Missile Air Conditioning

SUMMARY:

The air conditioning unit used for environmental control of the missile has three subsystems. If any one of these three develops a malfunction, an indication will appear. Such malfunction may prevent launching of the missile until the trouble is corrected. Safety precautions must always be observed when troubleshooting or maintaining the equipment.

QUESTIONS:

1. List the sections of the missile that normally receive conditioned air.

2. Why is nitrogen gas used in conjunction with environmental control?

3. What does the term "environmental control" mean?

4. What are some of the environmental control items that require checking?

REFERENCES:

T.O. 21-SM75-1 General Manual

T.O. 21-SM75-1F-2-7 Missile Air Conditioning System Analysis and Maintenance

DAY 51

AEROSPACE GROUND EQUIPMENT

OBJECTIVES:

To familiarize you with the use and purpose of aerospace ground equipment, test and checkout equipment.

INTRODUCTION:

A weapon system includes much more than an aircraft or a missile. It is a combination of the support equipment, test equipment, control consoles and trained personnel required to keep the aircraft or missile in an operational condition, to get it into the air, and to accomplish its mission.

Aerospace Ground Equipment (AGE) is that equipment required on the ground to make a weapon system operational in its intended environment. AGE is divided into two main categories: Maintenance Ground Equipment and Operating Ground Equipment. This text considers selected items of AGE which are considered representative.

MAINTENANCE GROUND EQUIPMENT (MGE)

Maintenance Ground Equipment is that portion of aerospace ground equipment that is used by maintenance personnel for putting the missile and its component parts into an operational condition after it has been tendered inoperational as a result of malfunctions or other reasons. This includes equipment for performing leak checks, resistance and continuity checks and pressure checks. Also included in this category is that equipment used for handling the missile, such as trailers and dollies.

STANDARD TEST EQUIPMENT

Vacuum Tube Voltmeter (VTVM) - An electrical meter incorporating a vacuum tube amplifier. It is an extremely accurate voltmeter and ohmmeter with a wide range. The panel usually consists of:

One meter with several scales - linear for voltage measurement and non-linear for resistance measurement.

Three controls - one function switch for mode of operation, one range switch to select range of voltage or resistance to be measured, and one adjustment knob for zeroing the meter prior to use.

Four test leads - a "common" or "ground" lead, a DC voltage lead, an AC probe and lead, and an OHMS lead.

Model 545 Oscilloscope (Tektronix) - An accurate and widely adaptable unit with the following advantages:

Greater accuracy over a wide range of frequencies obtained through plug-in preamplifiers.

Accurately calibrated sweep speed permitting direct reading of time intervals and frequencies of observed signals.

Immediate determination of location of the trace when the screen is blank (off-scope).

A capability for magnification of selected portions of a trace (delayed-sweep expansion).

Oscilloscope or Recorder: - An instrument for making a permanent record of some item versus time. To do this, a clock-like motor moves a piece of graph paper at constant speed past a pen which moves across the graph paper at right angles to the direction the paper is pulled. The pen movement is controlled by the function to be recorded (voltage, temperature, etc.).

Digital Voltmeter - A measurement instrument with a display somewhat like the mileage portion of an automobile speedometer (odometer). It is therefore easier to read than a standard voltmeter. It is also much more accurate because comparision and feedback arrangement are used to obtain the readout.

Electronic Counters - A circuit capable of counting discrete digital information. Digital counting means that each piece of information has a definite starting and stopping place. Electronic counters are used in direct counting, computers, and "EPUT" meters (events per unit of time). The counter can be built to count in any desired number system by using binary and/or ring circuits.

Frequency Measurement Equipment - Determines frequencies by direct counting of the peaks and comparing an unknown to a known frequency with an oscilloscope. The comparison method uses tones from national time standard station, WWV, to display on the oscilloscope, and compare with the frequency to be calibrated. Since WWV tones are at a known frequency, the unit under test can be calibrated correctly. Such calibration is usually done by the PMEL (precision measurement equipment lab). Frequency values are important since AC voltages are used to maintain very accurate motor speed in equipment such as gyros.

Non-electronic standard test equipment includes items such as micrometers, thermometers, pressure gages, and flow meters.

MISSILE SPECIALIZED TEST EQUIPMENT

This design of this type of equipment varies considerably between weapon systems. It will be covered in the appropriate OZR Course.

TRANSPORTATION EQUIPMENT

Transport systems are varied and no specific system serves more than one type missile. It would be economically advantageous if one set of transporters could be used for every missile but because of the construction and configuration of each missile, this is not feasible. There is transport equipment for airborne, ground, component and section handling.

Typical ground handling equipment for a weapon system will include:

Transporter - A means of moving a missile by road. In some instances, this unit is used as a portion of the erection system. When such an application is made the unit is called a Transporter-Erector.

Shipping Dolly - Normally used for supporting the missile during shipment by air. In some cases the dolly is a multiple unit.

Power Packs - Used on the various shipping devices when a requirement exists for electrical power during shipping such as guidance system gyro heat.

Engine Section Dolly - Special equipment used in the maintenance areas to move the engines through their maintenance sequence or from one area of the maintenance building to another.

Re-entry Vehicle Dolly (two dollies) - A maintenance dolly, whose function is the same as the Engine Section Dolly. An indexing dolly with the capability of moving the R/V varying amounts in any direction.

Cranes - Generally used in the maintenance building for moving components from place to place or dolly to dolly. In silo configuration cranes are used to place the missile on the launcher either stage by stage, or in its entirety. Cranes range is size from small hand units and overhead types to large, self-propelled units such as the Coles and MC-1.

OPERATING GROUND EQUIPMENT (OGE)

Operating Ground Equipment is that portion of Aerospace Ground Equipment that is a functional part of a system and operates with the aerospace vehicle and/or item as an essential element. OGE could be considered as that equipment which is absolutely necessary for launch, but sometime includes that equipment which is normally used to support a launch.

LAUNCH CONTROL AND MONITOR SYSTEM

This system is one of the primary components in any missile weapon system. Its primary purpose is continuous monitoring of the AGE and missile components and initiation and control of the launch countdown. This system consists of several components as required by the specific weapon system.

Atlas "D"	3 Launch Control Officer Consoles 3 Launch Operator/Analyst Consoles 3 Status Panels 1 Guidance Set 1 Master (Launch) Sequencer Group
Atlas "E" Atlas "F"	1 Launch Control Officer Console 1 Launch Analyst Console 1 Master (Launch) Sequencer Group
Titan I	L Launch Control Officer Console 1 Equipment and Facility Console 1 Guidance Set 1 Master (Launch) Sequencer Group
Titan II	1 Launch Control Officer Console 1 Launch Complex Facilities Console 1 Master (Launch) Sequencer Group
Minuteman	1 Launch Control Officer Console 1 Master (Launch) Sequencer Group

Launch Control Officer Console - Varies in capability from complete control and monitoring being vested in this one unit on the Minuteman to a limited capacity with subordinate units on other systems.

Launch Operator/Analyst or Launch Complex Facility Console - A subordinate console which continuously monitors the missile and AGE during standby and countdown. In some configurations a part of the control is vested in this console.

Status Panel - When used, this panel monitors and supplies a quick reference of the weapon system status. In some systems the unit becomes inoperative when countdown commences and the readings are transferred to the major monitoring consoles.

Guidance Set - Associated with weapon systems employing radio guidance, it functions as checkout equipment during countdown. Programmed operations, arm and pre-arm, staging and other vital signals may, also be checked during ground operation. During flight, it monitors the trajectory samples information sent from the missile and sends back steering and discrete commands to achieve a satisfactory trajectory.

Master (Launch) Sequencer Group - Used by all weapon systems that have countdown procedure prior to launch. This unit initiates and controls the sequence of events, insures continuity of the sequence and holds or stops the countdown if a system malfunctions. All sequencers employ the same principle but the sizes will vary with the makeup of the weapon. Some sequencers may contain 900 relays while others can control with fewer than 200. Sequencers may control the entire countdown automatically once started or just complete portions of the countdown and require another manual signal to initiate the next sequence of events.

HYDRAULIC PUMPING UNIT (HPU)

This unit supplies hydraulic pressure for external operations such as shelter or hatch removal or missile erection. Internal operations such as engine gimbal check-out also require the use of ground hydraulics. This unit may provide both operations, but an independent system for each operation is more common. The hydraulic system will play an important part in the size of the electrical power production system because of the number and size of electric motors required to drive hydraulic pumps.

PNEUMATIC SYSTEM

Various gases under pressure are used for propellant transfer, missile bottle and tank pressurization and in some instances to actuate the missile release mechanisms. It is especially important in the Atlas since the propellant tank pressurization maintains structural rigidity a failure may cause the missile to collapse.

ELECTROTHEODOLITE

There are pros and cons on the various forms of guidance - all inertial and radio types. One of the cons on the all-inertial system is the time spent in aligning the system. A theodolite is a necessity and is a very sensitive piece of equipment subject to damage if not used or treated correctly. A guidance alignment console and the theodolite are used for positioning and maintaining the position of the stable platform during countdown. Without this equipment a hit is not possible and therefore the utmost care must be taken to insure that this unit is in perfect operating order.

MISSILE SAFETY

The need for safety in the missile field cannot be over-emphasized. In your work area you will probably encounter safety hazards every day. Here are some of the more important hazards you will encounter:

Danger from falling objects.

Failure to wear proper protective clothing or equipment when engaged in maintenance operations.

Danger from the whipping action of pressurized lines and from escaping pressurized gases.

Danger of electrocution from high voltage lines.

Ever present potential fire hazards.

Freezing of skin tissue or body members from liquid oxygen and liquid nitrogen.

Possibility of an explosive mixture being formed if spilled hydraulic fluid, grease, oil, fuel and foreign material combines with liquid oxygen.

Danger of asphyxiation when working with toxic cleaners in confined areas.

The use of hard hats, check lists and common sense will minimize injuries to personnel and damage to equipment. In addition to the normal precautionary measures, know your safety procedures. Know where the safety snowers, eye-wash fountains, and fire extinguishers are located and how to use them. These things may save your life.

SUMMARY:

We have introduced you to the broad category of equipment referred to as Aerospace Ground Equipment, which includes Operational Ground Equipment and Maintenance Ground Equipment. In some cases it may be impossible to identify a piece of equipment as either MGE or OGE, because it seems to fit both classifications. But, because of its importance, you will become as familiar with certain pieces of AGE as you are with your car.

QUESTIONS:

1. Define Aerospace Ground Equipment.

2. Define Operational Ground Equipment and Maintenance Ground Equipment.

3. What is the difference between Test Equipment and Checkout Equipment?

4. What is the purpose of the Power Pack used during transportation of the missile?

5. What is a Digital Voltmeter?

6. What is the purpose of the standby or continuous status panel?
QUICK REFERENCE

7. What item controls the sequence of events in a countdown?
LAUNCH SEQUENCER

REFERENCES:

1. AFR 60-1.

2. General Manuals of the SM-65, SM-75, and SM-80 Weapon Systems.

Missile Launch/Missile Officer
Missile Fundamentals Branch
Department of Missile Training
Sheppard Air Force Base, Texas

OBR1821B/3121-3-III-13
Student Study Guide
16 February 1962

Days 52 and 53

LAUNCH CONTROL AND COUNTDOWN

OBJECTIVES:

To familiarize you with the squadron support area's functions and relationship to launch control; launch site, its components and function; personnel requirements; Missile Alert/Ready condition; and the missile countdown.

REFERENCES:

General Manuals of SM65, 68 and 80

SAC Reg 20-20.

INTRODUCTION:

The employment of strategic missiles in our defense force has introduced new concepts of operations and logistical support. An understanding of these functions and how one supplements the other is essential to the unit mission.

In this study guide the general operational concept and the direct support functions are introduced.

Squadron Support Area (Support Base)

The Support Base serves as the "home base" for the entire missile squadron. It includes the housekeeping activities for the organization such as supply and administration. The various shops that are required for accomplishing maintenance beyond the capabilities of the combat crews are located here. Storage and maintenance for the re-entry vehicles and in most cases, the LOX plant are also located here.

This Support Base is usually associated with or a part of a well established SAC base, and for good reasons--time, money and existing logistic support.

The following major facilities are provided there:

A maintenance function called Missile Assembly and Maintenance Shops. This function houses all the specialist maintenance functions such as hydraulics, pneumatics, propulsion, electronics and may also house the squadron administrative functions. One of the major functions performed at the MAMS is the Receiving Inspection. When the missile is received, it is inspected and checked to insure its readiness for installation in the launcher.

LOX Plant - for the production of cryogenic supplies. Most liquid rocket systems have a requirement for LOX and Liquid Nitrogen. The major by-product is gaseous nitrogen which is used extensively in the field.

Munitions Maintenance Squadron - is responsible for all phases of operation concerning the R/V.

LAUNCH SITE

The Launch Site is that group of structures where the missile is housed and launched. This can vary from a very complex installation as with the Titan I or Atlas D, to a much more simplified site such as Minuteman employs. Other systems will be between these extremes.

A Launch Site generally consists of these essentials:

1. Launch Control Center

   a. Launch control and monitoring devices
   b. Communications network.
   c. Power generation or distribution system.

2. Equipment Area

   a. Power generation and distribution system.
   b. Hydraulic power supplies.
   c. Air conditioning units.
   d. Logic or sequencing equipment.

3. Propellant Storage Facilities:

   a. Fuel and oxidizer storage.
   b. Pneumatics.

4. Launcher Area

   a. Silo, coffin, or above ground missile enclosure.
   b. This area may house much of the equipment mentioned above.

The type of structure and number of units described above will be dependent on the type and series of weapon system. Some sites are so compact that two structures will house all of the above functions. Others, because of guidance criteria and other considerations, employ a number of structures. But most of the equipment is typical of any weapon system.

In most instances, the site survival requirement, referred to as overpressure minimums, dictates the type of facilities used to house the missile and equipment. This will determine whether the site is an above ground or underground installation. These overpressure minimums have been established as three categories:

1. Soft - Can withstand no overpressure.

2. Semi-hard - must be able to withstand a minimum of 25 PSI.

3. Hard - must withstand a minimum of 100 PSI.

The physical profile or squadron configuration of each of the weapon systems is denoted by numerical terms such as "3x3" "11x9", "1x12", etc. These terms will explain at a glance the number of control centers per squadron, the number of missiles per control center and the resultant squadron strength. Using the "3x3", the first three denotes the number of missiles per control center, the second three is the number of control centers per squadron. Multiply the two figures and you come up with squadron strength.

SITE SELECTION

This is an area of ever-changing requirements. Criteria today differs considerably with those initially established when the field was new. Each weapon system has its peculiar requirements that may differ considerably from any basic criteria set up in the past. Future evolution will also bring about additions or changes. Some current factors are targeting or range, support facilities, geological structure, morale, land availability, booster impact, to name a few, and much can be said concerning each of these factors.

PERSONNEL REQUIREMENTS

You are already familiar with the support Base requirements, organization and utilization of personnel, so we will confine this discussion to those people who man the Launch Site. It is not feasible to speak in specific terms as to who makes up the crews that man the site; for each weapon system and weapon series dictate the numbers and specialists makeup of these crews. Most systems employ these basic people, but their use of these people may differ considerably. The launch crew is presently referred to as the Missile Combat Crew and is generally made up of Missile Combat Crew Commanders (formerly called launch control officers), BMAT's, MMT's and EPPT/S's.

Establishment of the ready condition

Establishment of the missile alert/ready condition includes emplacement of the missile on the launcher, indexing the re-entry vehicle to the missile, performing a post installation, inspection and using operational ground equipment to checkout all systems. At the completion of all maintenance, servicing and checkout of the missile and OGE will be ready for a tactical countdown after which the alert/ready condition is established.

After the alert/ready condition has been established the Missile Combat Crew Commander is responsible for maintaining this condition. He may call for assistance from the MAMS in the way of mobile maintenance teams of specialist dispatch as required.

Maintaining the ready condition

Maintaining the alert/ready condition is generally a monitoring, analyzing and controlling function, and the accomplishment of the daily maintenance plan. The specifics involved will vary with weapon systems.

COUNTDOWN:

When you think of a countdown, perhaps this suggests a scene in which a launch control officer is counting backwards from ten to zero. Or it may have an entirely different suggestion for you, depending on previous associations.

As a part of missile jargon, the term implies a very significant function in the life of missile men. Because it pertains to launching a missile, this is the period of time just prior to launch during which a certain chronological sequence of events must occur. As these events occur, various subsystems and components are being reached or checked to determine their operational capability.

Accomplishing a countdown doesn't necessarily mean that a missile is to be launched. There are practice countdowns that serve the purpose of qualifying crews for the missile concerned. There are also countdowns that are required after maintenance has been accomplished to determine whether or not proper corrective action has been taken, and whether or not the subsystem will now function properly.

Practice countdowns, or those called for by maintenance, can be either wet or dry, in a liquid fuel system, depending on whether or not propellants are to be loaded. This is determined by the purpose for which the countdown is being accomplished. Normally, if an event fails to occur, it will terminate the countdown, unless it is simulated. Therefore, if the propellants are not to be loaded, certain signals will have to be simulated because the events must generally occur in a specified order or sequence. Simulating these signals will be accomplished by a launch sequencer, or perhaps by a special item of ground handling equipment, depending on the weapon system.

Missile and R/V batteries will not be activated if the missile is not to be launched. There may be other events of a practice countdown that are to be simulated, depending upon the circumstances.

Countdowns are divided into phases which will vary from one system to another. Certain related events may be grouped together within a phase. For example, we might refer to a mechanical phase during which the missile will be positioned for launch, the engines will be gimballed, and other mechanical events will occur. In an electrical phase, most of the electrical circuits and electronic components will be checked. During another phase, propellants will be loaded. Pressurization of lines and tanks must be accomplished. Each weapon system will be different in regards to the phases. In the Thor, for example, there are five distinct phases, but in the Titan there are only three. Others may still be different, but most all systems have similar basic requirements.

The time element is very important, and it is imperative that the countdown time be kept to a minimum. Therefore, the events are arranged in a sequence that will be most conductive to saving time. In some systems, there are eight or nine hundred events that must occur in their proper sequence; and some events, because of their nature, must occur as prerequisites to others. Because of this the sequencing equipment is so designed that the failure of any one event will result in a "hold", or in some cases, a termination of the countdown. If the countdown is terminated, the missile must be returned to the standby or ready condition by correcting the malfunction. If a launch is still desired the countdown must be started at the beginning. If the malfunction resulted in a "hold", countdown may be resumed after corrective action has been taken. There are limits as to how long a "hold" may continue without resulting in a shutdown.

As you can see a countdown is much more than a mere ritual. Much planning has gone into the proper arrangement of the events; and unless all of these events occur properly, all resistances, voltages and pressures are within their tolerances, and all the other requirements are met, launch will not occur and everything done may have been done in vain.

SUMMARY

As you can see, the Support Base has certain functions and responsibilities that are supplementary to those of the Launch Site. As in any organization, team work and an understanding of all the various functions in the organization are necessary to accomplish the squadron objectives - to be able to defend the nation at an instant's notice. This not only requires team work and an understanding of all the various jobs, but especially high skill levels of all the individual people in their own jobs. Only then can we measure up to this objective.

REVIEW QUESTIONS

1. Who has the responsibility of establishing the ready condition of a missile system?

2. Give some of the factors that are considered in the selection of a launch support area.

3. What is the purpose of the countdown?

4. Why is the storing of liquid oxygen in the missile tanks impractical?

5. Who is the officer in charge of the launch site?

6. Who is responsible for accomplishing organizational type maintenance at the launch site?

7. What are the by-products of a LOX plant?

DAY 54
NEW DEVELOPMENTS

OBJECTIVES:

To acquaint you with the current and future space projects and with the current and proposed developments in the missile field.

INTRODUCTION:

A look into the history of rocketry goes back several centuries to the Chinese who are given credit for having first used this principle of propulsion. Their vehicles were crude when compared to those of today, but the principles of propulsion (force that made their vehicle go) were essentially the same as those used in current missiles. The methods of producing this force has changed greatly, and the current vehicles have very little resenblence to those built by the Chinese.

Rocketry, as we know it, has a more recent beginning, having been born during the first quarter of this century. Dr. Robert Goddard is recognized as the father of American rocketry, and he made his findings and evaluation about the time of World War I and in the decade following. Early work of this nature was done in Germany about the same time by H.Oberth. The valid claim to a "first" in this field goes to the Russians. They had begun research in the same area at the end of the nineteenth century.

With the advent of rocketry, dreams of some day traveling to the moon began to take on a new meaning. These dreams had actually begun after the invention of the telescope, when man got the idea that the moon might be another solid sphere akin to the earth, but no one at that time could visualize a means of traveling in the type of environment that existed between the earth and moon.

With the progress that has occurred in recent years in the field of propulsion and the development of huge vehicles capable of carrying tons of propellants, space travel including the possibility of traveling to other planets has taken giant strides. Events are occurring every day that are making thoughts along these lines more realistic.

To coordinate our efforts in the field of rocketry and space exploration, a national organization was formed which is know as the National Aeronautics and Space Administration.

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

This administration, hereafter referred to as NASA, has a five point program.

* The development of a comprehensive program for the study of peaceful utilization of space.

* Conducting research leading to practical solutions of problems of aeronautics and space flight.

* Developing and operating appropriate vehicles for scientific investigation and practical utilization of space for peaceful purposes.

* Arranging for participation by the scientific community in planning and conducting scientific flight of aircraft and space vehicles.

* Providing for the widest practicable and appropriate dissemination of information concerning these activities and results.

The above statments describe the mission, or missions that were assigned to this organization, and give a general idea of the broad area of responsibilities that it has in launcing our nation into the space age.

To guide the personnel assigned to NASA, (which includes military personnel and prominent scientists) the organization was given three objectives.

* To produce scientific data on the environment of our solar system and galaxy, essential to all space utilization and better understanding of the physical universe and its relation to men.

* To study practical applications of earth satelilites to weather research and forecasting, long distance communication, navigation and similar tasks.

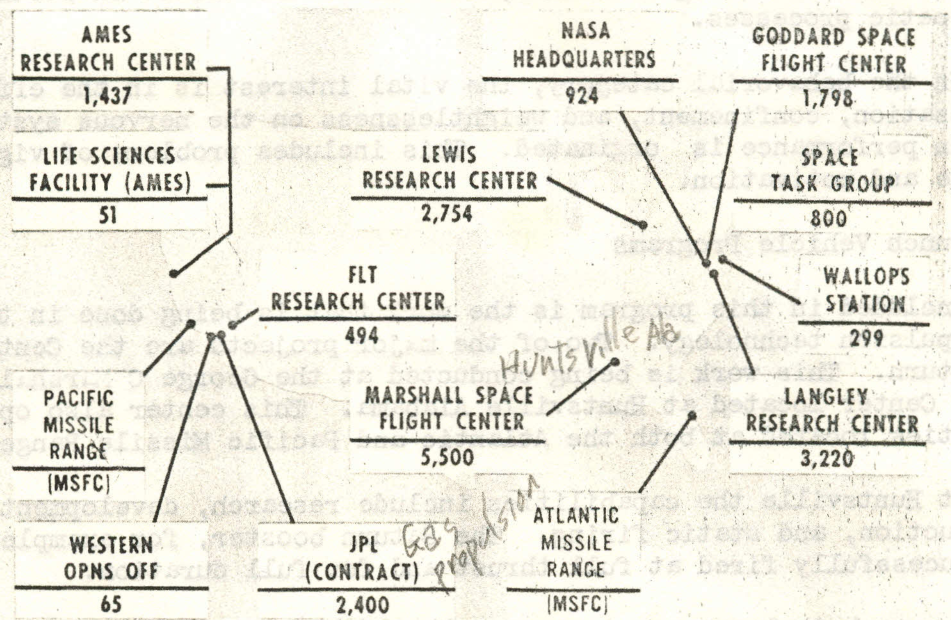
* To explore the problems of man in space, at first in short earth satellites and later in flights to the moon and beyond.

In the National Aeronautics and Space Act, which established NASA, great emphasis was placed on the promotion of international cooperation in outer space. This program of cooperation includes such things as joint, satellite projects in which the US provides the booster and the other country provides the hardware of instruments and other devices at their expense. Launches are made in the US under US control and supervision. There are other aspects of this cooperative program, such as joint sounding rocket projects, ground based support projects and others.

SPACE FLIGHT PROGRAMS

These programs include the scientific exploration of space, the application of meteorology and communications, and the man-in-space program and are accomplished at four centers. The first of these, the Goddard Space Flight Center, is located at Beltsville, Maryland, near Washington as shown in Figure 1. This center is responsible for all the orbiting satellites, such as Echo and Tiros. Wallops Island Station, which is located at Wallops Island, Va., is responsible for launching facilities for sounding rockets and for the Scout vehicle. A sounding rocket is one that will go up to 4000 miles, or one earth's radius, and then fall back to earth. It carries a relatively inexpensive payload that is easy to launch and may be used to gain information that is needed in preparation of satellite flights.

The Jet Propulsion Labratory is a part of the California Institute of Technology, and works for NASA under contract. It is responsible for lunar and planetary missions. The fourth installation of the Space Flight Program is the Space T sk Group located at Langely Field, Va. This installation has the full management responsibility of our man-in-space program.



NASA Facilities and Population - Figure 1

Life Sciences

The second technical program considered is the Life Sciences Program. This program consists of biology, medicine, and behavorial sciences. These activities are conducted at the Ames Research Center, located at Moffet Air Force Base near San Francisco, and have a twofold program. The first objective is to study the effect of extraterrestrial, (that is out of the atmosphere) environment on all types of living organisms, and the second involves the medical and bioengineering effort required in support of our man-in-space program. This has an immediate application to Project Mercury and will continue to be used in subsequent programs, such as Apollo.

Located at the Ames facility are wind tunnels ranging from subsonic to supersonic, as well as hypervelocity. The latter can give simulated velocities up to 25 to 30 times the speed of sound. Here projectiles can be fired from guns into a controlled environment which closely resembles the condition of a re-entry vehicle coming back into the earth's atmosphere. This portion of the program is concerned with giving protection and performance in manned space flight.

That portion of the program dealing with biomedical phenomena is concerned with two characteristics of the space environment which are not present on earth. They are, first, the broad spectrum of unfiltered ionizing radiation, and second, the phenomenon of weightlessness. Of these two, weightlessness is the greater unknown. Of primary concern is the effect of weightlessness on such things as bodily functions, electrical phenomena associated with brain activity, functioning of the heart and the breathing mechanism, as well as the effect on fertilization and genetic processes.

In the behavorial category, the vital interest is in the effects of ilosation, confinement, and weightlessness on the nervous system, wherein performance is orginated. This includes problems of vigilance, fatigue and motivation.

The Launch Vehicle Programs

Included in this program is the work that is being done in the area of propulsion technology. Two of the major projects are the Centaur and the Saturn. This work is being conducted at the George C Marshall Space Flight Center located at Huntsville Alabama. This center also operates facilities located at both the Atlantic and Pacific Missile Ranges.

At Huntsville the capabilities include research, development, construction, and static firing. The Saturn booster, for example, has been sucessfully fired at full thrust and for full duration.

The technical program is managed by four program offices which report to Headquarters of NASA. They are the Launch Vehicle Office, Space Flight, Advanced Research, and the Life Sciences.

NASA PROJECTS

First a look into propulsion research where NASA has conducted programs relating to chemical, nuclear and electrical rockets is provided.

Propulsion Problems

One aspect of concern is the problem of specific impulse of propellants. Specific impulse can be thought of as a measure of the efficiency of the utilization of the propellant. There is a direct relationship between jet horsepower per pound of thrust and specific impulse.

The problem with chemical fuels is that the total horsepower in the jet thrust must be provided by the chemical energy in the fuels. Consequently, the major problem is to get fuels with a high energy content in order that the specific impulse can be increased. At the present time, research has just about reached the limit of the possibilities of chemical fuels.

To extend these limits, research has been conducted on such things as tri-propellants, but the outcome of this is very uncertain, and a very large increase of specific impulse of chemical fuels is not practically obtainable in the reasonable near future.

The next step is the nuclear rocket, where the situation is different. Here plenty of fuel energy is available but the problem is how to use it. Specific impulse of nuclear fuel is sufficiently high for use in interplanetary travel, but the basic problem of reaching impossible temperatures for the materials, both in the reactor and in other parts of the components, such as the nozzle throat, must be solved.

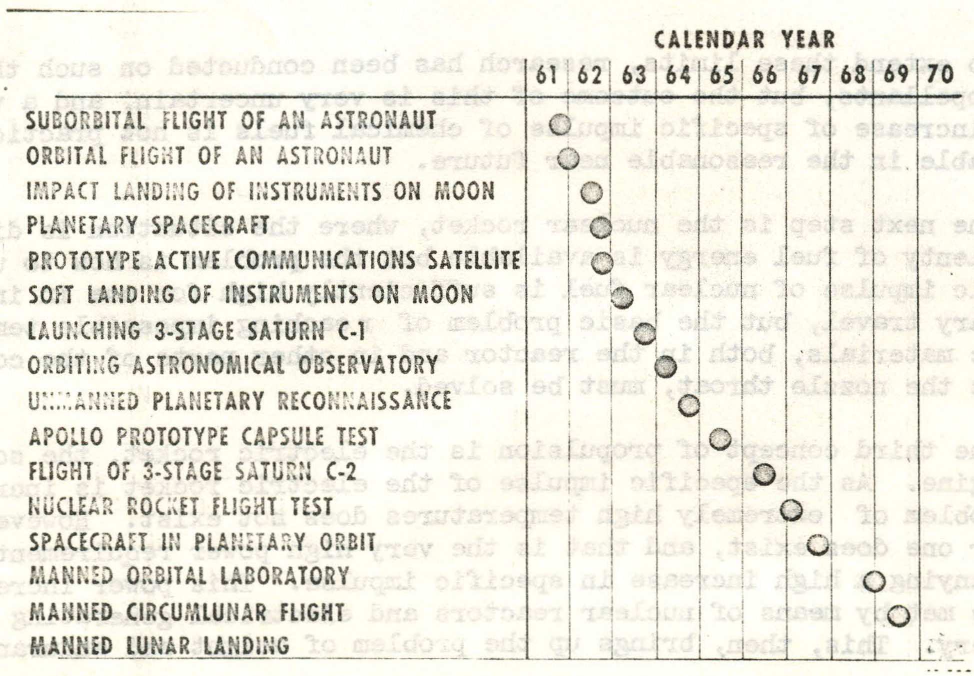
The third concept of propulsion is the electric rocket, the so-called ion engine. As the specific impulse of the electric rocket is increased, the problem of extremely high temperatures does not exist. However, another one does exist, and that is the very high power requirements accompanying a high increase in specific impulse. This power increase must be met by means of nuclear reactors and electrical generating machinery. This, then, brings up the problem of weight and endurance.

This large weight prohibits the use of electrical rockets for launching vehicles from the earth, but it is a practical means of accelerating vehicles once they are placed into space. There a small amount of power will provide a continued acceleration.

The above discussion points up some of the problem areas in the development of high energy propellants. Much of this research has been conducted by NASA, or by institutions that are under contract to NASA.

Man In Space Program

The man-in-space program as indicated in Figure 2 is perhaps the one most immediate importance. This program falls into three general types of missions. These are manned orbit around the earth, man traveling through the enterplanetary medium, and man exploring the moon and other planets.



NASA Mission Milestones - Figure 2

The first step for the manned exploration of space is Project Mercury. The goal of this project is to put a man into an orbit more than a hundred miles above the earth, let him circle the earth at least three times, and then bring him back safely. As of this writing, two manned sub-orbital flights into space have been mande, and present plans call for the next trip to be an orbital flight.

The booster vehicles for the sub-orbital flights were Redstone missiles, and for the orbital flights they will be Atlas missiles. In each a Little Joe booster is used as an emergency escape system.

The orbital flights, like the sub-orbital, will be launched from Cape Canaveral. The Atlas booster will place the spacecraft into orbit at a speed of about 18,000 miles per hour. After three orbits, each of which will take about 90 minutes, the pilot will fire small rockets which will slow the capsule's speed slightly. This will be just enough to allow the earth's gravity to start pulling the capsule down. As it enters the atmosphere, drag will slow it down to about 700 miles per hour. This will be followed by a series of parachutes which will be deployed to gently lower the craft into the Atlantic Ocean.

Project Mercury is only the first step in our man-in-space program. The next step is designated Project Apollo.

Apollo is a more sophisticated program in which man actually performs useful functions in space. This spacecraft will be capable of manned circumlunar flight as a logical step toward the goal of eventually landing man on the moon.

This program has two mission objectives. The first is flight to the vicinity of the moon, and the second is an orbiting laborator, in earth orbit, as a necessary step before permanent manned space stations can be established in earth orbit. The circumlunary flight will involve the solution of many problems associated with a manned landing on the moon. This is especially true of earth re-entry and recovery. The vehicle for boosting Apollo into space is the Saturn launch vehicle.

A modular concept may be employed in the design of the Apollo spacecraft. This concept means that various building blocks, or modules, are employed for different phases of the system.

The first of these would be the command center, which would house the three man crew, and the second would be the propulsion unit which could serve to make midcourse and terminal guidance corrections, but its main purpose would be to provide propulsion for emergency escape considerations at any speeds up to maximum velocity. In this sense it might be compared with the escape tower on the Mercury capsule.

The command center and the propulsion module would probably be the same, regardless of the mission; that is, earth orbit, or circumlunar flight. The third module, the mission module, would differ, depending on the mission. It could serve as an earth-orbital laboratory, with ample capacity for scientific instrumentation and reasonably long lifetimes in orbit.

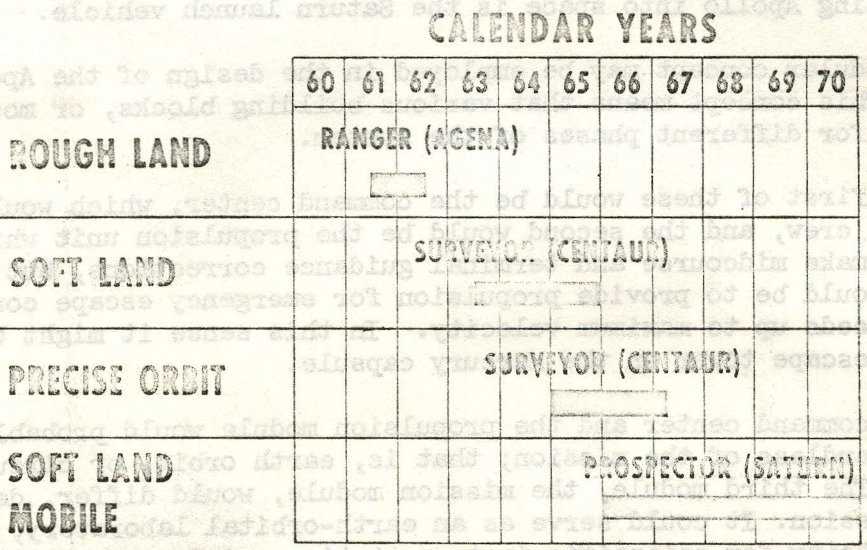
Other developments are needed before this system is ready. One is an environmental control system which will be capable of supplying a livable atmosphere for a crew for several weeks. Attitude control systems will have to be fuilt and tested, and suitable power supplies will have to be developed.

A major requirement is an on-board propulsion systme which will have to get the spacecraft back toward earth from any place between here and the moon in case the launch vehicle malfunctions, or any other emergency occurs.

Following the completion of Project Apollo, the next projects will include space stations and lunar landings and exploration.

Lunar Programs

As indicated in figure 3, NASA will progress into a four stage lunar program. These are rough landing, soft landing, precise orbit, and soft landing mobile.



Lunar Program

Figure 3

The first of these, the rough landing stage, will have the code name Ranger. Project Ranger, using the Atlas Agena B launch vehicle, will first be launched in a highly elliptical earth orbit. This will be to check such subsystems as attitude control and telemetry, plus making extensive measurements of interplanetary radiations, particles and fields using various pieces of complex equipment.

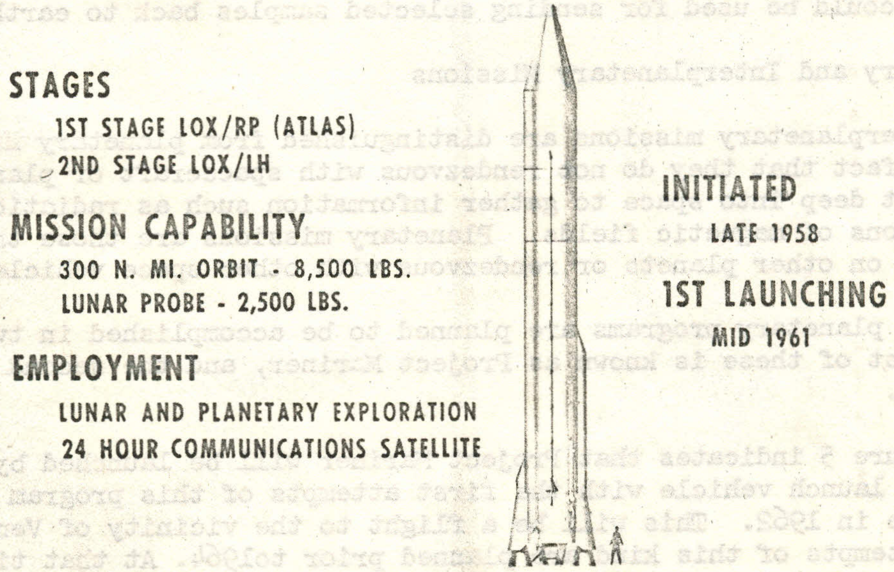
The final objective of Project Ranger is to land an instrumented capsule on the lunar surface, and to view the lunar surface with television and gamma ray spectrometry during the descent phase of the flight.

During early phases of the flight attitude control jets will maintain three-axis stabilization with the solar panels oriented towards the sun and the high gain antenna pointed toward the earth. During the last ten hours of the 66 hour flight, the gamma ray spectrometer is expected to be monitoring radioactivity in the lunar surface, which will provide clues to the nature of the lunar formation.

At about 2000 miles altitude, the vidicon telescope will be activated, and will take approximately 100 pictures prior to the firing of the capsule retrorocket at slightly under 20 miles altitude. These pictures will be televised back to earth.

The landing capsule will carry a highly sensitive single axis seismometer. The instrument will remain active for from 1 to 3 months and will indicate any seismic activity present in the lunar surface due to internal disturbance or meteoroid impact. Five flights are planned for this project, terminating some time in 1962.

Project Surveyor, using the Centaur as its launch vehicle, will begin in 1963, and it will include seven attempts to land several hundred pounds of equipment on the moon. (See Centaur in Figure 4).



Centaur - Figure 4

These will be soft landings. Information gained with this project will be required by both more advanced unmanned and manned landing missions. This will include guidance, control, communications, power and landing technology.

Project Surveyor will land about 750 pounds on the lunar surface, of which about 250 pounds will be scientific instrumentation. This will include several television cameras, some with color-stereo capabilities. There will be equipment for measuring chemical and mineralogical composition of surface and subsurface samples collected with the aid of drills. Physical properties of the samples, such as density, magnetic permeability, electrical resistivity, thermal conductivity and hardness will be determined.

Also included in Project Surveyor will be missions of precise lunar orbitor which will be used for observational purposes in conjunction with surface exploration.

Project Prospector, using a Saturn as its launch vehicle, will be a continuation of the Surveyor program. This will lend mobility to the observations. A mobile vehicle will be free to explore the surface of the moon. A second payload will be an assembly of rockets and equipment to return a lunar sample to earth.

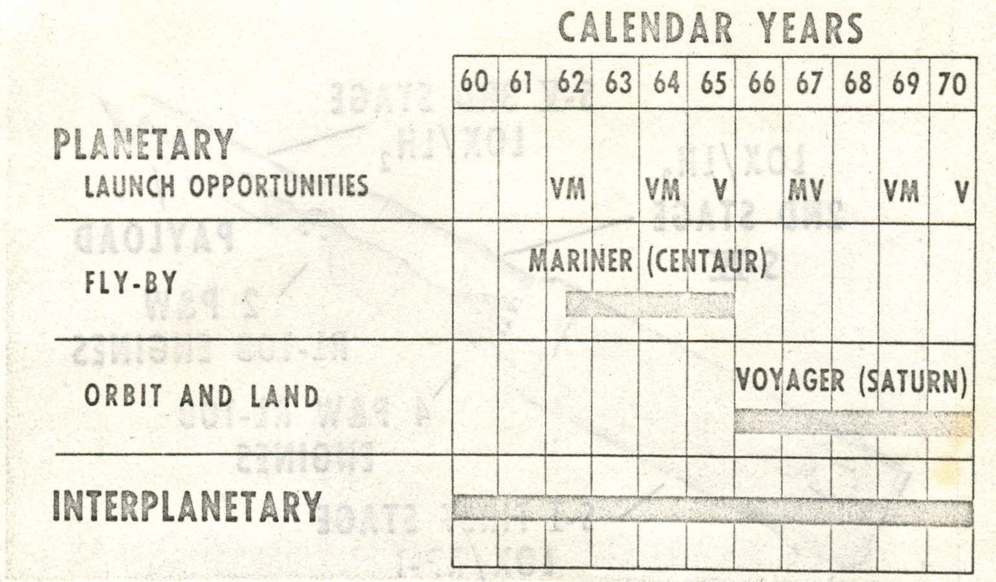
This spacecraft will probably be used to supply man once he has landed on the moon. The mobile vehicle could be remotely operated from the lunar surface or it could be converted to a "jeep". The sample return system could be used for sending selected samples back to earth.

Planetary and Interplanetary Missions

Interplanetary missions are distinguished from planetary missions by the fact that they do not rendezvous with spacecraft or planets. They are sent deep into space to gather information such as radiation or variations of magnetic fields. Planetary missions are those that orbit or land on other planets or rendezvous with other space vehicles.

The planetary programs are planned to be accomplished in two phases. The first of these is known as Project Mariner, and the second is Project Voyager.

Figure 5 indicates that Project Mariner will be launched by using the Centaur launch vehicle with the first attempts of this program planned for sometime in 1962. This will be a flight to the vicinity of Venus. Two more attempts of this kind are planned prior to1964. At that time a more advanced version of the Mariner spacecraft is expected to be sent to the vicinity of Mars.



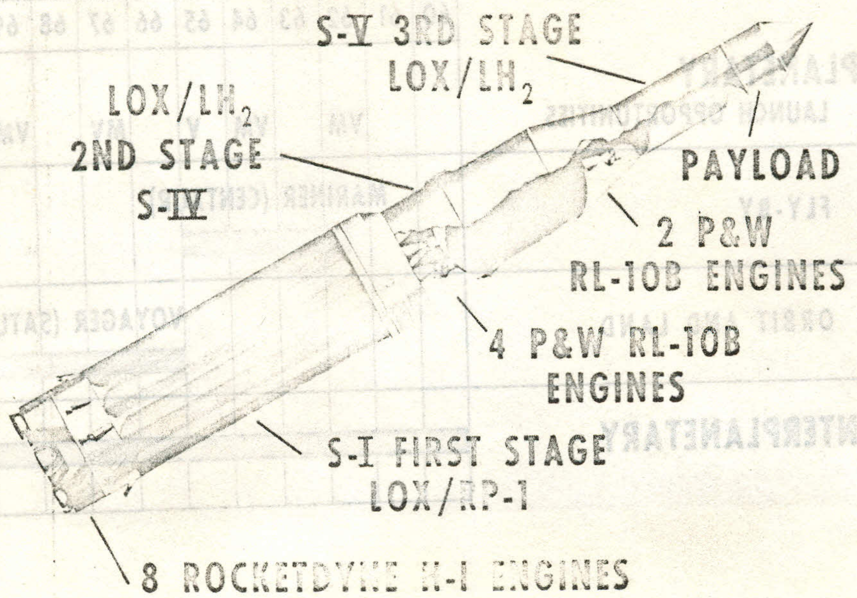
Planetary and Interplanetary Program

Figure 5

The purpose of Mariner is to study radiation enroute, and to scan the planets for surface temperature distribution, examine the atmospheric constituents, and to study the magnetic field. Also, if the spacecraft gets close enough, the radiation detectors may obtain useful information relating to trapped particles near the planet surfaces.

One problem in the program for exploring Venus and Mars is the fact that Venus is in a suitable position at intervals of about one and one-half years and Mars about two years. That means that if one of these schedules is missed, considerable time is lost before it is again practical to make another attempt.

Following closely on the heels of Project Mariner is the more advanced program of Project Voyager, this will be a Satury launched vehicle which will be capable of orbiting a 2400 pound capsule around Venus or Mars, and this capsule will in turn, while it is still orbiting, be able to eject a several hundred pound capsule capable of surviving atmospheric entry and descent to the surface of the planet (See Figure 6). Thus the orbiting capsule would observe the planet and its atmosphere from several hundred miles, while the landing capsule would make detailed measurements during descent and on the ground. Data from the orbiting capsule would be relayed back to E rth by means of television.



Saturn C-1
Figure 6

Other Projects

There are many other projects with which NASA is concerned. The Pioneer Space Probes and Project Echo are two of these.

Project Echo is part of the passive communications satellite program. The term passive means that the spacecraft is merely a reflector of signals transmitted from the ground. The Echo spacecraft is a large sphere, 100 feet in diameter, the skin being a thin plastic with a film of aluminum on the outside. Radio signals were sent to the Sphere by ground transmitters and reflected back to the ground receiver.

Following the passive communications program, we have the active communications program. This differs from the passive in that the vehicle carries a radio receiver and transmitter. Signals sent from the earth are received in the satellite and retransmitted back to earth.

SUMMARY:

There are many other NASA projects that could be mentioned; however, from what has been presented here, it can be seen that NASA is concerned with all aspects of space travel. They are concerned with aerospace medicine, propulsion techniques and developing space vehicles. All of these programs are conducted with peaceful purposes in mind. However, all of them can be easily adapted to military requirements if the need arises.

QUESTIONS:

1. NASA has five parts to their mission. What are they?

2. Where are the various Space Flight Centers located in NASA and what is their basic responsibility?

3. What are the basic missions for the Man in Space Program?

4. What is Apollo Program and what are the B sic objectives?

5. What is Project Ranger and what will be its launch vehicle?

6. What is Project Surveyor?

7. What is Project Prospector?

8. What is Project Mariner?

9. What booster vehicle will be used for the above projects?

REFERENCE:

Current Missile and Aviation publications.

Aeronautical and Space Sciences Report to Eight-Seventh Congress